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THE EFFECTS OF WHITE-TAILED DEER ON PLANT COMMUNITIES WITHIN INDIANA STATE PARKS

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ABSTRACT: The white-tailed deer (*Odocoileus virginianus*) thrives in the habitat mosaic currently found in Indiana and may reach population densities that alter the structure and composition of forest ecosystems in the absence of population control through predation. Our research was initiated to examine the relationship of deer browsing to the condition of the plant communities within Indiana State Parks. During the summer of 1996, thirteen Indiana State Parks and five control areas (where deer hunting was permitted) were sampled to evaluate the impact of deer on these plant communities. During the summer of 1997, one park was added, and fourteen parks were sampled. Significant declines (versus control areas) in the percent cover of herbaceous species and the density of woody stems 50-200 cm in height were observed. For example, both measures were significantly less in three parks in 1997, an additional two parks had significant declines in percent cover of herbaceous species, and one park had a significant decline in the density of woody stems. In general, our research suggests that white-tailed deer populations are impacting Indiana State Parks at varying levels and that these impacts are changing the structure and composition of the plant communities therein.

KEYWORDS: Deer browse, garlic mustard, herbivory, *Odocoileus virginianus*, pawpaw.

INTRODUCTION

White-tailed deer (*Odocoileus virginianus*) are highly adaptable and thrive in the agricultural mosaic created by modern land use. In the absence of population regulation by predation, hunting, or disease, populations can quickly increase to numbers exceeding the carrying capacity of their habitat (Anderson, 1997). White-tailed deer had been extirpated in Indiana by the late 1880s as a result of habitat destruction and unregulated harvest, but they were successfully reintroduced during the 1930's and 1940's. Within 15 years of those reintroductions, deer were beginning to cause localized damage to crops and the native vegetation in areas around their release sites. The first modern deer hunt in Indiana was held in 1951 to remove the annual surplus of deer and lessen crop damage (Mumford and Whitaker, 1982; Brown County State Park Deer Study Committee, 1993).

Excessive populations of white-tailed deer can have a profound effect on plant species composition and community structure in forest systems (Deelen,

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et al., 1996; Redding, 1995; Anderson and Katz, 1993; Strole and Anderson, 1992; Balgooyen and Waller, 1995; Frelich and Lorimer, 1985; Anderson and Loucks, 1979; Telfer, 1972). For the purposes of this study, we defined overabundant populations as populations that have reached a level where they are beginning to negatively impact plant communities. In managed systems, the selective foraging habits of white-tailed deer have posed many concerns over stand regeneration after harvest (Redding, 1995; Trumbull, *et al.*, 1989; Marquis, 1974). Selective foraging can cause a shift in herbaceous species composition toward non-palatable species (Bowersox, *et al.*, 1995; McCormick, *et al.*, 1994).

Dramatic understory alterations resulting from excessive deer browsing are becoming more frequent and may increase the possibility of local extirpation of some more preferred plant species (Strole and Anderson, 1992). In Brown County State Park, Parker and Van Kley (1993) found that the high density of deer in the park had virtually removed the subcanopy and greatly reduced the herbaceous ground cover. Little recovery of the understory plants was evident in the spring of 1994 following the removal of approximately 400 deer during December 1993 (Parker and Brown, 1994). Since that time, deer reductions have been initiated in other Indiana State Parks where the effects of excessive deer populations have been observed on plant communities. Herein, we present the results of a study initiated to monitor the impact of white-tailed deer on the plant communities in Indiana State Parks. Specifically, we assess the relationship between high densities of white-tailed deer and plant communities in Indiana State Parks by examining how herbaceous ground cover, woody browse species abundance, and understory species richness (S), evenness (E), and diversity (Shannon-Weiner, H′) have responded.

MATERIALS AND METHODS

Study Area. During May and June 1996, 13 Indiana State Parks were examined to assess the effect of white-tailed deer on plant community condition (Figure 1). These parks are located throughout the State and were selected to provide a range of size, shape, and landscape context. To control for possible regional variations in species and growing conditions, the parks were clustered by Natural Region as defined by Homoya, *et al.* (1985). A single control area where deer hunting was permitted was sampled within each Natural Region. Data collected by the Indiana Department of Natural Resources on the number of deer killed per unit of hunter effort in state parks and fish and wildlife areas (unpublished data) suggest that hunting reduces the density of white-tailed deer (Figure 2). Areas which have been hunted for many years, such as fish and wildlife areas and Charlestown State Park, have lower numbers of deer harvested per hunter-day than do recently hunted state parks. The number of deer harvested per hunter-day is declining in parks where repeated hunting has occurred, such as Brown County, Potato Creek, and Pokagon State Parks.

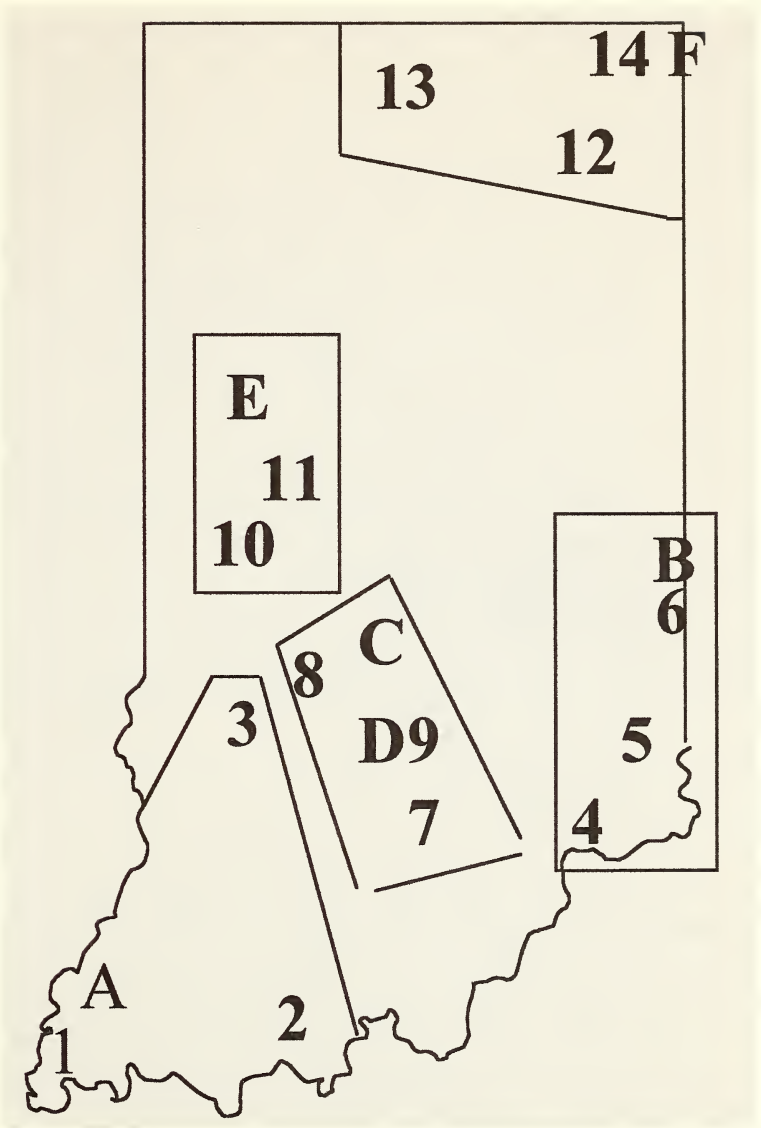

Figure 1. Locations of the Indiana State Parks and control areas studied during 1996 and 1997 by Natural Region: **Southwestern Lowlands Natural Region**, 1 = Harmonie, 2 = Lincoln, 3 = Shakamak State Parks as well as A = Indian Mounds Farm (control); **Bluegrass Natural Region**, 4 = Clifty Falls, 5 = Versailles, and 6 = Whitewater State Parks as well as B = Webster Farm (control); **Highland Rim Natural Region**, 7 = Spring Mill, 8 = McCormick's Creek, and 9 = Brown County State Parks as well as C = Yellowwood State Forest (control) and D = Morgan-Monroe State Forest (control); **Central Till Plain Natural Region**, 10 = Turkey Run and 11 = Shades State Parks as well as E = Martell Experimental Forest (control); **Northern Lakes Natural Region**, 12 = Chain O' Lakes, 13 = Potato Creek, and 14 = Pokagon State Parks as well as F = Oakhill Camp (control). Polygons indicate groupings of parks with a control area based upon a Natural Region.

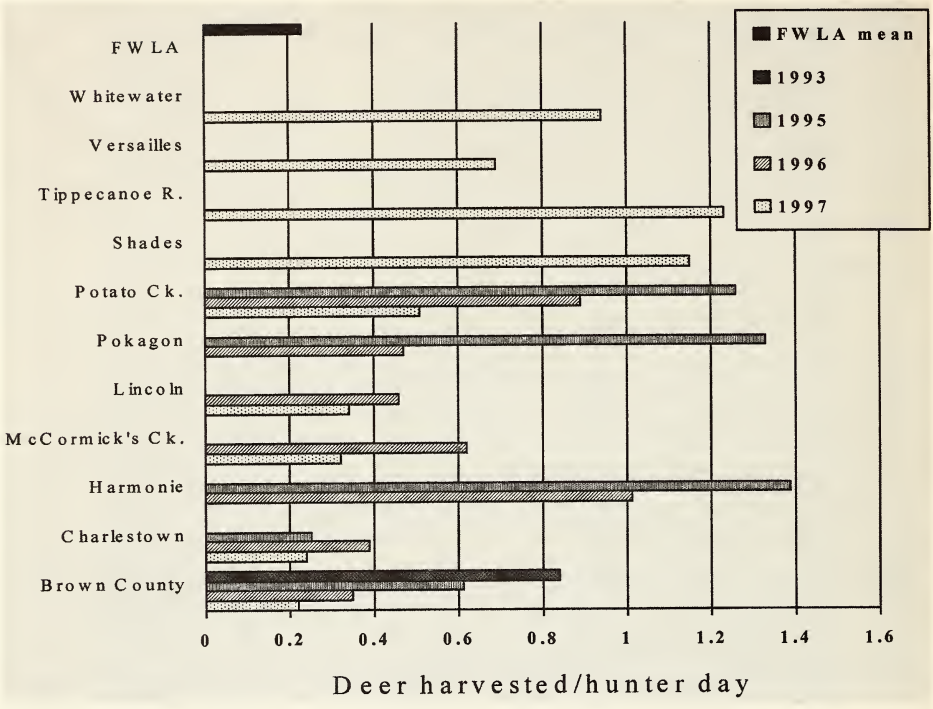

Figure 2. Number of deer harvested per hunter-day for Indiana State Parks that have had deer population reductions and the mean deer harvest per hunter-day on Indiana fish and wildlife areas from 1986 to 1995.

In 1996, six forest stands were randomly selected within the central area of each park using U.S. Geological Survey quad maps and ground reconnaissance. Harmonie, Versailles, Spring Mill, McCormick's Creek, Turkey Run, and Pokagon State Parks all had three existing plots (Brown, 1996), so three additional sites were selected to provide a total of six 300 m^2 circular sample plots per park. All experimental plots were located within mesic communities of closed canopy mature hardwood forest. Aspect, ground flora species, and overstory tree species composition were used to discern mesic sites. Plots were permanently marked with rebar for future monitoring. Similarly, six 300 m^2 circular plots were established in each control area.

During May and June 1997, the above sites were revisited, and one additional park was examined. Five established plots in Brown County State Park (Brown, 1996) were resampled, and one additional plot was established. Three existing plots in Yellowwood State Forest (Brown, 1996) were also sampled.

Field Sampling Design. During May and June 1996 and 1997, we sampled ground flora coverage on line transects running parallel to the contour of the slope on six sample plots per area. On each slope, a base stake was randomly placed at approximately mid-slope to serve as the end of the center 10 m line transect. Two additional 10 m line transects were placed at random distances

(between two and five meters) parallel to the center transect. One of these transects was located upslope from the center transect, and one was located downslope from it. The distance in centimeters of the line transect covered by each herbaceous species was recorded. These distance values were then used to calculate percent cover. The overlap of woody plants less than 50 cm in height was included in this category. The number of woody stems 50 to 200 cm in height was tallied by species on a 50 m^2 circular plot centered at the base stake. The stem tallies provided a density estimate of the number of stems per 50 m^2 for each plot. These tallies were then converted to stems per hectare. The density of woody stems was measured in all the parks sampled in 1996 but was resampled in 1997 only in parks that had deer reductions during the winter of 1996 (Harmonie, Lincoln, McCormick's Creek, Pokagon, and Potato Creek State Parks). Woody stem density was recorded on all the plots in Brown County State Park, which was added in 1997.

Data Analysis. Regression analysis indicated that a significant correlation did not exist between sampling date and mean percent cover ($F_{1,21} = 0.0113$, $P = 0.916$, $R_2 = 0.0005$). Therefore, the means for each park were considered independent. The mean percent cover of the herbaceous species and woody stem densities were then compared for each year between parks and control areas using a one-way ANOVA and Tukey's pairwise multiple comparisons test (Jandel Scientific, 1995). All comparisons were done by Natural Region to control for regional variations in percent cover and woody stem density. The Kolmogorov-Smirnov normality test was used to test the normality for the percent cover and woody stem data (Jandel Scientific, 1995). The data from the majority of parks and controls for all variables were normally distributed (78-100%), so no transformations were used to improve the normality of the data.

Species richness (S), evenness (E), and diversity (Shannon-Weiner, H′) were calculated for each plot using the distance covered by each species in relation to the total transect distance (3000 cm/plot). All herbaceous species and any woody vegetation less than 50 cm in height covering a transect were included in the calculation of the above estimates. The mean values for each park and for its control area were compared using a one-way ANOVA and Tukey's pairwise multiple comparisons test. These comparisons were done by Natural Region to control for regional variation in plant community composition and structure. Sedges (*Carex* spp.) and grasses (Poaceae) were combined into one group for analysis. The Kolmogorov-Smirnov normality test was used to test the assumption of normality. Due to the short duration of this study and the limited sample size, no significant differences were detected between years for any of the factors examined ($p > 0.05$).

The composition of the herbaceous communities was analyzed by computing the percent cover of each individual species encountered in a park during 1997. The species that contributed the most to the total percent cover are reported in the text. These figures illustrate the uneven distribution of plant species within and between sites. The composition of the sapling layer (stems 50-200

cm in height) at each park and control area was analyzed by examining the number of stems of each species per hectare. These data are reported where obvious differences existed. The 1997 data were used because these data were the most recent and were available for all fourteen parks discussed in this paper.

RESULTS

Southwestern Lowlands Natural Region. In 1996, one park (Harmonie State Park) had significantly less herbaceous cover than the control area ($p < 0.05$, Table 1). The differences in other parks were not significant. Woody stem density was not significantly different for any of these parks (Table 2). Mean plot species richness (S), evenness (E), and Shannon-Weiner species diversity (H′) of the parks did not differ significantly from their values in the control area (Tables 3-4).

In 1997, Harmonie State Park was again the only park with significantly less herbaceous cover than the control area ($p < 0.05$, Table 1). Lincoln and Harmonie State Parks did not differ significantly in density of woody stems per hectare from their control area (Table 2). Woody stem density in Shakamak State Park was not recorded during the 1997 field season because no deer reduction was conducted in this park in the winter of 1996. Mean plot species richness, evenness, and diversity of the parks also did not differ significantly from their values in the control area in 1997 (Tables 3-4).

The sapling layer in Harmonie State Park was dominated by papaw (*Asimina triloba*), a species that is not consumed by white-tailed deer. This species may mask differences in woody stem density between the park and its control area. The composition of the sapling layer at Harmonie State Park in comparison to its composition in the control area in 1997 reflected this relationship (Figure 3). The herbaceous layer in the parks sampled was dominated by May apple *(Podophyllum peltatum*), Christmas fern (*Polystichum acrostichoides*), and jack-in-the-pulpit (*Arisaema triphyllum*). May apple accounted for approximately 58% and 38% of the total herbaceous cover in Lincoln and Shakamak State Parks, respectively, but only accounted for 20% of the total herbaceous coverage in the control area. Christmas fern was most common in Shakamak State Park, where it accounted for approximately 13% of the total herbaceous cover. Christmas fern made up approximately 5% of the coverage at the control area. Jack-in-the-pulpit accounted for 17% of the total herbaceous cover in Harmonie State Park and was also quite common in the control area, where it accounted for 18% of the total herbaceous coverage. The extensive coverage of Star-of-Bethlehem (*Ornithogalum umbellatum*) on one plot at Shakamak State Park accounted for approximately 8% of the total percent cover of herbaceous species in the park. This species was not present on sample plots in any of the control areas or any other park.

Bluegrass Natural Region. In 1996, the values for mean percent cover of herbaceous species for Clifty Falls, Whitewater, and Versailles State Parks were not significantly different from their control area (Table 1). However, the den-

Table 1. Comparisons of mean percent cover of herbaceous species between parks and control areas by Natural Region. All tests were done with a one-way ANOVA and Tukey's pairwise multiple comparisons test. An asterisk (*) denotes a significant difference between a park and its control area ($p < 0.05$).

	Mean Percent Cover		Standard Error	
	1996	1997	1996	1997
Southwestern Lowlands Natural Region				
Harmonie State Park	4.7*	6.8*	1.8	2.8
Lincoln State Park	18.6	21.8	3.0	6.3
Shakamak State Park	29.6	35.7	9.8	9.1
Control Area (Indian Mounds Farm)	30.9	31.7	3.2	4.1
Bluegrass Natural Region				
Clifty Falls State Park	24.2	32.4	6.8	9.6
Versailles State Park	32.7	44.6	6.9	7.9
Whitewater State Park	40.2	42.5	6.2	6.7
Control Area (Webster Farm)	31.9	36.4	3.8	4.7
Highland Rim Natural Region				
Spring Mill State Park	38.5	41.5	4.7	4.6
McCormick's Creek State Park	21.3	25.6	7.5	7.4
Brown County State Park		6.3*		1.2
Control Area (Morgan-Monroe State Forest)	45.1	33.6[1]	11.9	4.7
Central Till Plain Natural Region				
Turkey Run State Park	37.7	42.1	3.7	7.0
Shades State Park	39.2	34.6	3.1	1.9
Control Area (Martell Experimental Forest)	47.6	50.5	5.4	5.1
Northern Lakes Natural Region				
Chain O'Lakes State Park	32.7*	28.1*	3.9	4.7
Potato Creek State Park	12.2*	14.8*	2.8	4.1
Pokagon State Park	26.6*	27.7*	1.8	2.8
Control Area (Oakhill Camp)	58.4	48.2	6.4	5.7

[1] In 1997, three plots sampled that year in Yellowwood State Forest were included in the calculation of this mean.

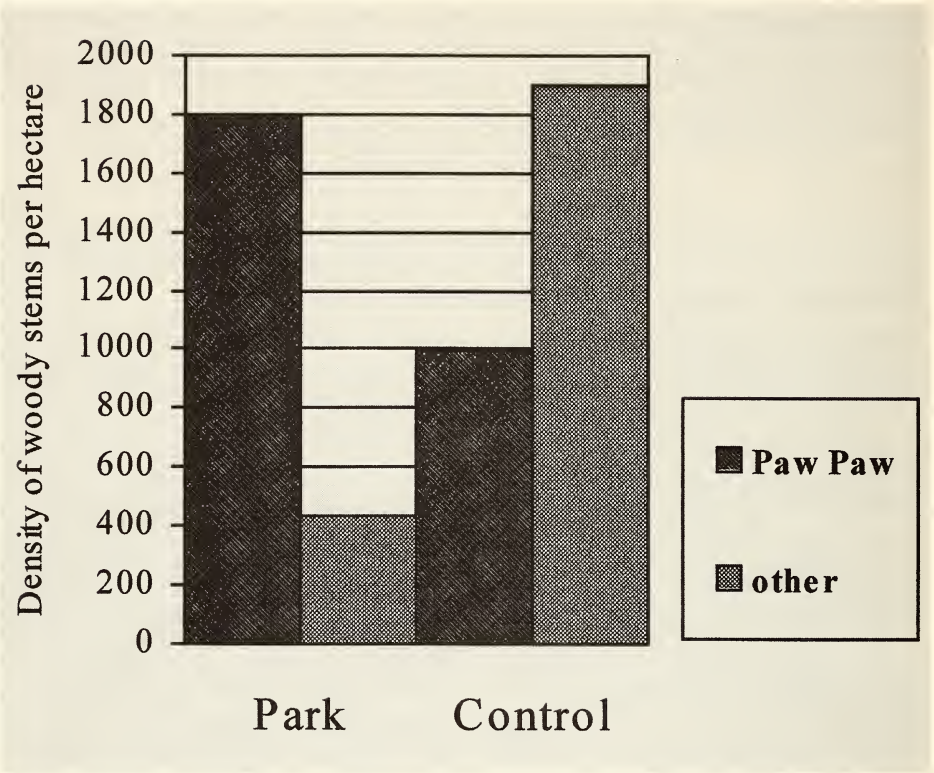

Figure 3. Density of woody stems 50-200 cm in height per hectare of pawpaw versus all other woody species in Harmonie State Park and its control area (Indian Mounds Farm) in May 1997.

sity of woody stems per hectare (50-200 cm in height) within both Whitewater and Versailles State Parks was significantly less than that of the control area ($p < 0.05$, Table 2). Clifty Falls State Park did not display a significant difference (Table 2). The mean plot species richness of Clifty Falls State Park was significantly less than that of the control area ($p < 0.05$, Table 3), but the mean plot species richness of Versailles and Whitewater State Parks did not differ significantly from that of the control area (Table 3). Species evenness and diversity on the sample plots did not differ significantly from the values for the control area for any park in this region (Table 4).

In 1997, no significant differences in percent cover of herbaceous species were found for the parks in the Bluegrass Natural Region (Table 1). Mean plot species richness, evenness, and diversity did not differ significantly from those recorded for the control area (Tables 3-4). Since none of the parks had deer reductions during the winter of 1996, the density of woody stems was not recorded during the 1997 field season.

In Versailles State Park, the herbaceous layer was dominated by narrow-leaved spleenwort (*Athyrium pycnocarpon*), twinleaf (*Jeffersonia diphylla*), gar-

Table 2. Comparisons of mean density of woody stems 50 to 200 cm in height per hectare (MDWS) between parks and control areas by Natural Region. All tests were done using a one-way ANOVA and Tukey's pairwise multiple comparisons test. An asterisk (*) denotes a significant difference between a park and its control area ($p < 0.05$).

	MDWS		Standard Error	
	1996	1997	1996	1997
Southwestern Lowlands Natural Region				
Harmonie State Park	2200	2233	844	967
Lincoln State Park	1267	1000	458	329
Shakamak State Park	1767		418	
Control Area (Indian Mounds Farm)	2667	2900	786	942
Bluegrass Natural Region				
Clifty Falls State Park	5600		1077	
Versailles State Park	1467*		360	
Whitewater State Park	1067*		406	
Control Area (Webster Farm)	8867		2372	
Highland Rim Natural Region				
Spring Mill State Park	3500		1035	
McCormick's Creek State Park	1100*	1200*	184	455
Brown County State Park		667*		146
Control Area (Morgan-Monroe State Forest)	4667	5156[1]	986	1125
Central Till Plain Natural Region				
Turkey Run State Park	2333		1084	
Shades State Park	2200		1141	
Control Area (Martell Experimental Forest)	1200		459	
Northern Lakes Natural Region				
Chain O'Lakes State Park	3066		1455	
Potato Creek State Park	1166*	767*	1047	727
Pokagon State Park	400*	233*	258	158
Control Area (Oakhill Camp)	8366	4767	2705	1204

[1] In 1997, three plots sampled that year in Yellowwood State Forest were included in the calculation of this mean.

lic mustard (*Alliaria officinalis*), and wild ginger (*Asarum canadense*). These species comprised 54% of the total percent cover at the park in comparison to 3% of the total percent cover at the control site in 1997. The mean plot species richness, evenness, and diversity were lower in Versailles State Park than in the control area, but the differences were not significant under the constraints of this study. Garlic mustard accounted for approximately 16% of the total percent cover of herbaceous species in Whitewater State Park but only for 3% of the cover in the control area. Narrow-leaved spleenwort, twinleaf, and wild ginger were not common in the park. At Clifty Falls State Park, wild ginger accounted for approximately 25% of the total percent cover of herbaceous species. This species was not present on transects sampled at the control area but was present on the slopes sampled. May apple accounted for an additional 15% of the total coverage of herbaceous species at Clifty Falls State Park while only accounting for 9% of the total coverage at the control area.

Highland Rim Natural Region. In 1996, Spring Mill and McCormick's Creek State Parks did not display significant differences in mean percent cover of herbaceous species (Table 1). McCormick's Creek State Park had significantly fewer stems per hectare 50-200 cm in height than the control area ($p < 0.05$, Table 2). The density of woody stems per hectare at Spring Mill State Park was not significantly different than that of the control area (Table 2). Mean plot species richness was significantly less in both parks than in the control area ($p < 0.05$, Table 3). The mean plot species evenness and diversity of these parks did not differ significantly from their values in the control area (Table 4).

In 1997, the same situation existed at Spring Mill and McCormick's Creek State Parks as in 1996 (Table 1, 2, 4) with the exception of species richness. The value for richness was slightly higher in the parks in 1997 and no longer significantly different from the richness of the control area ($p > 0.05$, Table 3). Woody stem density was not sampled in Spring Mill State Park during the 1997 field season. Three plots sampled in Yellowwood State Forest in May 1997 were combined with the control plots from Morgan-Monroe State Forest to provide a better representation of the range of variability in this Natural Region. Brown County State Park had significantly less herbaceous cover and fewer woody stems per hectare in 1997 than the control areas ($p < 0.05$, Table 1-2). Mean plot species richness was also significantly different from that of the control areas for this Natural Region ($p < 0.05$, Table 3). Mean plot species diversity and evenness were not significantly different from their values in the control areas (Table 4).

In this Natural Region, wild ginger, May apple, and wood nettle (*Urticastrum divaricatum*) accounted for more of the cover than any other single species in 1997. Wild ginger accounted for 32% of the total herbaceous cover at Spring Mill State Park and for 11% of the total herbaceous cover at McCormick's Creek State Park. This species was not present on any of the transects at Yellowwood State Forest and only accounted for 1% of the herbaceous cover at Morgan-Monroe State Forest. Wood nettle was only recorded at McCormick's Creek State Park, where this species accounted for approximately 20% of the total herba-

Table 3. Comparisons of mean plot understory herbaceous species richness between parks and control areas by Natural Region. All tests were done using a one-way ANOVA and Tukey's pairwise multiple comparisons test. An asterisk (*) denotes a significant difference between a park and its control area ($p < 0.05$).

	Species Richness		Standard Error	
	1996	1997	1996	1997
Southwestern Lowlands Natural Region				
Harmonie State Park	11.0	14.3	3.2	3.6
Lincoln State Park	17.8	18.0	2.8	1.5
Shakamak State Park	16.0	17.3	2.4	1.8
Control Area (Indian Mounds Farm)	17.8	21.8	1.3	1.0
Bluegrass Natural Region				
Clifty Falls State Park	18.7 *	21.8	2.9	2.9
Versailles State Park	23.3	24.5	1.1	1.9
Whitewater State Park	25.5	29.0	1.4	1.1
Control Area (Webster Farm)	29.5	31.5	3.9	3.5
Highland Rim Natural Region				
Spring Mill State Park	20.7 *	21.8	2.1	2.7
McCormick's Creek State Park	19.3 *	21.5	1.6	1.8
Brown County State Park		14.2 *		1.7
Control Area (Morgan-Monroe State Forest)	26.7	26.3 [1]	0.8	1.8
Central Till Plain Natural Region				
Turkey Run State Park	21.2	21.5	3.0	2.4
Shades State Park	26.0	28.3	2.2	3.0
Control Area (Martell Experimental Forest)	22.8	23.0	0.8	0.7
Northern Lakes Natural Region				
Chain O'Lakes State Park	22.0	21.3	1.9	1.7
Potato Creek State Park	12.0 *	15.2	2.0	2.0
Pokagon State Park	20.2	19.8	3.1	3.6
Control Area (Oakhill Camp)	24.8	25.2	2.1	1.5

[1] In 1997, three plots sampled that year in Yellowwood State Forest were included in the calculation of this mean.

ceous cover. May apple was recorded at Spring Mill and McCormick's Creek State Park, where it accounted for approximately 13% and 26% of the total herbaceous cover, respectively. This species was not present on any of the transects in Yellowwood State Forest and only made up 10% of the herbaceous cover at Morgan-Monroe State Forest. The most abundant species by cover in Brown County State Park was jack-in-the-pulpit, which accounted for approximately 14% of the total herbaceous cover. Jack-in-the-pulpit accounted for approximately 5% of the total herbaceous cover in Yellowwood State Forest and 11% of the herbaceous cover in Morgan-Monroe State Forest.

Central Till Plain Natural Region. In 1996, the two parks sampled in this Natural Region (Turkey Run and Shades State Parks) were not significantly different in their percent herbaceous cover from their control area (Table 1). No significant difference was found between these parks and their control area for the density of woody stems (Table 2). The mean plot species richness, evenness, and diversity of the parks in this Natural Region did not differ significantly from their values in their control area (Table 3-4).

In 1997, with the exception of woody stem density (not recorded in 1997 for these parks), the same conditions existed as in 1996. No significant differences in percent cover of herbaceous species were detected (Table 1), and the mean plot species richness, evenness, and diversity did not differ significantly from the values for the control area (Table 3-4).

Christmas fern, May apple, snakeroot spp. (*Sanicula* spp.), and Virginia creeper (*Parthenocissus quinquefolia*) were common in the herbaceous layers of Turkey Run and Shades State Parks. Christmas fern accounted for approximately 8% and 4% of the total herbaceous cover in Turkey Run and Shades State Parks, respectively. This species accounted for < 1% of the herbaceous cover at the control area. May apple was the most abundant species in terms of coverage. This species accounted for approximately 16% and 34% of the total herbaceous cover in these parks while only accounting for 3% of the total herbaceous cover in the control area. Snakeroot spp. were most abundant in Turkey Run State Park, where they comprised 19 % of the total herbaceous cover. This group accounted for 6% of the total herbaceous cover at the control area. Virginia creeper was moderately abundant and made up approximately 4% and 7% of the total herbaceous cover, respectively, in these parks, while accounting for < 1% of the cover in the control area. Wood nettle was common in Shades State Park, where it accounted for 10% of the total herbaceous cover. This species accounted for 2% of the cover in the control area.

Northern Lakes Natural Region. In 1996, all three parks (Chain O' Lakes, Pokagon, and Potato Creek State Parks) in the Northern Lakes Natural Region had significantly lower mean percent covers of herbaceous species than the control area ($p < 0.05$, Table 1). Pokagon and Potato Creek State Parks had significantly fewer woody stems 50-200 cm in height per hectare than the control area ($p < 0.05$, Table 2). In Chain O' Lakes State Park, the mean stem density did not differ significantly from its value in the control area (Table 2). The mean plot

Table 4. Comparisons of mean plot understory species evenness and species diversity (Shannon-Weiner) between parks and control areas by Natural Region. All tests were done using a one-way ANOVA and Tukey's pairwise multiple comparisons test. An asterisk (*) denotes a significant difference between a park and its control area ($p < 0.05$).

	Evenness		Diversity	
	1996	1997	1996	1997
Southwestern Lowlands Natural Region				
Harmonie State Park	0.81	0.78	1.8	1.9
Lincoln State Park	0.60	0.59	1.7	1.7
Shakamak State Park	0.69	0.59	1.8	1.7
Control Area (Indian Mounds Farm)	0.73	0.68	2.1	2.1
Bluegrass Natural Region				
Clifty Falls State Park	0.71	0.71	2.0	2.2
Versailles State Park	0.68	0.68	2.2	2.2
Whitewater State Park	0.70	0.68	2.2	2.3
Control Area (Webster Farm)	0.77	0.80	2.6	2.8
Highland Rim Natural Region				
Spring Mill State Park	0.66	0.66	2.0	2.0*
McCormick's Creek State Park	0.70	0.68	2.1	2.1
Brown County State Park		0.81		2.1
Control Area (Morgan-Monroe State Forest)	0.76	0.80[1]	2.5	2.6[1]
Central Till Plain Natural Region				
Turkey Run State Park	0.68	0.68	2.1	2.1
Shades State Park	0.66	0.65	2.2	2.2
Control Area (Martell Experimental Forest)	0.78	0.75	2.4	2.4
Northern Lakes Natural Region				
Chain O'Lakes State Park	0.77	0.77	2.4	2.3
Potato Creek State Park	0.65	0.68	1.6	1.8
Pokagon State Park	0.56	0.60	1.7	1.8
Control Area (Oakhill Camp)	0.71	0.70	2.3	2.3

[1] In 1997, three plots sampled that year in Yellowwood State Forest were included in the calculation of this mean.

species richness of Potato Creek State Park was significantly less than that of the control area ($p < 0.05$, Table 3). The mean plot species richness of the other parks did not differ significantly from the richness of the control area (Table 3). The mean plot species evenness and diversity of the parks did not differ significantly from the values found at the control area (Table 4). Deer reductions were conducted during the winter of 1996 in Pokagon and Potato Creek State Parks but not in Chain O' Lakes State Park.

In 1997, with the exception of woody stem density in Chain O' Lakes State Park (not recorded in 1997), the same conditions were observed as in 1996 (Tables 1-4). While the herbaceous cover at Pokagon State Park was significantly less than that in the control area, the extent of the reduction in herbaceous cover may have been masked by the extensive coverage of the exotic garlic mustard in this park (Figure 4).

Garlic mustard accounted for approximately 32% of the total herbaceous cover in Pokagon State Park but did not show up on any transects at the control area. May apple was also abundant in these northern parks and accounted for 11%, 29%, and 26% of the total herbaceous cover in Chain O' Lakes, Potato Creek, and Pokagon State Parks, respectively. This species accounted for 9% of the total cover of herbaceous species on the control area.

DISCUSSION

These data suggest that some Indiana State Parks are being negatively impacted by their resident populations of white-tailed deer. Areas where deer hunting historically has been permitted generally have higher mean percent covers of herbaceous species than areas where hunting historically has been prohibited (Figure 5). Hunted areas also tend to have higher densities of woody stems 50-200 cm in height (Figure 5). However, the density of woody stems 50-200 cm in height was quite variable between control areas (Figure 5). This variability may be a result of past disturbance. Therefore, the use of a single control area per Natural Region may not provide a wholly adequate representation of the range of variability present within a given Region, but, in most cases, one control area does provide a reasonable approximation. Taking this limitation into account, several trends were apparent. Deer may not have significantly reduced the diversity or evenness of the herbaceous plant communities in the majority of the parks sampled during this study. However, the deer did significantly reduce the mean percent cover of herbaceous species and the densities of woody stems in several parks. The changes may indicate that either most species are being utilized in proportion to their abundance or that the composition of the herbaceous layer has shifted to less palatable species.

The plant communities are dominated by a few rather common species in each park. These species and species that are known to actually increase as browse intensity increases on the remainder of the plant community (*i.e.*, garlic mustard) may mask the impacts of overbrowsing in its early stages. Garlic mustard is not often consumed by deer and tends to increase in abundance as deer abun-

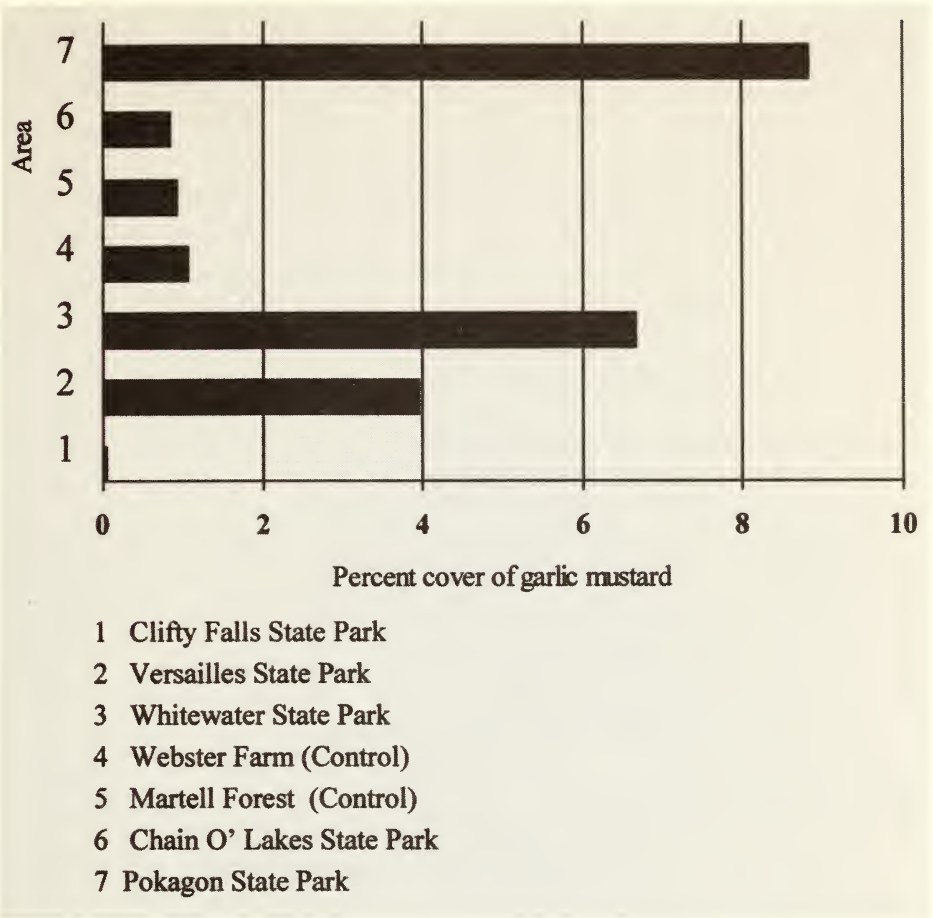

Figure 4. Percent cover of garlic mustard in Indiana State Parks and control areas sampled during May and June 1997.

dance increases (McShea and Rappole, 1997). Several parks across the State have high cover of garlic mustard (Figure 4). However, the differences in cover for garlic mustard are not statistically significant ($p > 0.05$).

Some of the more severely impacted parks, such as Brown County and Harmonie State Parks, appear to attain higher mean plot species evenness and diversity than less impacted parks in their respective Natural Regions. White-tailed deer are selective browsers when resources are abundant, but they switch to a generalist diet when resources become scarce (Nudds, 1980). Therefore, in the most severely impacted parks, deer may have shifted to a generalist foraging strategy and are utilizing the limited plant resources in the park in proportion to each plant's abundance. Further confirmation comes from the patchy distributions of species found in the less severely impacted parks such as Spring Mill, Turkey Run, and Shades State Parks. As deer remove the more preferred species, less preferred species may increase in abundance. The removal of preferred

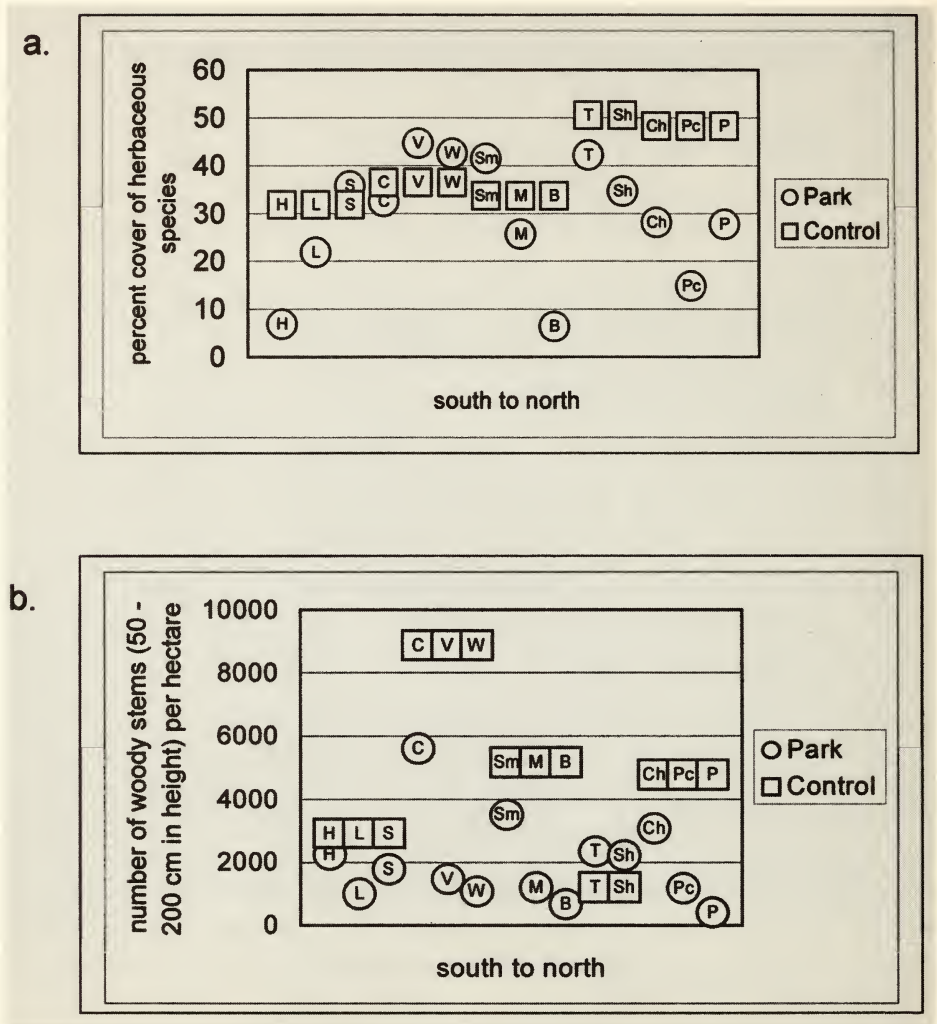

Figure 5. The relationship of the mean percent cover (a) of herbaceous species (1997) and the mean density (b) of woody stems (50-200 cm in height, most recent year of sampling for each area) within the State Parks with those values obtained within corresponding control areas: H = Harmonie, L = Lincoln, S = Shakamak, C = Clifty Falls, V = Versailles, W = Whitewater, Sm = Spring Mill, M = McCormick's Creek, B = Brown County, T = Turkey Run, Sh = Shades, Ch = Chain O' Lakes, Pc = Potato Creek, and P = Pokagon State Parks. The corresponding control areas are indicated by the above code within a square.

species may continue until only less preferred species remain, at which time these species would be eaten in proportion to their respective palatabilities.

The selective use of preferred species by white-tailed deer can lead to the local extirpation of plant species when deer densities are in excess of their carrying capacity (Anderson, 1997). Local extirpation results from disproportion-

ately intense browsing on relatively uncommon species (Strole and Anderson, 1992). Deer have been found to continue consumption of preferred species until those species become very rare before switching to less preferred species (Gillingham and Bunnell, 1989; Westoby, 1974). The significant declines in species richness in five parks were not consistent between years. This variation suggests that species richness may vary on a year-to-year basis. More intense sampling will be needed to determine if species are being lost from the parks due to excessive browsing by deer.

The apparent differences in plant community condition between parks suggests that the parks sampled were being impacted at varying levels. Some parks, such as Spring Mill State Park, are just starting to show evidence of overbrowsing. Other parks, such as Harmonie State Park, showed more evidence. Harmonie had approximately 85% less herbaceous cover than its control area, which is located just outside the Park's boundary. Several variables may lead to the uneven distribution of damage in parks that have not allowed deer hunting for similar lengths of time. Important variables may be the history of deer herd growth in the area, the attitudes of the local people towards poaching, the ease of effective policing of poaching, and the attitudes of the local land owners about legal hunting (Hansen, *et al.*, 1997). Also, the physical attributes of each park—shape, size, and landscape context—may be important. Exclosures have now been established in all the parks sampled and may, over time, improve our understanding of the dynamics of their plant communities.

High densities of white-tailed deer can dramatically alter the species composition of forest communities (Anderson, 1997; Redding, 1995; Strole and Anderson, 1992; Frelich and Lorimer, 1985; Anderson and Loucks, 1979) and negatively impact the populations of other animals, such as song birds (deCalesta, 1994; DeGraaf, *et al.*, 1991). The population levels of deer in Indiana State Parks are influenced by many factors that are beyond the control of resource managers, and the identification of overabundance can be difficult in its early stages. Research is needed to identify the point at which a deer population is beginning to exceed the carrying capacity of its habitat and what predisposes some areas to develop more severe problems with deer overabundance than others.

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