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ENVIRONMENTAL AND CULTURAL INFLUENCES ON FOREST FRAGMENTATION PATTERNS IN NORTHEASTERN INDIANA

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ABSTRACT: Forests in Wabash County, Indiana, covered 9.2% of the County as of the late 1960s. These forests were highly fragmented, with a median size of 3.4 ha. Forests on the coarser soils of the Northern Lakes Natural Region were more fragmented than those in the Bluffton Till Plain Section of the Central Till Plain Natural Region. The difference probably reflects different historical and modern patterns of land use for agriculture.

KEYWORDS: Forest fragmentation, land use patterns, landscape ecology, Wabash County.

INTRODUCTION

In many regions of the world, relatively unmanaged habitats exist as fragments in a matrix of human-controlled ecosystems. Habitat fragmentation is known to significantly modify the microclimate of isolated forests (Brothers and Spingarn, 1991; Saunders, *et al.,* 1991). The resulting edge effect as well as the influence of impeded migration have been implicated in changes in plant reproductive biology (Aizen and Feinsinger, 1994), plant species composition (Brothers, 1993), bird demography (Robinson, *et al.,* 1995), and other aspects of community structure and function (Saunders, *et al.,* 1991). These effects constitute significant problems for the regional maintenance of biodiversity (Fahrig and Merriam, 1994). Thus, describing fragmentation patterns and factors which may influence these patterns is an important component for developing conservation strategies.

In this paper, the modern patterns of fragmentation (numbers and size of isolated forests) are described for Wabash County, Indiana, formerly a forested region which now has been largely converted to agricultural use. The relationships between the characteristics of modern forest fragments, underlying environmental features, and the human history of the region were examined by

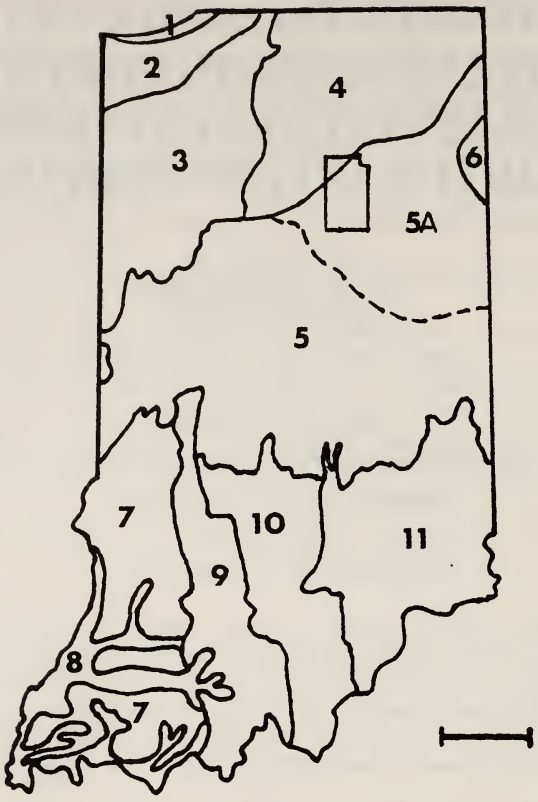

Figure 1. Location of Wabash County, Indiana (rectangular outline) in relation to the Natural Regions of Indiana (Homoya, *et al.,* 1985). Key to the Natural Regions: 1 = Lake Michigan; 2 = Northwestern Morainal; 3 = Grand Prairie; 4 = Northern Lakes; 5 = Central Till Plain (5A = Bluffton Till Plain Section); 6 = Black Swamp; 7 = Southwestern Lowlands; 8 = Southern Bottomlands; 9 = Shawnee Hills; 10 = Highland Rim; and 11 = Bluegrass. Most sections of the Natural Regions are not shown. The scale bar is 50 km; north is toward the top.

comparing the size, shape, and isolation of the fragments in the two Natural Regions that occur in the northern section of the County.

MATERIALS AND METHODS

Study area. Wabash County, Indiana, was studied because its vegetation has experienced great modification since European settlement and because the border between two major Natural Regions passes through the County. Wabash County is located in northeastern Indiana (Figure 1). Elevations range from 200 to 280 m.a.s.l. The climate is cool-temperate, with a mean annual precipitation of 94 cm, a mean annual temperature of 9.6° C, a mean January temperature of -2° C, and a mean July temperature of 24° C at Wabash (Schaal, 1966;

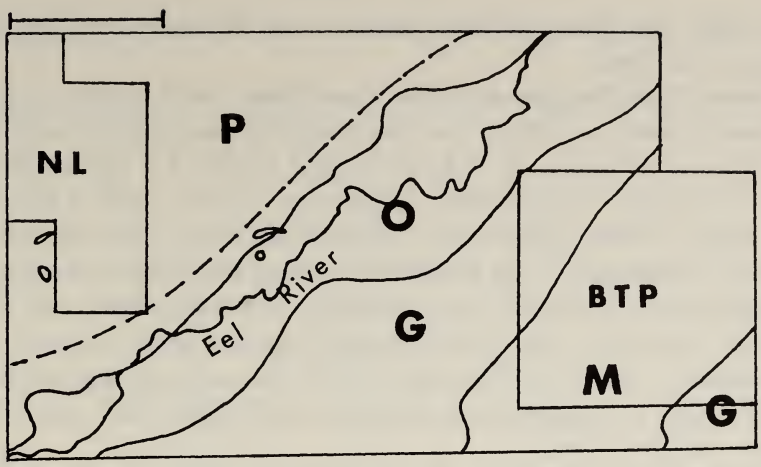

Figure 2. A map of northern Wabash County showing the location of the Northern Lakes Natural Region and the Bluffton Till Plain Section in relation to major geological features. The boundaries of the geological features are irregular and trend southwest to northeast. Key: P = Packerton Moraine; O = glacial outwash; G = ground till; and M = Mississinewa moraine. The boundary between the Northern Lakes and Central Till Plain Natural Regions (Homoya, *et al.,* 1985) is indicated by a dashed line. The scale bar is 5 km; north is toward the top.

Ruesch, 1983). Surface geological materials and drainage patterns are of Wisconsin age (Wayne and Thornbury, 1951). Presettlement vegetation was dominated by deciduous forests with small areas of barrens and prairies on dry uplands and wet prairies, marshes, and fens in the lowlands (Helm, 1914; Kuchler, 1964; Lindsey, *et al.,* 1965; Homoya, *et al.,* 1985).

The northwestern corner of the County lies within the Northern Lakes Natural Region (Homoya, *et al.,* 1985), while the remainder of the County is in the Central Till Plain Natural Region, Bluffton Till Plain Section (Figures 1 and 2). These regions differ considerably in both geology and vegetation.

The portion of the Northern Lakes Natural Region in Wabash County includes the rolling landforms of the Packerton Moraine (Wayne and Thornbury, 1951). Before European settlement, the primary vegetation was *Quercus-Carya* forest with frequent ponds and small areas of prairie and wetland (Helm, 1914; Lindsey, *et al.,* 1965; Homoya, *et al.,* 1985).

The remainder of the County lies in the Bluffton Till Plain Section of the Central Till Plain Natural Region. This area contains two types of landscape, nearly flat till plain and the low, clayey Mississinewa moraine. The Eel River Valley, with coarse outwash-derived soils, occupies a narrow strip parallel to the Packerton Moraine (Wayne and Thornbury, 1951; Ruesch, 1983). Presettlement vegetation was dominated by *Acer-Fagus* forest with swamps on

the till plain and *Quercus-Carya* forests in the outwash area (Helm, 1914; Lindsey, *et al.,* 1965).

County-Wide Fragment Numbers and Sizes. The fragmentation patterns for Wabash County as a whole were determined by measuring the area of every piece of forest indicated on U.S. Geological Survey 7.5' topographic maps (North Manchester North, North Manchester South, Silver Lake, Roann, Servia, Lagro, Wabash, Richvalley, South Whitley West, Somerset, Lafontaine, and Peoria Quadrangles). The air photos on which these maps were based were taken between 1948 and 1967 and field checked between 1962 and 1969. No systematic comparison was made between fragments shown on the maps and those existing at the time of the study (1989). The area of each fragment was measured using a transparent plastic grid, which allowed the area to be estimated to within ± 0.1 ha.

Environmental Influences. To examine the possible correlations between land use patterns and landforms, two large plots were delineated (Figure 2), one in the Northern Lakes (NL) Natural Area (3460 ha) and the other in the Bluffton Till Plain (BTP) Section (5180 ha). Every forest fragment was located in the plots on the relevant topographic maps listed above. The area of each fragment was measured using a transparent plastic grid. The perimeter of the fragment and the distance to the nearest neighboring fragment were measured with a ruler.

Finally, the number of edges was counted for each fragment, because increased numbers of edges and vertices increase edge effects (Malcolm, 1994). Roads were counted as edges, even if forest occurred on both sides of the road, because barriers the width of a highway right-of-way have been shown to induce edge effects (Rich, *et al.,* 1994). Using these techniques, distances could be measured to c. 5 m, and areas could be estimated to within c. 0.1 ha. The smallest distinguishable fragments on the maps were approximately 0.2 ha.

Since proximity to streams is likely to affect land use, fragments were classified as either lowlands or uplands. Lowlands were crossed by or had at least one edge contiguous with a stream identifiable from maps. Thus, four types of fragment were identified: Northern Lakes upland, Northern Lakes lowland, Bluffton Till Plain upland, and Bluffton Till Plain lowland.

The differences among the four fragment types were analyzed using nonparametric statistical methods, because most variables did not have normal distributions. When the Kruskal-Wallis test indicated that a significant difference existed among the four types of fragments, the Mann-Whitney test was used to make further comparisons. Since only the comparisons between natural regions and forest types were relevant, statistical tests were applied only to comparisons of the Northern Lakes upland to the Northern Lakes lowland, the Bluffton Till Plain upland to the Bluffton Till Plain lowland, the Northern Lakes upland to the Bluffton Till Plain upland, and the Northern Lakes lowland to the Bluffton Till Plain lowland. Other comparisons were not made because they were irrelevant for comparing Natural Regions and forest types. (Additional

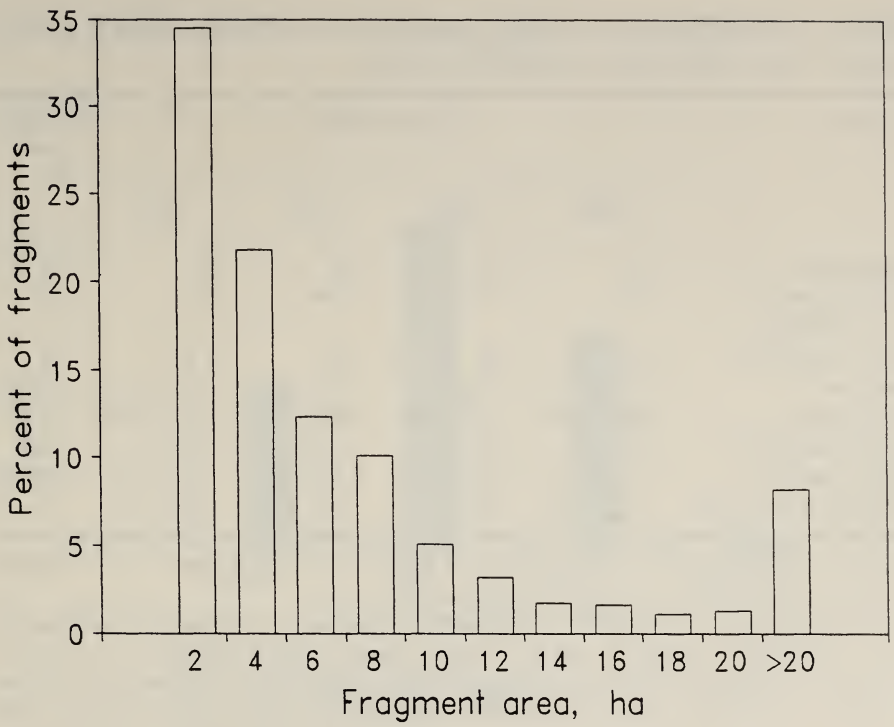

Figure 3. Size distribution of forest fragments in Wabash County.

extraneous tests would increase the risk of spurious statistical results in multiple comparisons.) All statistical tests were performed using SPSSPC+.

Soil drainage and topography were also compared between plots. To study soil drainage, the soil types occurring at the corners of the grid formed by the county road system (1.6 km spacing between roads) were determined. Then, each point was classified based on soil drainage from very poorly to well drained (Ruesch, 1983). A χ^2 test was used to compare the distribution of drainage conditions in the two plots.

To examine topographic complexity, linear transects were placed at random (15 in the Northern Lakes Natural Region and 20 in the Bluffton Till Plain Section) on U.S. Geological Survey 7.5' topographic maps. Each transect was equivalent to 500 m in length. Elevations were estimated at 10 evenly spaced points on the transect. The coefficient of variation was calculated for each transect. The Mann-Whitney test was used to check for differences in the coefficient of variation between the Northern Lakes Natural Region and the Bluffton Till Plain Section.

RESULTS

Fragment Numbers and Sizes, Whole County. In Wabash County, 1292 forest fragments (11.8 fragments per 1000 ha) were found. The number of fragments declined approximately logarithmically with increasing area (Figure 3).

Table 1. Characteristics of forest fragments in northern Wabash County, Indiana. Values are mean ± standard deviation.

Variable	Fragment Type[1]				Significance Test[2]
	BTPU	BTPL	NLU	NLL	
Sample size	49	33	68	24	N
Density (number per 1000 ha)	9.5	5.9	20.1	6.7	A
Area forested (%)	4.5	3.0	6.1	5.2	N
Area (ha)	4.7 ± 5.0	5.1 ± 4.2	3.2 ±4.0	7.4 ± 12.6	B,D,E
Perimeter (m)	900 ± 670	1170 ± 770	830 ± 780	1310 ± 1460	B,C
Area/perimeter (m)	42 ± 23	40 ± 22	31 ± 33	42 ± 51	B,E
Edges (number)	7.3 ± 5.3	9.4 ± 5.2	9.2 ± 9.0	13.8 ± 17.5	B,C,E
Neighbor distance (m)	130 ± 110	180 ± 150	110 ± 110	120 ± 130	F

[1] BTPU = Bluffton Till Plain upland; BTPL = Bluffton Till Plain lowland; NLU = Northern Lakes upland; and NLL = Northern Lakes lowland.

[2] N = no significance test possible; A = distribution of fragments is significantly nonrandom (χ^2 test, $P < 0.05$); B = significant difference among groups (Kruskal-Wallis test, $P < 0.05$); C = significant difference between the Bluffton Till Plain upland and the Bluffton Till Plain lowland; D = significant difference between the Northern Lakes upland and the Northern Lakes lowland; E = significant difference between the Bluffton Till Plain upland and the Northern Lakes upland; F = no significant differences among groups (Kruskal-Wallis test, $P > 0.05$). For C-E, the statistical test used was the Mann-Whitney test, with $P < 0.05$ indicated as significant.

The mean area was 6.4 ± 8.1 ha (mean ± standard deviation); the median was 3.4 ha; and 90% of the fragments were < 19.1 ha. Only 9.2% of the 1090 km^2 area of the County was forested.

Environmental Influences. Significant differences among the four fragment types were found for every variable except distance to the nearest neighbor (Table 1). Compared to the Northern Lakes uplands, the Bluffton Till Plain uplands had a lower area and area-to-perimeter ratio as well as greater numbers of edges. The Bluffton Till Plain lowlands had longer perimeters and more edges than the Bluffton Till Plain uplands. The Northern Lakes lowlands were greater in area than the Northern Lakes uplands. No significant differences were found between the Bluffton Till Plain lowlands and the Northern Lakes lowlands.

Soil drainage conditions differed significantly between the Northern Lakes Natural Region and the Bluffton Till Plain Section, with the Northern Lakes Natural Region having more xeric soils (Figure 4). The coefficients of variation for elevation were 0.012 ± 0.007 for the Northern Lakes Natural Region and 0.005 ± 0.002 for the Bluffton Till Plain Section. The difference between them was highly significant (Mann-Whitney test, $P < 0.01$).

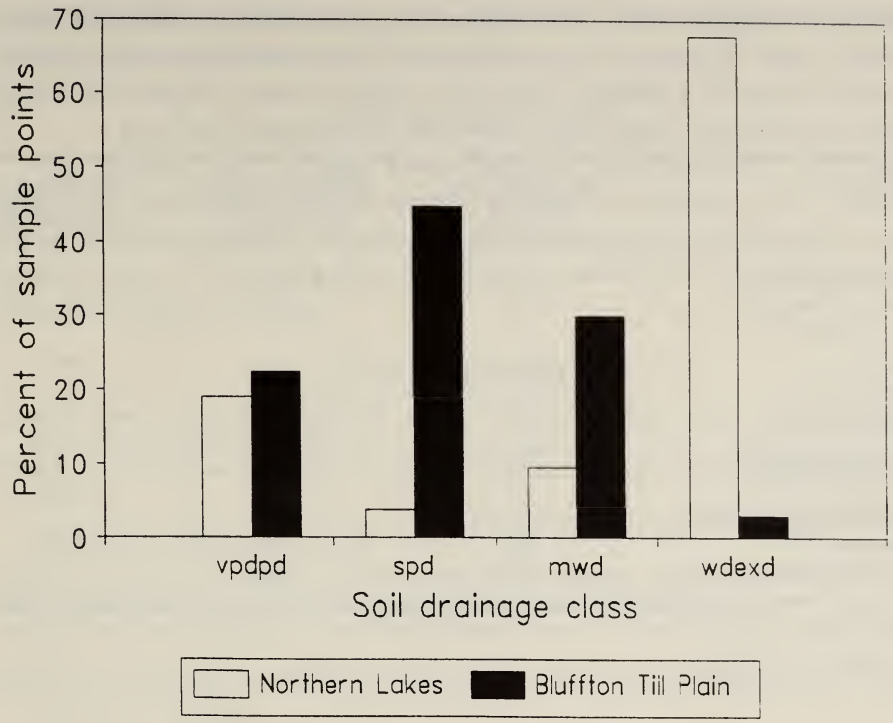

Figure 4. Soil drainage classes in the Northern Lakes Natural Region and the Bluffton Till Plain Section study plots. Drainage classes: vpd = very poorly drained; spd = somewhat poorly drained; mwd = moderately well drained; and wdexd = well drained or excessively drained. Poorly drained soil types did not occur in these samples. The number of sample points was 53 for the Northern Lakes Natural Region and 67 for the Bluffton Till Plain Section.

DISCUSSION

The once-continuous forest of Wabash County now exists as a large number of small, isolated blocks. The characteristics of these forest fragments in Wabash County are similar to those in other areas of the eastern deciduous forest that have been heavily used for agriculture or housing (Table 2).

The modern pattern of fragmentation in upland forests reflects the environmental patterns resulting from Wisconsin glaciation. Forests on the coarse soils of the Packerton Moraine (the Northern Lakes upland) display the maximum degree of fragmentation; that is, forest fragments in the Northern Lakes uplands are the most numerous and the smallest. In addition, these fragments have the smallest area-to-perimeter ratio and are expected to show the strongest edge effects. Lowland fragments, while differing from upland fragments in some variables, did not differ between the Northern Lakes Natural Region and the Bluffton Till Plain Section. While the upland forests have diverged, the

Table 2. A comparison of forest fragment characteristics in Wabash County, Indiana, with fragments from other areas. The values reported are means, except as noted. For Wabash County, the values for area forested and density apply to the entire County; other values are for the study plots only.

Variable	Wabash County Indiana	Onondaga County New York[1]	Cadiz Township Wisconsin[2]
Area forested (%)	9.2	25	10
Density (fragments per 1000 ha)	11.8	15.2	11.1
Area (ha)	6.4	8.1	9.0
Median area	3.4	3.3	—
Perimeter (m)	975	—	—
Median perimeter	720	776	—
Area/perimeter (m)	37	—	—
Median area/perimeter	34	32	—
Distance (m)	134	—	207
Median distance	101	57	—

[1] Hill, 1985
[2] Sharpe, *et al.*, 1987

lowland, streamside forests have been fragmented in similar ways in both regions.

These patterns of fragmentation relate primarily to land use patterns. Settlement and land clearing for agriculture began in the late 1820s; however, the amount of land in use in many areas was constrained for decades by poor soil drainage, especially in the Bluffton Till Plain Section (Helm, 1884). Effective, large-scale drainage systems did not become widespread until late in the 19th century (Kohnke and Robertson, 1966). Although first settlement in both the Northern Lakes Natural Region and the Bluffton Till Plain Section occurred within a 10-yr period, the expansion of farming in the Bluffton Till Plain Section lagged behind its expansion in the Northern Lakes Natural Region by several decades (Helm, 1884). At present, agriculture is the primary land use; in the early 1980s, 77% of Wabash County was farmed, mostly as cropland (Ruesch, 1983).

Further, the greater topographic diversity (i.e., higher coefficient of variation for elevation) in the Northern Lakes Natural Region plot implies that agricultural operations were based on more numerous, smaller units. Thus, the greater degree of fragmentation in the Northern Lakes Natural Region is due at least in part to a longer, more complicated history of agricultural land use.

The lesser degree of fragmentation occurring in the lowlands of both the Northern Lakes Natural Region and the Bluffton Till Plain Section may also be traced to agricultural practices. Lowland fields are difficult to manage because of limitations on working the land in the early spring (Ruesch, 1983).

Therefore, lowland forests have less agricultural value and have tended to remain more intact than those of the uplands.

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