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FIFTEEN YEARS OF FOREST SUCCESSION IN HAPPY VALLEY, JEFFERSON COUNTY, INDIANA

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ABSTRACT: In April 1974, a major tornado severely damaged the forest in Happy Valley, Jefferson County, Indiana. The pre-tornado forest was a sugar maple-Ohio buckeye community. In the fall of 1974, the forest was sampled on three transects across the valley. Virtually all the canopy trees had been removed or damaged; the dominant species (dbh ≥ 5 cm) in the most disturbed part of the forest were sugar maple, white oak spp., and white ash. Seven years later, the forest was sampled along the same three transects and described as a sugar maple-elm spp.-Ohio buckeye-redbud community. Fifteen years after the tornado (this study), the forest was sampled along the same transects and found to be a sugar maple-slippery elm community. Of secondary importance in the more severely damaged northern portion of the valley were sycamore and black maple on the valley floor and basswood, hackberry, and species of the white oak section of *Quercus* on the slopes. Of secondary importance in the less damaged southern portion of the valley were black walnut and box elder on the valley floor and white ash and northern red oak on the slopes. Predictions of change in forest structure and composition are discussed relative to the recent history of forest recovery.

KEYWORDS: *Acer saccharum, Aesculus glabra,* forest composition, forest structure, *Fraxinus americana,* Jefferson County, Indiana, mixed mesophytic forest, *Quercus* spp., *Ulmus rubra.*

INTRODUCTION

On 3 April 1974, a major tornado blew through the town of Hanover in southeastern Indiana, traversing the Hanover College campus and the adjacent wooded Happy Valley rendering extensive damage to both. In the fall of 1974, Bailey and MacMillan (1977) censused the standing live trees (dbh ≥ 5 cm) which remained. They found that the storm had reduced the tree population by as much as one-third. With virtually all canopy trees removed and a large portion of the forest floor exposed, Happy Valley became a natural laboratory for studying secondary succession.

Analysis of pre-tornado data (collected at different times by J. Dan Webster and J. Davis) suggested that the original valley forest was a sub-climax sugar maple-Ohio buckeye (*Acer saccharum-Aesculus glabra*) community. Following the tornado, Bailey and MacMillan (1977) described the remaining forest as a sugar maple-white ash-white oak spp. (*A. saccharum-Fraxinus americana-Quercus* spp.) community. In 1981, Martin and MacMillan (1982) recensused the valley forest and found that sugar maple, elm (*Ulmus*) spp., Ohio buckeye, and redbud (*Cercis canadensis*) were dominant in the most severely damaged (northern) part of the valley, whereas sugar maple, white ash, and white oak spp. remained dominant in the less disturbed (southern) portion of the valley.

The objectives of the present study were to (1) catalog the current structure and composition of the Happy Valley forest, (2) compare the changes that had occurred in the forest community over the last fifteen years, and (3) suggest what further changes might occur in community structure in the valley forest in the future.

STUDY SITE

Happy Valley is located at 38° 43′ N and 85° 27′ W in the Muscatatuck Flats and Canyons Section of the Bluegrass Natural Region of southeastern Indiana (Homoya, *et al.,* 1985) adjacent to Hanover College, Jefferson County, Indiana. The valley runs approximately northwest to southeast and is an area of rather sharp relief. From the flat Avonburg, Rossmoyne, and Ryker silt loam soils (0 to 6% slopes) that surround the valley, the wooded slopes with Eden-Caneyville complex soils (25 to 60% slopes) descend 75 m to a narrow valley floor with Dearborn channery silt loam soils (Nickell, 1985). An intermittent stream that drains upland agricultural fields and woodlands flows through the valley and empties into the Ohio River. The full width of the valley and approximately two-thirds of its total length were included in this study. Three line transects were followed across the valley: transects 1 (north) and 2 (mid) lie within the windthrow area and transect 3 (south) lies south of the most damaged area (Figure 1). These were the same transects laid out by Bailey and MacMillan in 1974 and followed by Martin and MacMillan in 1981.

METHODS

The point-centered-quarter method described by Cottam and Curtis (1956) was used to sample the tree population, using sampling intervals of 15 m. The field data collected included distance along the transect, point-to-tree distance, diameter at breast height (dbh), species, and comments or observations. Nomenclature follows that of Gleason and Cronquist (1991).

Transect 1 was 345 m long and included 95 stems; transect 2 was 405 m long and included 109 stems; and transect 3 was 390 m long and included 103 stems. The data were analyzed using the methods of Cox (1990) to estimate mean point-to-tree distance, mean area per tree, and total density of trees (number of trees/hectare). Relative density, relative frequency, and relative dominance (i.e., basal area) were calculated and then summed to yield the importance value by species.

Data from transects 1 and 2 were combined to provide more complete information about the damaged area; this area is referred to as the "damaged woods." Martin and MacMillan (1981) referred to the same area as the "woods." Data

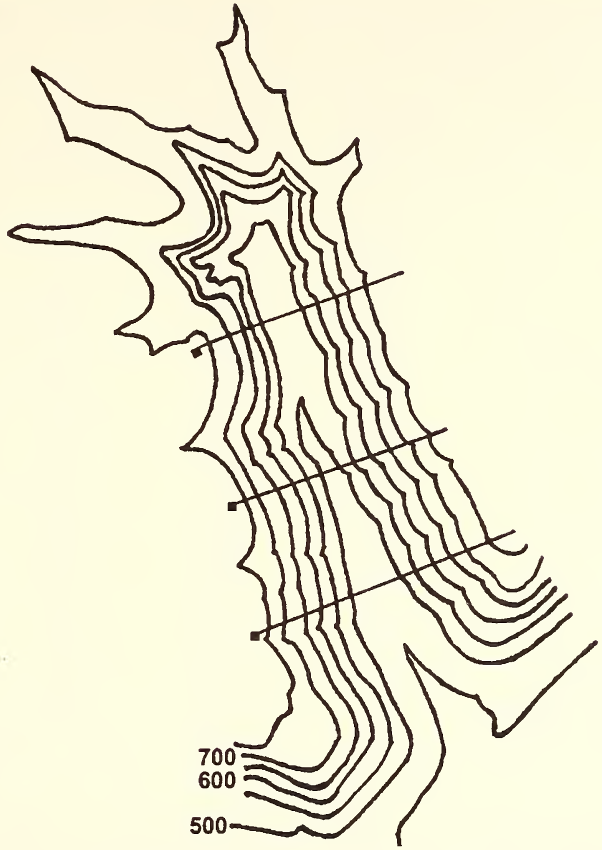

Figure 1. A map of Happy Valley, Jefferson County, Indiana, showing the location of the three transects discussed in the text. Transect 1 is at the top of the map, and transect 3 is at the bottom.

from the relatively less damaged area (transect 3 at the south end of the valley) was used for comparison.

Comparisons of the vegetative communities sampled on the three transects were made using Sorenson's quotient of similarity (Brower, *et al.*, 1990) and the Bray and Curtis (1957) similarity index as measures of community similarity. Sorenson's quotient of similarity is calculated as:

$$CC_S = 2C/(s_1 + s_2)$$

where C is the number of species common to both sites, s_1 is the number of species at site 1, and s_2 is the number of species at site 2. The Bray and Curtis similarity index is calculated as:

$$CC_B = (2W/(a + b))100$$

where W is the sum of the lower importance values for those species which are common to both sites, a is the sum of the importance values for all the species at site 1, and b is the sum of the importance values for all the species as site 2.

Table 1. The characteristics of the Happy Valley forest along transect 1 (north end of the valley) fifteen years after the tornado.

Species	Relative Density	Relative Frequency	Relative Dominance	Importance Value
Ulmus rubra	33.33	19.66	29.78	82.77
Acer saccharum	22.92	21.31	22.10	66.33
Tilia americana	9.38	13.11	3.05	25.54
Acer nigrum	8.33	11.48	3.69	23.50
Platanus occidentalis	1.04	1.64	15.43	18.11
Cercis canadensis	8.33	8.20	1.46	17.99
Quercus rubra	1.04	1.64	10.40	13.08
Quercus michauxii	3.12	4.92	3.55	11.59
Aesculus glabra	2.08	3.28	3.60	8.97
Celtis occidentalis	3.12	3.28	1.62	8.02
Paulownia tomentosa	2.08	3.28	2.48	7.84
Carya cordiformis	1.04	1.64	2.15	4.83
Liriodendron tulipifera	1.04	1.64	0.31	2.99
Juglans nigra	1.04	1.64	0.19	2.87
Ostrya virginiana	1.04	1.64	0.10	2.78
Fraxinus quadrangulata	1.04	1.64	0.09	2.77

RESULTS

Composition of the Forest After 15 Years. Slippery elm and sugar maple were dominant on transect 1 (importance values = 83 and 66, respectively), based on their relative density, frequency, and dominance (Table 1). These two species were followed by basswood (*Tilia americana*) on the mesic east-facing slope and black maple (*Acer nigrum*) on the valley floor (importance values = 26 and 24, respectively). For basswood and black maple, their large relative frequency but not their basal area significally influenced their importance values. Redbud was relatively abundant on the drier west-facing slope, but its small basal area kept its importance value (18) low. On the other hand, one large sycamore (*Platanus occidentalis*), its top damaged but its trunk still intact, and one large red oak (*Quercus rubra*) had importance values of 18 and 13, respectively. These values were nearly equal to those of the more numerous redbud. Nine other species had lower importance values.

On transect 2 (Table 2), sugar maple was clearly the dominant species (importance value = 91) followed by slippery elm (importance value = 54). These two species were important in all three relative measures. Slippery elm was abundant across the valley, whereas sycamore (importance value = 30) and boxelder (*Acer negundo*; importance value = 10) tended to replace sugar maple near the creek bed, while chinquapin oak (*Quercus muehlenbergii*; importance value = 26) was more abundant on the west-facing slope. Hackberry (*Celtis occiden-*

Table 2. The characteristics of the Happy Valley forest along transect 2 (middle portion of the valley) fifteen years after the tornado.

Species	Relative Density	Relative Frequency	Relative Dominance	Importance Value
Acer saccharum	38.53	27.79	24.52	90.84
Ulmus rubra	22.02	20.84	10.68	53.54
Platanus occidentalis	2.75	2.78	24.91	30.44
Quercus muehlenbergii	6.42	6.95	12.14	25.51
Celtis occidentalis	4.59	6.95	2.36	13.90
Fraxinus americana	2.75	4.17	6.72	13.64
Aesculus glabra	3.67	4.17	3.13	10.97
Acer negundo	4.59	4.17	0.86	9.62
Quercus michauxii	1.83	2.78	4.59	9.20
Acer nigrum	2.75	4.17	0.74	7.66
Prunus serotina	2.75	4.17	0.50	7.42
Ostrya virginiana	2.75	4.17	0.47	7.39
Quercus rubra	0.92	1.39	4.05	6.36
Juglans nigra	0.92	1.39	2.98	5.29
Catalpa speciosa	0.92	1.39	1.13	3.44
Gymnocladus dioica	0.92	1.39	0.14	2.45
Quercus velutina	0.92	1.39	0.08	2.39

talis), white ash, and Ohio buckeye had importance values of 14, 14, and 11, respectively. Nine other species had lower importance values.

At the southern end of the valley, sugar maple was dominant (importance value = 73), although it was nearly replaced by black walnut (*Juglans nigra*; importance value = 34) and box elder (importance value = 21) on the valley floor (Table 3). Slippery elm was again second in importance (importance value = 43) due to both frequency and basal area. White ash, red oak, and black maple (importance values = 28, 21, and 18, respectively) had moderate importance values. Seven other species had lower importance values.

Data from the most damaged area of the valley (transects 1 and 2) were combined in Table 4 for comparison with the less-damaged transect 3 and with previous studies of the Happy Valley forest. In the damaged woods data (Table 4), sugar maple (importance value = 80) and slippery elm (importance value = 65) were dominant due to their high density, frequency, and dominance (i.e., basal area). Sycamore and chinquapin oak had moderate importance values (importance values = 26 and 15, respectively) based on their relative dominance. Black maple (importance value = 15) was next due to its frequency; basswood, hackberry, swamp chestnut oak (*Quercus michauxii*), and Ohio buckeye (importance values = 12, 11, 10, and 10, respectively) had intermediate importance values. Fourteen other species had lower importance values.

Table 3. The characteristics of the Happy Valley forest along transect 3 (southern portion of the valley) fifteen years after the tornado.

Species	Relative Density	Relative Frequency	Relative Dominance	Importance Value
Acer saccharum	32.04	23.08	18.15	73.27
Ulmus rubra	8.74	12.31	21.50	42.55
Juglans nigra	7.77	7.69	18.18	33.64
Fraxinus americana	10.68	9.23	8.47	28.38
Quercus rubra	3.88	4.62	12.30	20.80
Acer negundo	8.74	6.15	5.67	20.56
Acer nigrum	5.82	7.69	4.65	18.16
Maclura pomifera	3.88	4.62	6.18	14.68
Aesculus glabra	4.85	7.69	1.22	13.76
Cercis canadensis	4.85	4.62	1.53	10.99
Quercus michauxii	3.88	4.62	1.49	9.99
Celtis occidentalis	1.94	3.08	0.46	5.48
Asimina triloba	1.94	3.08	0.10	5.12
Carpinus caroliniana	0.97	1.54	0.09	2.60

Values of Sorenson's quotient of similarity (Brower, *et al.,* 1990) for these three transects ranged from 0.468 to 0.645 (Table 5). For the Bray and Curtis (1957) similarity index, the values ranged from 59.48 to 64.72.

Structure of the Forest After 15 Years. The mean point-to-tree distance in the damaged woods region of the valley (transects 1 and 2) decreased by 33% in seven years and by 41% in 15 years (Table 6). In the less disturbed region of the valley (transect 3), the mean distance decreased by 5% in seven years (1974 to 1981) and by 13% in 15 years. Mean tree density increased by 117% in 7 years and by 178% in 15 years in the most disturbed area; in the less disturbed area, density increased by 17% in 7 years and by 37% in 15 years.

DISCUSSION

Damaged Woods Data Compared Over 15 Years. When data from 1974, 1981, and 1989 are compared, the importance value of the dominant sugar maple is seen to decrease from 122 in 1974, to 82 in 1981, and to 80 in 1989; this represents a 34% decease in importance. At the same time, the importance value of fast-growing slippery elm increased from 17 in 1974, to 34 in 1981, and to 65 in 1989; this represents an increase of 276% in importance. The sugar maples must have been understory trees in 1974; then, when the canopy was destroyed, they were released and grew rapidly. After 15 years, their relative density and frequency had diminished due to the more rapid proliferation of other species such as slippery elm. If these trends continue, slippery elm will soon be the dominant tree in this most-damaged portion of the valley.

Table 4. A summary of the data from the most severely damaged portion (transects 1 and 2 combined) of the Happy Valley forest fifteen years after the tornado.

Species	Relative Density	Relative Frequency	Relative Dominance	Importance Value
Acer saccharum	31.22	24.81	23.64	79.67
Ulmus rubra	27.32	20.30	17.60	65.22
Platanus occidentalis	1.95	2.26	21.47	25.68
Quercus muehlenbergii	3.41	3.76	7.73	14.90
Acer nigrum	5.36	7.52	1.81	14.69
Tilia americana	4.39	6.02	1.11	11.52
Celtis occidentalis	3.90	5.26	2.09	11.25
Quercus michauxii	2.44	3.76	4.21	10.41
Aesculus glabra	2.93	3.76	3.30	9.99
Quercus rubra	0.98	1.50	6.35	8.83
Cercis canadensis	3.90	3.76	0.53	8.19
Fraxinus americana	1.46	2.26	4.28	8.00
Acer negundo	2.44	2.26	0.55	5.25
Ostrya virginiana	1.95	3.01	0.34	5.30
Juglans nigra	0.98	1.50	1.97	4.45
Prunus serotina	1.46	2.26	0.32	4.04
Paulownia tomentosa	0.98	1.50	0.90	3.38
Carya cordiformis	0.49	0.75	0.78	2.02
Catalpa speciosa	0.49	0.75	0.72	1.96
Liriodendron tulipifera	0.49	0.75	0.11	1.35
Gymnocladus dioica	0.49	0.75	0.09	1.33
Quercus velutina	0.49	0.75	0.05	1.29
Fraxinus quadrangulata	0.49	0.75	0.03	1.27

Large boles of several species survived the tornado but then declined in importance later. One possible explanation for this pattern is that the tops of the trees were damaged by the cyclonic winds, opening the boles for infection. When the trees were censused after the tornado in the fall of 1974, the boles were still intact, and they contributed to the overall importance value of the species. However, after 7 and 15 years, the damaged and infected boles had died or fallen and were not counted. This pattern is illustrated by the change in importance value and rank order of white ash, whose importance value changed from 21, to 5, and then to 8 and, whose rank changed from second, to fifteenth, and then to twelfth in 1974, 1981, and 1989, respectively. Black walnut's importance value and rank also reflect this pattern; its importance value changed from 14, to 1, and then to 4, and its rank from seventh, to twenty-first, and then to fifteenth in 1974, 1981, and 1989, respectively. White ash is predicted to increase in importance over the next 5 to 10 years as the large seedling population in the valley grows into the sapling stage. The importance value of slow-growing black walnut is expected to decrease over the next several years until the canopy closes.

Table 5. A comparison of similarity between transects using Sorenson's quotient of similarity (Brower, *et al.,* 1990) and the Bray and Curtis (1957) similarity index as measures of community similarity.

Paired Transects	Community Similarity Sorenson	Bray and Curtis
1 & 2	0.606	61.28
1 & 3	0.600	59.48
2 & 3	0.645	61.34
1 + 2 & 3	0.468	64.72

Sycamore exhibited a different pattern. Many sycamore on the valley floor were windthrown by the tornado. However, a few large boles still remained upright after 15 years, and their damaged tops were bushy with small branches. Sycamore's importance value changed from 18, to 14, and then to 26, and its rank from fourth, to eighth, and then to third in 1974, 1981, and 1989, respectively. This pattern of change is due almost entirely to the persistent large trees that add greatly to the relative dominance compared to the dynamic changes of the many small stems of most other species growing on the valley floor. The importance of sycamore in the valley is predicted to decrease as the large old stems die and as other species increase in basal area. However, a second factor may complicate this picture. Some fallen sycamore boles with adequate root systems have live branches that are very tree-like in height and diameter. Whether or not these trees-from-logs will continue to survive is hard to predict.

Basswood, an infrequent subcanopy tree on the mesic east-facing slope and valley floor, forms coppices. Thus, its relative density and relative frequency values are moderate, but its relative dominance value is small. Its importance value changed from 4, to 14, and finally to 12, and its rank from thirteenth, to seventh, and then to sixth in 1974, 1981, and 1989, respectively. Basswood's relative density and relative frequency should decease and its relative dominance should increase as one of the multiple stems in each coppice becomes stronger and larger.

The importance value for redbud was 4, 17, and 8, and its rank was fifteenth, fourth, and eleventh in 1974, 1981, and 1989, respectively. This variation is due mostly to changes in its relative density and relative frequency. The apparent fluctuation in importance value might be due to relatively rapid growth and a short lifespan. In this case, continued oscillation of redbud's importance value is expected in the future. Another possibility is that redbud would show rapid growth when the canopy was destroyed and then die as the canopy closed. In this case, redbud's importance value will remain low.

The importance value of Ohio buckeye went from 15, to 35, and then to 10, and its rank went from sixth, to second, and then to ninth in 1974, 1981, and 1989, respectively. This pattern was due to the abundance of moderate-diam-

Table 6. Changes in Happy Valley forest structure over the fifteen years following the tornado of 1974.

Year	Transect Number	Mean Point-To-Tree Distance (m)	Mean Area/Tree (m^2)	Density (trees/ha)
1973[a]	Pre-tornado	4.4	19.5	512
1974[b]	Mean of 1 + 2	4.9	23.6	426[d]
	3	3.9	15.2	625
1981[c]	Mean of 1 + 2	3.3	11.0	926[d]
	3	3.7	13.7	730
1989[e]	Mean of 1 + 2	2.9	8.5	1186[d]
	3	3.4	11.7	857

[a] J. Davis, unpubl. data.
[b] Bailey and MacMillan, 1977.
[c] Martin and MacMillan, 1982.
[d] The mean data from transects 1 and 2 represent the more damaged area of the valley.
[e] Present data.

eter buckeye stems that had their tops blown off in the tornado. These stems branched rapidly at the top, persisted for a few years, and contributed to the large importance value in 1981. However, the stems had become infected, died, and fallen by 1989. The importance value of shade-tolerant Ohio buckeye is predicted to increase once the canopy closes.

The importance value of hackberry has changed little in the last 15 years; its importance value was 10, 11, and 11, and its rank was tenth, tenth, and seventh in 1974, 1981, and 1989, respectively. This stability appears to be due to its abundance and rapid growth. Hackberry's importance value is predicted to remain stable over the next several years.

Oaks have been a minor component of the damaged woods in Happy Valley since the tornado. However, their specific identification has been difficult. What Bailey and MacMillan (1975) identified as *Quercus bicolor* (swamp white oak) is now identified as *Q. michauxii* (swamp chestnut oak), and what they identified as *Q. borealis* is now correctly named *Q. rubra* (northern red oak). For that reason, and because of the difficulty in identifying oak saplings, Martin and MacMillan (1982) grouped them into the red oaks and white oaks.

Tulip (or yellow) poplar (*Liriodendron tulipifera*), an invader species of disturbed sites, was not found in the disturbed woods in 1974, but the species had an importance value of 2 in 1981 and 1 in 1989; it ranked nineteenth and twentieth in 1981 and 1989, respectively. The importance value of this fast-growing species is predicted to increase over the next 5 years.

Community Similarity. Sorenson's quotient of similarity and the Bray and Curtis similarity index were used to compare the plant communities sampled on the three transects across Happy Valley (Table 5). In all comparisons between transects, community similarity values were less than 65%, indicating quite dissimilar communities. Even the comparison between transects 1 and 2, which represent that portion of the valley most damaged in the 1974 tornado, shows dissimilar composition. This difference is also seen in the species found on transects 1 and 2 (Tables 1 and 2). Unfortunately, no record of the pre-tornado composition of the northern end of the valley exists for comparison.

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