Stand Structure of Shagbark Hickory (*Carya ovata*) and Soil Properties in an Extremely Fragmented Woodlot in Northeastern Illinois

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The stand structure of shagbark hickory *(Carya ovata)* and soil properties in an extremely fragmented woodlot were examined in northeastern Illinois. The goal of this preliminary study was to examine the effect of extreme forest fragmentation (in a golf course environment) on the structure of oak-hickory remnants and the impact of golf course management on soil properties associated with these remnants. Seedling densities for shagbark hickory, density and basal area for all trees present, and soil samples (pH, bulk density, organic matter, and macronutrient concentrations) were obtained for each remnant and compared to a larger forest plot (11 ha). Shagbark hickory seeds collected from the study site were germinated and grown under two different conditions; fertilized and non-fertilized, to assess the effect of nutrient amendments on seedling growth and persistence. Seedling densities in woodlot remnants indicated shagbark hickory is capable of establishing within a fragmented environment. However, the stand structures indicated a lack of recent recruitment to the sub-canopy. Soil nutrient concentrations were highly variable with no clear trends among remnants. Fertilizer application to germinants indicated that shagbark hickory seedlings have a negative sensitivity to golf course levels of nutrient application. This research suggests that golf course management practices need to take into consideration the persistence of long-lived tree species within fragments to maintain a wooded course environment.

Keywords: Stand structure, shagbark hickory (Carya ovata), forest fragmentation, soil characteristics, golf course management.

When forests become fragmented, one of the ecological concerns resulting from the fragmentation is the influence of the surrounding and secondary vegetation on the remaining vegetation community. Most studies have focused on the impact of edge creation and vegetation alterations along the perimeter of fragments (e.g. Brothers and Spingarn 1992; Goldblum and Beatty 1999; Matlack 1994; Williams-Linera 1990). The edge environment is considerably different from the fragment core environment and is, therefore, more susceptible to increased sun exposure, wind damage, change in microclimate, water flux, and potential invasion of weedy and exotic species (Cox 1997; Hill 1985; Saunders et al. 1991). A smaller forest fragment has an increased edge-area/interior-area ratio in comparison to a larger fragment and, therefore, degrees of disturbance may be related directly to fragment size and shape, and edge/interior ratios.

Forest fragmentation may affect tree seedling abundance in many different types of forest communities, from tropical to temperate, through increased tree mortality (Laurance 1991; Williams-Linera 1990) and modifications in plant-animal interactions (Benitez-Malvido 1998). The ability of a tree species to survive to the sapling stage was suggested by Gibson et al. (1988) to be most affected by ecosystem fragmentation, whereas adult trees are less sensitive to changes in environmental conditions. The repercussion of this hierarchical sensitivity is that it may take hundreds of years to see influences of fragmentation on vegetation communities with long-lived species as the dominant component (Saunders et al. 1991).

Species characteristics can further determine the success or failure of individuals within a fragment and the composition of forest fragments. This study examined a fragmented oak-hickory forest and focused on shagbark hickory (*Carya ovata*; scientific names and authorities provided in Appendix 1). The native range of shagbark hickory encompasses most of the eastern United States from eastern Texas east to North Carolina, southeastern Minnesota east to southwestern Maine, and north into southern Quebec and Ontario (Graney 1990). Shagbark hickory produces heavy seeds that are animal dispersed, and germination rates are fairly high (Graney 1990). Successful establishment therefore does not rely on an individual's ability to set seed, but rather the ability of seedlings to survive and compete within a fragment. Shagbark hickory is classified as a 'climax' species, with an intermediate degree of shade tolerance, but it also responds well to high light conditions by increasing growth rates (Graney 1990).

This study investigates the regeneration capacity of shagbark hickory within an extremely fragmented temperate deciduous oak-hickory woodlot utilizing several very small woodlot remnants found within a golf course environment, and the impact of management practices on these fragments. Golf courses occupy 750,000 ha of land in the United States (Salvensen 1996) and North American golfers expect landscaped courses with lush greens and fairways. Although these courses may create a striking landscape for golfers, they dramatically alter the structure of the native vegetation community. Many courses are constructed within natural forested areas to achieve the aesthetic value golfers are searching for. Golf course construction isolates areas of forest into many small patches, resulting in extreme examples of ecosystem fragmentation. Golf course development and maintenance practices may also affect physical and chemical properties of soil within remnants which may in turn affect the vegetation community. Fertilizers and pesticides are commonly used in golf course maintenance based on the principle that impeccable turf is the structure upon which a well-manicured course is attained. Application of nitrogen fertilizers sometimes induces deficiencies of other nutrients, which can limit overall tree growth (Kimmins 1997). The use of lime-based soil amendments can increase soil pH, which may be beneficial for certain species, but in the case of the oak-hickory forest this could produce an environment unlike the naturally-occurring acid soils commonly found in the oak-hickory biome (Ware and Howe 1974).

This preliminary study of golf course woodlot remnants addressed two questions. Firstly, what is the effect of extreme forest fragmentation on the structure of oak-hickory remnants? Secondly, does golf course management alter soil properties in remnants leading to excess nutrients that in turn may affect associated vegetation?

Study Site

This study took place in Kane County, northeastern Illinois, approximately 100 km west of Chicago (Figure 1). The study site, Rich Harvest Links, is a private 18-hole golf course located in Sugar Grove, Illinois (Figure 2). Kane County has a humid, temperate climate, favorable for hardwood forests and prairie grasses (Goddard 1979). Average summer temperatures are 22°C and 63 percent of the total annual precipitation falls as rain between April and September. The surficial geology of the region is attributed to glaciation, as most of the county is covered with loess varying in thickness from several centimetres in the eastern section to two metres in the southwestern section of the county (Goddard 1979). The study site is dominated by silt loam soils that have developed in loess and underlying glacial materials (Goddard 1979).

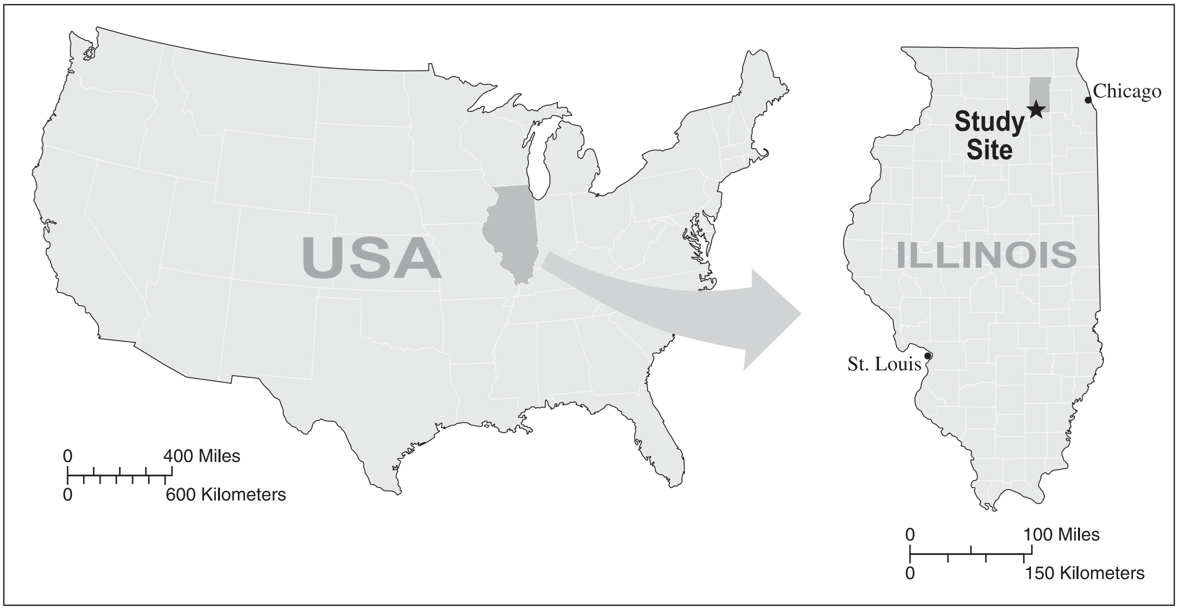

Figure 1: Location of study site, Rich Harvest Links, Sugar Grove, Kane county, Illinois.

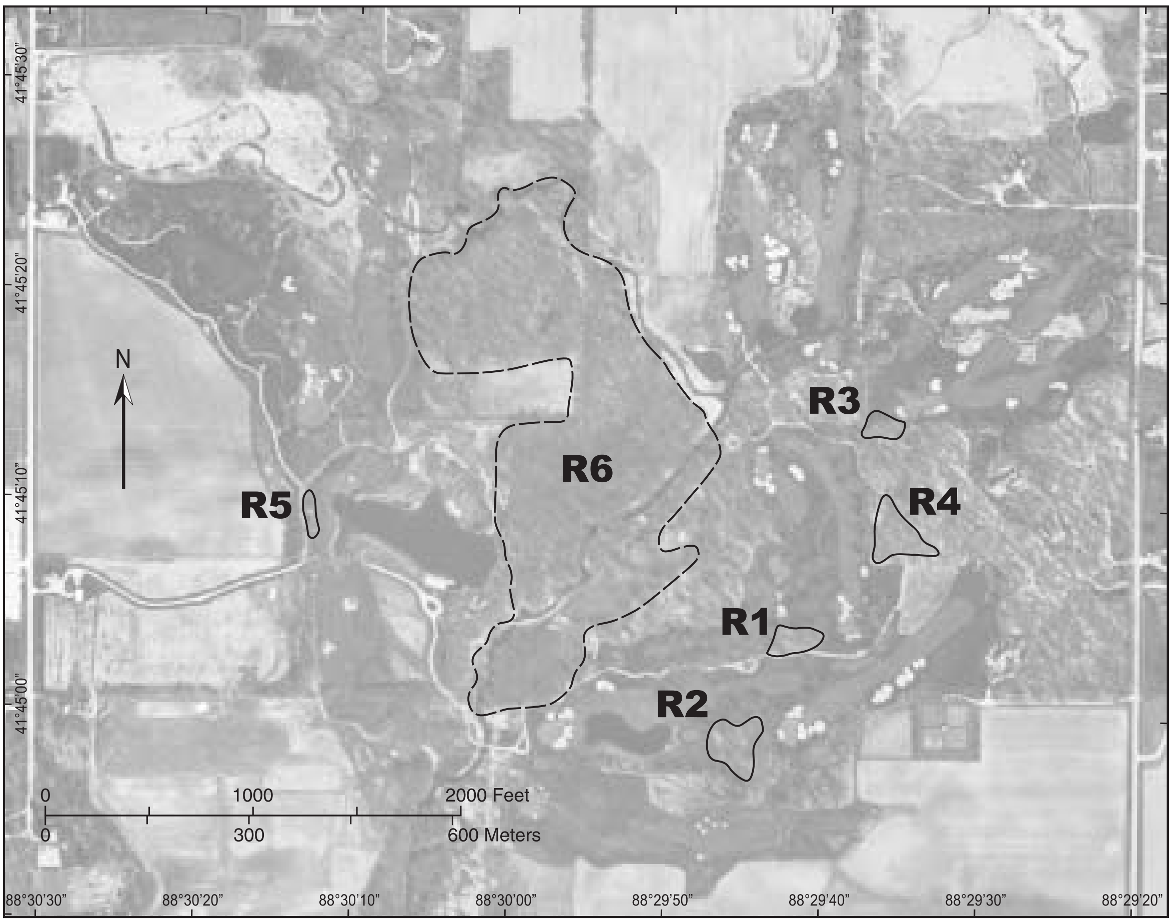

Figure 2: Study site layout showing forest remnant (R1-R6) orientation and size, Rich Harvest Links Golf Course, Sugar Grove, Kane county, Illinois.

Abundant hardwood forests were present in the eastern portion of Kane County and prairies were present in the western portion at the time of European settlement (1830s) (Goddard 1979). Oak *(Quercus sp.)* and hickory *(Carya sp.)* groves were once considered abundant in the region, but now exist mostly as tiny fragments in county forest preserves. Today, oak-hickory forests tend to be dominated by older individuals with little evidence of recent regeneration. This lack of small trees and saplings has resulted in a recognized regeneration gap (Iverson et al. 1989).

Table 1: Height (± s.d.), and density of seedlings in woodlot remnants, Sugar Grove, IL. Area (ha) for remnants 1 - 5 were determined by collecting GPS points for each remnant and using aerial photographs for R6. All values were calculated using data collected summer/fall 1998. Density values for R6 represent a range from 3 plots of data.

Location	Area (ha)	Average Height (cm)	Seedling Density ha^{-1}
Remnant 1	0.21	46.3 ± 25.2	297.5
Remnant 2	0.34	54.7 ± 38.0	351.1
Remnant 3	0.10	22.9 ± 7.2	20.5
Remnant 4	0.27	61.9 ± 40.3	67.3
Remnant 5	0.13	8.0 ± 2.8	70.4
Remnant 6	11.0	35.1 ± 12.8	0-1800

Construction of Rich Harvest Links golf course began in 1989 and continued until 1997. Previous land use of the site included agricultural crops such as corn and soybeans, open prairie, wetlands, oak-hickory woodlands, and previously grazed areas (Rich Harvest Links Management, personal communication, 1998). Within the golf course, existing forest remnants are generally not managed and have not been cleared of native vegetation since golf course construction, with one large section of the original woodland (approximately 11 ha) left largely unused by golf course construction (Figure 2). However, during this study it was noted that woodlot remnants and wooded areas within the golf course were often used to dump excess materials gathered from the course such as tree trimmings, grass clippings and even hickory nuts that have been cleared from the golf course fairways (personal observation 1998/1999). Course maintenance consists of fertilizer application from approximately April 1 to November 1. Fertilizers are applied up to the native vegetation boundary including the greens, fairways, and rough. Fertilizer composition varies for newer and older segments of the course.

Methods

Sample plots within the field site included five woodlot remnants (R1-R5) ranging in size from 0.10 ha to 0.34 ha (Table 1), and one larger remnant (R6, approximately 11 ha in extent) representing the best approximation of continuous forest in the area (Figure 2). Plots used in this study were chosen from a number of highly fragmented woodlot remnants that survived golf course construction and were preserved for aesthetic reasons. The remnants chosen for this study were the least disturbed in terms of golf course usage (i.e. no golf cart tracks). The largest section of the remaining original forest on the site (R6) was sampled for comparison to the other woodlots and to act as a control plot representing the largest available woodland in the area.

Shagbark hickory seedling heights and seedling, sapling, and tree densities were measured in all six woodlot remnants (R1-R6). In plots R1-R5, all seedlings (individuals < one m in height) found in the remnants were enumerated; in R6 three randomly located 100 m^2 sub-plots were censused for seedling density and height. For trees, diameter at breast height (dbh) was recorded for all individuals > five cm dbh present in the remnants (R1-R5). Diameter at breast height measurements were converted into basal areas (πr^2) per ha for comparative analysis for each species. In R6, due to its larger size, a plotless sampling technique, point centre quarter (PCQ), was used to gather tree species composition and density data (Mueller-Dombois and Ellenberg 1974). Comparison of tree data collected using both plot and plotless methods is well documented in the literature (e.g. Rigg et al. 1998). Tree cores were extracted 30 cm above the ground from a total of 19 mature shagbark hickories. Tree cores were air-dried, mounted, sanded, and rings counted using a stereomicroscope to determine minimum age. The regeneration status of shagbark hickory was assessed using size-class diagrams. Size-class distributions were combined for the five smallest remnants (R1-R5) and compared to the size-class distribution from the largest remnant (R6) using the Kolmogorov-Smirnov two-sample test (Siegal 1956).

Shagbark hickory seeds were gathered from the study site during autumn 1998 and cold treated by storing them in an airtight container for approximately 120 days at 5°C. Seed viability was determined by float method and viable seeds were placed in an unfertilized potting mix in the Northern Illinois University greenhouse, in February 1999. Post germination, a random subset of seedlings were fertilized once with 12 percent nitrogen, four percent phosphorous and eight percent potassium, at levels adjusted for the volume of soil in each pot to simulate golf course fertilizer conditions on the newer fairways (Rich Harvest Links Management, personal communication, 1998). Seedlings were harvested 16 weeks after germination and t-tests were used to compare the biomass of seedlings that received fertilizer and those that did not.

Within each forest remnant, surface soil samples between 10-20 cm depth, representative of the A horizon, were collected at five random locations and bulked for pH, organic matter, and soil fertility analysis. Five bulk density samples (five cm depth) were collected from each plot using the core method as described by Black and Hartge (1986). Composite soil samples were refrigerated for nutrient analysis (phosphorous, potassium, magnesium, calcium, sodium, sulpher, pH, organic matter content, and cation exchange capacity (CEC)), which was performed by Key Ag, Inc. (MaComb, IL).

Results

Stand Structure

Within remnants, the highest and lowest seedling densities of 351.1 stems ha^{-1} and 20.5 stems ha^{-1} were found in R2 and R3 respectively (Table 1). Seedling density in the largest remnant (R6) varied from no seedlings in one area to 1,800 seedlings ha^{-1}. However, it should be noted that there was an absence of mature shagbark hickory in the area of the remnant where no seedlings were recorded. Seedlings on average were tallest in the smaller remnants when compared to R6, with the tallest seedlings found (61.9 ± 40.3 cm) in R4 (Table 1).

Tree stem densities were greatest (601.3 stems ha^{-1}) in the larger forest fragment, R6, and lower in remnants R1-R5 with the lowest values in R4 (97.3 stems ha^{-1}) (Table 2). Although

Table 2: Density and basal area of all trees ≥5 cm dbh present in woodlot remnants (R1-R6), Sugar Grove, IL, 1998.

Loc.	Species	Density ha^{-1}	Basal Area m^2 ha^{-1}
R 1	Shagbark hickory	81.6	12.8
	Green ash	14.4	4.4
	Bur oak	9.6	5.9
	Total	**105.6**	**23.1**
R 2	White oak	20.5	6.6
	Spruce (ornamental)	5.9	0.08
	Shagbark hickory	17.6	3.4
	Hawthorne	8.8	0.5
	Green ash	2.9	0.02
	Cherry	49.7	1.6
	Bur oak	2.9	0.7
	Total	**108.3**	**12.9**
R3	White oak	10.3	1.3
	Shagbark hickory	61.8	5.3
	Hawthorne	144.1	2.1
	Hackberry	30.9	0.8
	Bur oak	41.2	8.5
	Total	**288.3**	**18**
R4	White oak	37.4	7.1
	Shagbark hickory	18.7	2.6
	Red oak	3.7	0.4
	Pine (ornamental)	3.8	0.2
	Green ash	18.7	1.3
	Bur oak	15	3.7
	Total	**97.3**	**15.3**
R 5	Slippery elm	15.6	1.2
	Shagbark hickory	31.3	7.1
	Hackberry	7.8	0.2
	Cherry	54.7	5.6
	Boxelder	86	2.3
	American elm	164.2	6.4
	Total	**359.6**	**22.8**
R 6	Slippery elm	81.5	2.8
	Shagbark hickory	112.1	4.7
	Red oak	61.1	4.6
	Hawthorne	20.4	0.3
	Hackberry	30.6	0.2
	Green ash	30.6	2
	Cherry	30.6	1.3
	Boxelder	20.4	0.1
	Black walnut	81.5	5.5
	Bitternut hickory	10.2	0.1
	Basswood	30.6	2.2
	American elm	91.7	2.8
	Total	**601.3**	**26.6**

several of the small remnants had fairly high stem densities (e.g. 359.6 stems ha^{-1} in R5), none were close to the highest value from one plot in R6 (1800 stems ha^{-1}). Stem density for shagbark hickory individuals ≥ five cm dbh was greatest in R6 (112.1 stems ha^{-1}) and ranged from 17.6 stems ha^{-1} (R2) to 81.6 stems ha^{-1} (R1) in the smaller remnants (Table 2). Other species with high stem densities when examined across all plots include the oak species (e.g. red oak with 61.1 stems ha^{-1} in R6), black walnut (81.5 stems ha^{-1} in R6), hawthorn (144.1 stems ha^{-1} in R3) and american elm (164.2 stems ha^{-1} in R5 and 91.7 stems ha^{-1} in R6) (Table 2).

Total basal area for shagbark hickory in all six remnants ranged from 2.6 m^2 ha^{-1} (R4) to 12.8 m^2 ha^{-1} (R1)(Table 2). Total basal area for all species combined was lowest in R2 (12.9 m^2 ha^{-1}), and greatest in R6 (26.6 m^2 ha^{-1}) (Table 2). Although the total basal area for all species in the largest remnant (R6) was the highest of all the plots, it was not significantly greater (at p=0.05) than several of the smaller remnants (R1: 23.16 m^2 ha^{-1} and R5: 22.86 m^2 ha^{-1}). In terms of basal area, shagbark hickory dominated or co-dominated many of the remnants comprising a low of 17 percent (R4 and R6) to a high of 55 percent (R1) of the total basal area in the remnants. Black walnut (R6) and the oaks (R2, R3 and R4) were the other species that consistently comprised a large percentage of the total basal area of the remnants (Table 2). Ring counts based on a small number of tree cores (n=19) taken randomly from measured shagbark hickory in R1-R6 suggest that the large individuals in these remnants may be upward of 125 to 150 years old.

Stand structure diagrams (Figure 3) indicated that there were a greater number of larger shagbark hickory individuals in the small remnants (mean dbh: 53.3 cm) than in the largest remnant (mean dbh: 28.1 cm). The largest individual recorded in R1-R5 was 77.8 cm dbh (R2) and in comparison the largest individual recorded in R6 was only 37.5 cm dbh. The size class distributions for individuals ≥ five cm dbh for remnants R1-R5 indicated a lack of recent recruitment to the small tree stage (5-15 cm dbh) with a majority of the stems occurring in the intermediate-size classes (25-55 cm). The distribution may be described generally as unimodal (Figure 3a). The size class diagram for the largest remnant (R6) showed a greater number of individuals represented in the smaller size classes, indicating recent recruitment success, but no larger/older individuals as in the smaller remnants (Figure 3b). A Kolmogorov-Smirnov two-sample test demonstrated a significant difference (p = 0.05) between the stand structure for R1-R5 and the stand structure of R6.

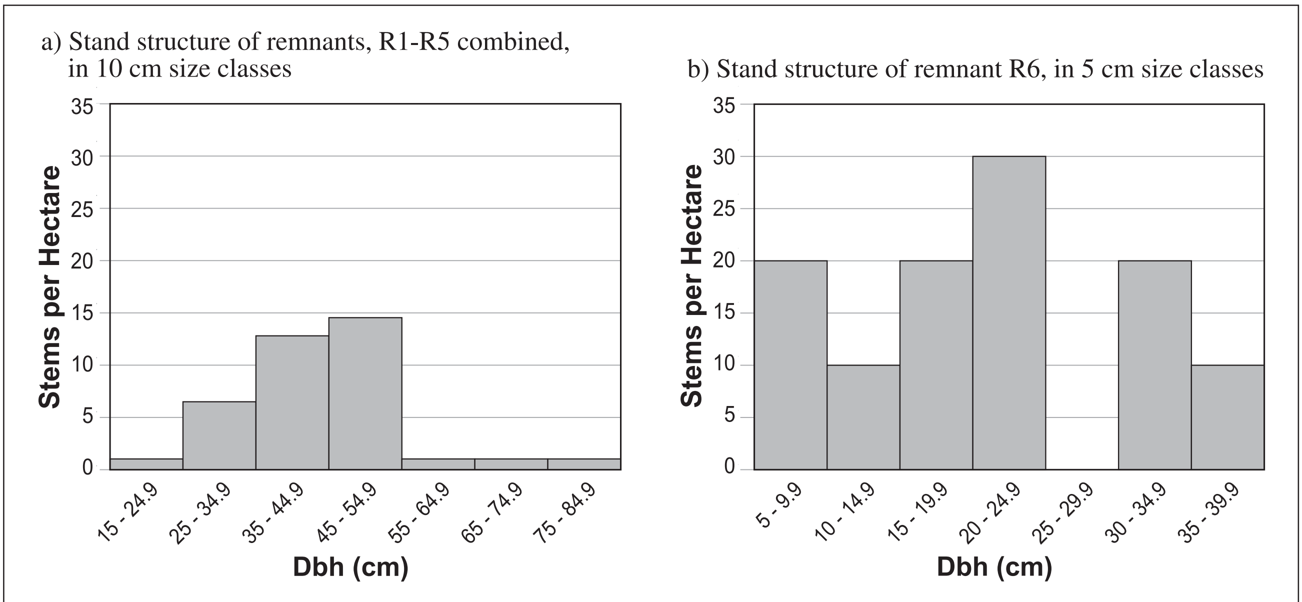

Figure 3: Size class diagrams for shagbark hickory, Sugar Grove, Illinois, 1998.

Table 3: Nutrient concentrations for composite soil samples for all remnants (R1-R6), Sugar Grove, IL, 1998. Macronutrients are measured in kg/ha and micronutrients are recorded in mg/kg.

Location	P kg/ha	K kg/ha	Mg kg/ha	Ca kg/ha	Na kg/ha	S kg/ha	Zn mg/kg	Mn mg/kg	B mg/kg	Cu mg/kg	Fe mg/kg
R1	58	401	988	4768	45	27.9	9.8	156.7	18.4	1.8	128.3
R2	54	495	1179	4990	47	26.5	9.5	122.0	18.0	1.9	105.0
R3	67	529	907	5111	43	27.2	13.1	195.5	16.0	1.6	98.6
R4	67	491	726	3750	45	23.31	0.0	155.3	14.8	1.5	102.4
R5	81	459	806	3790	56	25.1	15.9	121.4	16.4	1.9	112.4
R6.1	94	271	1532	5836	45	30.6	7.8	137.8	21.2	2.6	198.6
R6.2	105	242	1260	5736	45	30.6	7.8	137.8	21.2	2.6	198.6
R6.3	95	235	1230	5393	43	26.9	8.9	84.1	18.8	1.5	145.2

Seedling Germination

There was an 88 percent germination rate for greenhouse-sown shagbark hickory seeds within 1.5 months of planting. Seedling height and biomass were measured after 16 weeks of growth. The average height of unfertilized seedlings (11.25 cm) was slightly greater than the average height of the fertilized seedlings (10.56 cm), but this difference was not statistically significant. At 16 weeks, one of the unfertilized seedlings showed evidence of decreased vigor with slightly chlorotic leaves, whereas 17 of the 21 fertilized seedlings showed evidence of decreased health with browning leaves, five of which had lost their leaves completely. Sixteen seedlings were harvested from the fertilized and unfertilized pots to determine root and shoot biomass. Root biomass was significantly greater ($p = 0.05$, two tailed t-test) in the unfertilized seedlings, but there was no significant difference in shoot biomass between the two groups of seedlings. Overall, the average root to shoot ratio was greater for unfertilized seedlings (3.47) than fertilized seedlings (2.45).

Table 4: pH, cation exchange capacity, organic matter content for composite soil samples for all remnants (R1-R6), Sugar Grove, IL, 1998.

Location	pH	CEC cmol/kg	OM g/kg
R 1	6.8	14.9	28
R2	7.0	16.2	31
R3	6.9	15.5	33
R4	6.3	12.7	30
R5	6.5	13.1	23
R6.1	7.1	19.1	34
R6.2	7.1	17.9	34

Soil Analysis

Variations in nutrient concentration were found between soil samples collected from woodlot remnants, although no trends dominated. Phosphorus, magnesium, calcium, and sulphur tended to have slightly higher mean concentrations in R6 than in the other remnants, while the reverse was true for potassium (Table 3). Mean potassium concentrations were notably higher in remnants R1-R5 (475 kg ha^{-1}) than in R6 (249 kg ha^{-1}). Lower pH values in remnants R1-R6 (mean of 6.7) may have been associated with the application of nitrogen fertilizer by golf course managers, but since total nitrogen was not measured this relationship can only be hypothesized. Soil pH was on average slightly higher in R6 (mean of 7.1) (Table 4). Soil organic matter content was also higher in R6 (3.2 percent) than in remnants R1-R5 (2.9 percent) (Table 4). Average cation exchange capacity was notably higher, on average, in R6 (18.0 meq/100 g) than remnants R1-R5 (14.5 meq/100 g). Bulk density ranged from 0.94 g/cm^3 to 1.06 g/cm^3 in the remnants and no clear trend was indicated among the various remnants.

Discussion

Urbanization, industrialization, agriculture, and even recreation can result in the loss of natural forested areas. Understanding that a certain degree of forest fragmentation may be unavoidable with increasing human populations, it is practical to focus on ways to ensure the health and success of currently fragmented communities.

The longevity of forest communities in fragmented systems is determined by the ability of canopy species to regenerate under the environmental constraints of fragmentation. Within the study site seedling densities in forest fragments indicated that shagbark hickory is capable of establishing within a fragmented environment. However, stand structures show that stem numbers in the smaller size classes (5.0 – 29.9 cm dbh) are under-represented, especially in the smaller remnants. There is a high density of seedlings and of larger individuals, but almost no medium-sized individuals present in the understory or mid-canopy. This suggests that seedlings are establishing, but they are not persisting into the canopy. This is not surprising given the shade intolerance or at best intermediate shade tolerance of shagbark hickory. Even though large size classes are represented, the paucity of individuals in these size classes cannot be explained by age-related mortality. Ring counts suggest that the larger sized individuals in the remnants may be up to 150 years old. It is likely that selective clearing of woodlots by early settlers occurred approximately 100-150 years ago, based on settlement patterns in the region. In the largest remnant sampled (R6) there were no large individuals (> 40 cm dbh), but there was some evidence of recent recruitment to the mid-story of the forest with stems in the 5-10 cm size class. This suggests that the area of the forest from which the larger remnant originated was either disturbed (cleared or selectively logged) more recently than the area from which remnants R1-R5 were carved out, or that stems are suppressed in a canopy that is becoming increasingly dominated by species such as elm and basswood (Table 2).

To what extent can these extremely fragmented remnants be expected to sustain a canopy of shagbark hickory? Mudrack (1978) found that the Wisconsin bur oak and white oak forest types could not sustain themselves in stands less than eight ha in size. More recently, Brothers and Spingarn (1992) stated that mesic midwestern forest islands must remain larger than approximately 3.8 ha to sustain forest interior communities and shade tolerant species. Given the size of the study site remnants, most smaller than one ha (R1-R5) and only one plot larger (R6), edge characteristics such as the invasion of weedy species, increased exposure to wind damage, and changes in microclimate would dominate and little core environment can be maintained. For a shade intolerant species such as shagbark hickory this may not be such a concern due to increased light levels associated with increased edge.

Seedling densities in remnants R1-R5 were considerably lower than in the larger remnant, R6. There was an apparent decrease in seedling density with increasing distance from the edge of the larger remnant. This suggests that light levels near the edge of the larger forest remnant allow for greater regeneration. When remnants R1-R5 are examined, a trend emerges such that lower densities of shagbark hickory seedlings are associated with higher tree densities (all species combined), suggesting a similar light response with more dense and presumably darker stands having lower seedling densities.

Golf course maintenance practices, such as the disposal of clippings and grass cuttings in woodlot remnants, may also play a role in controlling seedling densities within fragments. The fragmented areas adjacent to the golf course are often used as dumping grounds for trimmed tree branches, grass clippings, leaves, and excess hickory nuts that have been collected to keep the fairways clear. This practice may bury some of the smaller seedlings beneath a blanket of heavy material disturbing physical growth, decreasing light levels, and perhaps causing above-average levels of water retention. Although this study noted seedling establishment in remnants, seedling densities were less than the potential densities (1800 stems ha^{-1}) found in the larger remnant (R6). Declines in seedling densities associated with dumping can only be suggested as the direct impact was not examined in the experimental design of this study.

Based on the results of the fertilized and non-fertilized seedlings grown from seeds collected from the study site, fertilizer addition did not increase seedling growth; in fact, the unfertilized seedlings' average height was greater than the fertilized seedlings'. Furthermore, only four of the 21 fertilized seedlings appeared to be healthy when they were harvested. Plants are most sensitive to increased nutrient levels at the seedling stage. However, these results differ from previous studies that found that shagbark hickory did not demonstrate a significant response to nutrient treatments (Lajtha 1994; Latham 1992). Lajtha (1994) concluded from a study of nutrient uptake in eastern deciduous tree seedlings that shagbark hickory had intermediate levels of nutrient uptake when subject to both high- and low- nutrient treatments. Lajtha (1994) also noted that species with low growth rates, such as shagbark hickory, are tolerant of decreased nutrients and are less responsive to increased nutrients. Individual seedlings in the field did not visually appear to be affected by either excess nutrient levels nor did they exhibit any signs of nutrient deficiency.

Soil nutrient concentrations at the study site were highly variable between remnants and no clear trends were apparent. It was expected that the small remnants (R1-R5) would be more influenced by golf course fertilizer treatments than the larger remnant R6. Potassium concentrations were greater in R1-R5 than in R6, which may be due to golf course fertilization, but most trends such as increases in calcium and magnesium in R6 are most likely associated with slightly increased levels of organic matter in that remnant. Nutrient availability is often limited by pH, which only varied slightly between the remnants with the more exposed and smaller remnants being slightly more acidic. The pH range (6.3-7.1) throughout the study site did not indicate that pH-dependent nutrient availability was negatively affecting plant growth. Bulk density values were similar for all remnants. The variability of soil physical and chemical properties does not appear to be a limiting factor in seedling establishment.

Management practices may be having a direct impact upon the regeneration and growth of shagbark hickory. Although fertilizers are not being applied directly to forest fragments in this golf course, the surrounding environment is being intensely managed. Montagnini et al. (1989) studied factors regulating nitrification in three forests of contrasting nitrifying activity: a pine-mixed hardwood forest, a black locust-dominated early successional forest, and a mature oak-hickory forest. Results showed that in a mature oak-hickory forest located in the southern Appalachians, nitrification was not stimulated by NH_4-N amendments but was increased slightly by a $CaCO_3$ amendment. In another study, Latham (1992) examined the differences in response to light and nutrient variations of six co-occurring eastern North American temperate upland forest seedlings, including shagbark hickory. The species represented various degrees of shade tolerance, drought tolerance, low nitrogen tolerance, density, wood anatomy, and seed size. Neither light treatments nor nutrient treatments had a significant effect on the mean daily change in height of shagbark hickory. Shagbark hickory displayed only moderately high initial height growth rates, but had tremendous allocation to root growth and exceeded all other species in all treatments for root/shoot dry mass ratio. In the current study there was also a significant difference in root biomass between fertilized and unfertilized seedlings, with average root to shoot ratios greater for unfertilized seedlings (3.47) than for fertilized seedlings (2.45).

Conclusion

Recent research has concentrated on forest fragmentation in natural communities in an effort to assess the impacts of forest fragmentation on the ecosystem (Gibson et al. 1988; Kellman 1996; Saunders et al. 1991). The ultimate goal is to maintain the landscape in its natural state, but as human populations continue to increase throughout the world, forests will undoubtedly be lost. The loss of forested land will take on many forms for many purposes such as urbanization, agriculture, and recreation. Therefore, as fragmentation continues it becomes essential to focus on ways to ensure the health and success of current fragmented communities.

Shagbark hickory is capable of regeneration in an intensely managed, fragmented environment, but size-class diagrams indicate that there is a lack of recruitment to the small tree stage even in small/high light fragments. Golf course maintenance practices may play an important role in explaining why very few seedlings continue into the juvenile stage. Methods of dumping tree trimmings, grass clippings, and leaves may be detrimental to seedling survival. Golf course fertilizer application may be harmful at the seedling stage as shown in the seedling germination section of this study, but more extensive research is needed to determine the potential for this damage, since long-term nutrient effects were not detectable based on soil nutrient concentrations in the study site. Fertilizer application on the greenhouse germinants were based on concentrations used for management of the golf course and our results suggested they were higher than what may run off the fairways after fertilizer application.

If this lack of seedling persistence continues within the current study site, there will not be appreciable numbers of younger shagbark hickory individuals to replace the mature trees as they die. Although seedling densities are much lower in the smaller remnants than in the larger remnant, they are successfully establishing. Management practices, including altering debris disposal practices and modifying nutrient amendments, need to be initiated to ensure the longevity of seedlings, if the golf course hopes to have their forest remnants persist through time.

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References

Benitez-Malvido, J. (1998). Impact of forest fragmentation on seedling abundance in a tropical rainforest. *Conservation Biology* 12:380-389.

Black, G. R. and Hartge, K. H. (1986). American Society of Agronomy – Soil Science Society of America, Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods —*Agronomy Monograph* 9:363-376.

Brothers, T. S. and Spingarn, A. (1992). Forest fragmentation and alien plant invasion of central Indiana old-growth forests. *Conservation Biology* 6:91-100.

Cox, G. W. (1997). *Conservation Biology, Concepts and Applications.* Wm. C. Brown Publishers, McGraw Hill, Dubuque.

Gibson, D., Collins, S. and Good, R. (1988). Ecosystem fragmentation of Oak-Pine forest in the New Jersey Pinelands. *Forest Ecology and Management* 25:105-122.

Goddard, T. M. (1979). *Soil Survey of Kane County, Illinois*. Soil Conservation Service.

Goldblum, D. and S.W. Beatty. (1999). Influence of an old field/forest edge on a northeastern United States deciduous forest understory community. *Journal of the Torrey Botanical Society* 126:335-343

Graney, D. (1990). Shagbark Hickory. *Silvics of North America* 2:219-225.

Hill, D. (1985). Forest fragmentation and its implications in central New York. *Forest Ecology and Management* 12:113-128.

Iverson, L. R., Oliver, R. L., Tucker, D. P., Risser, P. G., Burnett, C. D. and Rayburn, R. G. (1989). *The forest resources of Illinois: An atlas and analysis of spatial and temporal trends*. Illinois Natural History Survey Special Publication 11.

Kellman, M. (1996). Redefining roles: plant community reorganization and species preservation in fragmented systems. *Global Ecology and Biogeography Letters* 5:111-116.

Kimmins, J. P. (1997). *Forest Ecology.* Prentice Hall, New Jersey.

Lajtha, K. (1994). Nutrient uptake in eastern deciduous tree seedlings. *Plant and Soil* 160:193-199.

Latham, R. E. (1992). Co-occurring tree species change rank in seedling performance with resources varied experimentally. *Ecology* 73:2129-2144

Laurance, W. F. (1991). Edge effects in tropical forest fragments: Application of a model for the design of nature reserves. *Biological Conservation* 57:205-219.

Matlack, G. R. (1994). Vegetation dynamics of the forest edge – trends in space and successional time. *Journal of Ecology* 82:113-123.

Montagnini, F., Haines, B., and Swank, W. (1989). Factors controlling nitrification in soils of early seccessional oak-hickory forests in the southern Appalachians. *Forest Ecology and Management 26*:77-94.

Mudrack, F. E. (1978). *Equilibrium dynamics of oak islands in southeastern Wisconsin*. Unpublished MSc Thesis, University Wisconsin, Milwaukee, WI.

Mueller-Dombois, D. and Ellenberg, H. (1974). The count-plot method and plotless sampling techniques. *Aims and Methods of Vegetation Ecology.* Wiley International Edition (John Wiley and Sons), Toronto. Pgs. 110-120.

Rigg, L. S., Enright, N. J. and Jaffre, T. (1998) Stand structure of the emergent conifer *Araucaria laubenfelsii*, in maquis and rain forest, Mont Do, New Caledonia. *Australian Journal of Ecology* 23:528-538

Salvensen, D. (1996). Greening up the greens. *Planning* 62:4-9.

Saunders, D., Hobbs, R. and Margules, C. (1991). Biological consequences of ecosystem fragmentation: a review. *Conservation Biology* 5:18-30.

Siegal, S. (1956). *Nonparametric Statistics for the Behavioral Sciences*. McGraw-Hill, Kogakusha Ltd. Tokyo.

Ware, G. & Howe, V. K. (1974). The care and management of native oaks in northern Illinois. *The Morton Arboretum Plant Information Bulletin* 4:1-4.

Williams-Linera, G. (1990). Vegetation structure and environmental conditions of forest edges in Panama. *Journal of Ecology* 78:356-373.

Appendix 1: Scientific names for species and their authorities.

Common Name	Species and Authority
American elm	*Ulmus Americana* L.
Basswood	*Tilia americana* L.
Bitternut hickory	*Carya cordifomis* (Wagenh.) K. Koch
Black walnut	*Juglans nigra* L.
Boxelder	*Acer negundo* L.
Bur oak	*Quercus macrocarpa* Michx.
Cherry	*Prunus sp.*
Green ash	*Fraxinus pennsylvanica* Marsh.
Hackberry	*Celtis occidentalis* L.
Hawthorn	*Crataegus sp.*
Pine	*Pinus sp.* (ornamental)
Red oak	*Quercus rubra* Muhl.
Shagbark hickory	*Carya ovata* (Mill.) K. Koch
Slippery elm	*Ulmus rubra* Muhl.
Spruce	*Picea sp.* (ornamental)
White oak	*Quercus alba* L.