THE INFLUENCE OF WHITE-TAILED DEER ON THE BIODIVERSITY OF INDIANA STATE PARKS

Final Report Submitted To:

The Martin Foundation

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INTRODUCTION

The following report presents information acquired concerning white-tailed within Indiana state parks and their influence on other plant and animal species during 1996 and 1997. Support from your foundation has been crucial to this long-term research program. While this is a final report for your foundation, research concerning deer in state parks will continue in order to understand recovery processes as the deer population is reduced over the next few years.

This report is divided into three sections to make it more easily followed. The first section is an overview of the influence of white-tailed deer on plant communities within thirteen state parks spread across the Indiana landscape. This research was part of Chris Webster's thesis research for his Master of Science degree and was supervised by Dr. George Parker. His findings confirmed earlier research that deer were negatively affecting plant species within parks greater than 1000 acres in size, but had not significantly reduced plant species diversity. However, many preferred food species for white-tailed deer were greatly reduced in size and number, and in danger of being eliminated from several of the parks. The second part of Chris's thesis was to develop a more sensitive method of detecting over-browsing by deer before plant communities were severely damaged, and is presented in section two of this report. The size of three wide-spread and relatively common plant species were found to be good indicators of over-browsing and can be used to annually evaluate the condition of plant communities within state parks. The last section of this report is based on research that Brian MacGowan is completing for his Master of Science degree under the direction of Dr. Harmon Weeks. Brian's research examined the influence of habitat change on insects and birds within state parks due to over-browsing by white-tailed deer. He found a reduction in both insect and bird diversity as the damage to habitat became severe.

Dr. Andrea Easter-Pilcher was involved in the early formulation of this research and continues involvement through preparation of manuscripts for publication. She has moved from Purdue University to a University in Montana.

We hope you find this report informative. We have made great progress in solving the deer problem in Indiana's state parks which will greatly benefit the biological diversity that all of us enjoy.

Again, thanks for your support of this important research.

The Effects of White-tailed deer on Plant Communities in Indiana State Parks

published in Proceedings of Indiana Academy of Science 106: 213-231 1997 Webster, CR + GR Parker

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. This research was initiated to examine the relationship of deer browsing to the condition of plant communities within Indiana state parks. During the summer of 1996, thirteen Indiana State Parks and five control areas (where hunting is permitted) were sampled to evaluate the impact of deer on these plant communities. Significant declines in percent cover of herbaceous species, and density of woody stems 50 - 200 cm in height were observed in three parks in 1997. An additional three parks had significant declines only in percent cover of herbaceous species and two parks only had significant declines in the density of woody stems. In general this research suggests that white-tailed deer populations are impacting state parks in Indiana at varying levels, and that these impacts are changing the structure and composition of plant communities therein.

INTRODUCTION

White-tailed deer (*Odocoileus virginianus*) are highly adaptable and flourish 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 capacity of their habitat (Anderson 1997). White-tailed deer were extirpated from Indiana by the late 1880's due to habitat destruction and unregulated harvest, but were successfully reintroduced during the 1930's and 1940's. Within fifteen years of those reintroductions deer were beginning to cause localized damage to crops and native vegetation in areas around the release sites. The first modern deer hunt in Indiana was held in 1951 to remove the annual surplus of deer and reduce 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 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, Marquis 1972). Selective foraging can cause a shift in herbaceous species composition towards 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 extinction 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 within the park. Little recovery of the understory plants was evident in the spring of 1994 following the removal of approximately 400 deer during December of 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 of 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, understory species richness, evenness, and diversity have responded.

MATERIALS AND METHODS

Study Area. During May and June of 1996 thirteen Indiana State Parks were examined to assess the effect of white-tailed deer on plant community condition

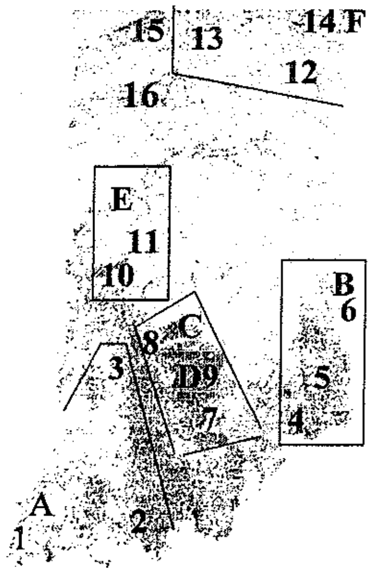

Figure 1. Locations of Indiana state parks (1=Harmonie, 2=Lincoln, 3=Shakamak, 4=Clifty Falls, 5=Versailles, 6=Whitewater, 7=Spring Mill, 8=McCormick's Creek, 9=Brown County State Park, 10=Turkey Run, 11=Shades, 12=Chain O' Lakes, 13=Potato Creek, 14=Pokagon, 15=Indiana Dunes, and 16=Tippecanoe River) and control areas (A=Indian Mounds Farm, B=Webster Farm, C=Yellowwood State Forest, D=Morgan Monroe State Forest, E=Martell Experimental Forest, F=Oakhill Camp) sampled during 1996 and 1997. Polygons indicate groupings of parks with a control area based upon natural region. Tippecanoe River and Indiana Dunes were compared to the mean of all control areas sampled.

(Figure1). 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 hunting is 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), suggests 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

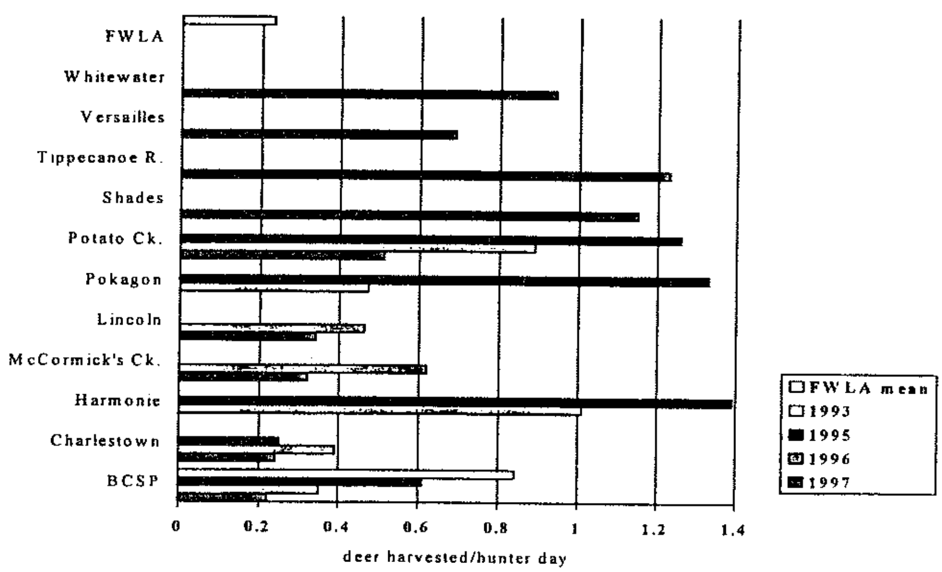

Figure 2. Number of deer harvested per hunter day for Indiana state parks that have had deer population reductions and the mean deer harvest per hunter day on Indiana fish and wildlife areas (FWLA) from 1986 to 1995.

and Charlestown State Park, have lower numbers of deer harvested per hunter-day than do recently hunted state parks. Deer harvested per hunter-day is declining in parks where repeated hunting has occurred such as Brown County, Potato Creek, and Pokagon State Park.

Six forest stands were randomly selected within the central area of each park using USGS Quad Maps and ground reconnaissance. Harmonie State Park, Versailles State Park, Spring Mill State Park, McCormick's Creek State Park, Turkey Run State Park, and Pokagon State Park all had three existing plots (Brown 1996), so three additional sites were selected to provide a total of six 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.

During May and June of 1997 the above sites were revisited and three additional parks were examined. Five established plots in Brown County State Park (Brown 1996) were resampled and one additional plot was established. In Indiana Dunes State Park one established plot (Brown 1996) was located and two additional plots were established. Only three sites were sampled at Tippecanoe River State Park and Indiana Dunes State Park due to limited area of mesic forest

Field Sampling Design. During May and June of 1996 and 1997 we sampled ground flora coverage on line transects parallel to the contour of the slope. On each slope at approximately midslope a base stake was randomly placed to serve as the end of the center 10m line transect. Two additional 10m line transects were randomly placed parallel to the center transect. One transect was located above the center transect and one was located below it. The distance of overlap of each herbaceous species was recorded in centimeters on each line transect. The overlap of woody plants less than 50 cm in height was included in this category. Density of woody vegetation 50 to 200 cm in height was tallied by species on a 50 m^2 circular plot centered at the base stake. The density of woody stems was measured in all the parks sampled in 1996, but was resampled only on parks that had deer reductions during the winter of 1996 (Harmonie, Lincoln, McCormick's Creek, Pokagon, and Potato Creek State Park). Woody stem density was recorded on all plots in the three additional parks sampled during 1997.

Data Analysis. Regression analysis indicated that there was not a significant correlation between sampling date and mean percent cover ($F_{1,21} = 0.0113$, $P = 0.916$, $R^2 = 0.0005$). Therefore, these means were considered independent. Mean percent cover of herbaceous species and woody stem densities were then compared for each year between parks and control areas with one-way ANOVA, with Tukey pairwise multiple comparison 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 assumption of normality for the percent cover and woody stem data (Jandel Scientific 1995). The data from the majority of parks and controls was normally distributed, so no transformations were used to improve the normality of data.

Species richness (S), evenness (E), and species diversity (Shannon-Weiner, H') were calculated for each plot from the distance covered by each species in relation to the total transect distance (3000 cm / plot). The mean values for each park and its control area were compared with one-way ANOVA, with Tukey pairwise multiple comparison test. These comparisons were also done by natural region to control for regional variations 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. The data from the majority of parks and controls was normally distributed so no transformations were used to improve the fit of the data. 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 ($p>0.05$).

RESULTS

Southwestern Lowlands Natural Region. In 1996 one park in this natural region (Harmonie State Park) had significantly less herbaceous cover than the control area ($p<0.05$, Table 1). The other parks in this region had lower mean percent cover of

Table 1. Comparison of mean percent cover of herbaceous species between parks and control areas by Natural Region. All test were done with one-way ANOVA, with Tukey multiple comparison test. An (*) 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*	1.85	2.76
Lincoln State Park	18.6	21.8	3.00	6.31
Shakamak State Park	29.6	35.7	9.77	9.09
Control Area (Indian Mounds Farm)	30.9	31.7	3.15	4.13
Bluegrass Natural Region				
Clifty Falls State Park	24.2	32.4	6.84	9.59
Versailles State Park	32.7	44.6	6.88	7.90
Whitewater State Park	40.2	42.5	6.25	6.67
Control Area (Webster Farm)	31.9	36.4	3.82	4.68
Highland Rim Natural Region				
Spring Mill State Park	38.5	41.5	4.67	4.65
McCormick's Creek State Park	21.3	25.6	7.47	7.43
Brown County State park		6.3*		1.18
Control Area (Morgan Monroe SF)	45.1	33.6[1]	11.91	4.73
Central Till Plain Natural Region				
Turkey Run State Park	37.7	42.1	3.72	6.99
Shades State Park	39.2	34.6	3.14	1.87
Control Area (Martell Experimental Forest)	47.6	50.5	5.41	5.01
Northern Lakes Natural Region				
Chain O' Lakes State Park	32.7*	28.1*	3.91	4.67
Potato Creek State Park	12.2*	14.8*	2.75	4.10
Pokagon State Park	26.6*	27.7*	1.75	2.81
Control Area (Oakhill Camp)	58.4	48.2	6.38	5.70
Grand Prairie Natural Region				
Tippecanoe River State Park		29.5		6.57
Control Area (mean of control areas)		39.5		2.47
Northwestern Morainal Natural Region				
Indiana Dunes State Park		4.7*		0.86
Control Area (mean of control areas)		39.5		2.47

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

Herbaceous species than the control, but these differences were not significant (p>0.05, Table 1). The mean number of woody stems per hectare was less in all the parks than the control, but none of these differences were significant (p>0.05, Table 2). Mean plot S, E and H' of the parks in this Natural Region did not differ significantly (p>0.05) from the control area. In 1997 Harmonie State Park was again the only park in this natural region with significantly less herbaceous cover than the control area (p<0.05, Table 1). Lincoln State Park and Harmonie State Park did not differ significantly in density of woody stems per hectare from their control area (p>0.05, Table 2). Woody stem density in Shakamak State Park was not recorded during the 1997 field season since no deer reduction was conducted in this park in the winter of 1996. Mean plot S, E, and H' of the parks in this Natural Region also did not differ significantly (p>0.05) from the control area in 1997.

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

	MDWS		Standard Error	
	1996	1997	1996	1997
Southwestern Lowlands Natural Region				
Harmonie State Park	2200	2233	843.80	966.67
Lincoln State Park	1267	1000	458.02	329.31
Shakamak State Park	1767		417.66	
Control Area (Indian Mounds Farm)	2667	2900	785.99	941.98
Bluegrass Natural Region				
Clifty Falls State Park	5600		1077.03	
Versailles State Park	1467*		360.25	
Whitewater State Park	1067*		405.52	
Control Area (Webster Farm)	8867		2372.43	
Highland Rim Natural Region				
Spring Mill State Park	3500		1035.05	
McCormick's Creek State Park	1100*	1200*	184.39	455.10
Brown County State Park		667*		146.06
Control Area(Morgan Monroe SF)	4667	5156[1]	986.13	1124.86
Central Till Plain Natural Region				
Turkey Run State Park	2333		1084.03	
Shades State Park	2200		1140.76	
Control Area (Martell Experimental Forest)	1200		458.98	
Northern Lakes Natural Region				
Chain O' Lakes State Park	3066		1454.80	
Potato Creek State Park	1166*	767*	1047.43	727.40
Pokagon State Park	400*	233*	258.20	158.46
Control Area (Oakhill Camp)	8366	4767	2704.77	1203.79
Grand Prairie Natural Region				
Tippecanoe River State Park		1067*		352.77
Control Area (mean of control areas)		4442		609.58
Northwestern Morainal Natural Region				
Indiana Dunes State Park		1600*		346.41
Control Area (mean of control areas)		4442		609.58

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

The sapling layer in Harmonie State Park is dominated by *Asimina triloba* (paw paw) which 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 versus the control area in 1997 reflects this relationship (Figure 3). The herbaceous layer of the parks sampled in this natural region

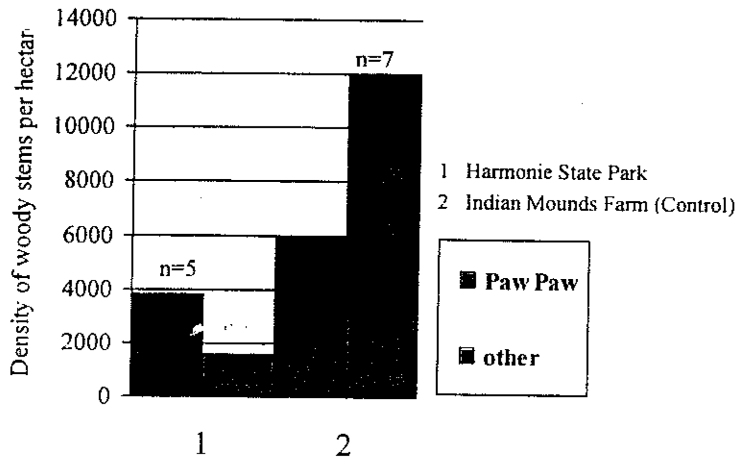

Figure 3. Density of woody stems 50 - 200 cm in height per hectare of paw paw versus all other woody species on Harmonie State Park and its control area (Indian Mounds Farm) in May of 1997.

are dominated by *Podophyllum peltàtum* (May apple), *Polystichum acrostichoides* (Christmas fern), and *Arisaema triphýllum* (jack-in-the-pulpit). *Podophyllum peltàtum* accounted for approximately 58 % and 38% of the total herbaceous cover in Lincoln State Park and Shakamak State Park respectively, while only accounting for 20% of the total herbaceous coverage at the control area. *Polystichum acrostichoides* was most common in Shakamak State Park where it accounted for approximately 13% of the total herbaceous cover. It made up approximately 5% of the coverage at the control area. *Arisaema triphýllum* accounted for 17% of the total herbaceous cover in Harmonie State Park, but was also quite common on the control area where it accounted for 18% of the total herbaceous coverage. The extensive coverage of *Ornithogalum umbellàtum* (Star-of-Bethlehem) on one plot at Shakamak State Park accounted for approximately 8% of the total percent cover of herbaceous species. This species was not present on sample plots within any of the control areas or any other park.

Bluegrass Natural Region. In 1996 the mean percent cover of herbaceous species for parks in this natural region were not significantly different from their control area ($p>0.05$, Table 1). Only one park (Clifty Falls State Park) had a lower mean percent cover than the control area. The mean percent cover on the remaining parks (Whitewater State Park and Versailles State Park) was greater than the control area, but not significantly different ($p>0.05$, Table 1). However, the density of woody stems per hectare (50-200 cm in height) within both Whitewater and Versailles was significantly less than that of the control area ($p<0.05$, Table 2). Clifty Falls State Park had a lower density of woody stems than the control area, but the difference was not significant ($p>0.05$, Table 2). The mean plot S of Clifty Falls was significantly less than the control area ($p<0.05$), but the mean plot S of Versailles and Whitewater State Parks did not differ significantly from the control area ($p>0.05$). E and H' did not differ significantly from the control area for any park in this region ($p>0.05$).

No significant differences in percent cover of herbaceous species were found in 1997 ($p>0.05$, Table 1). Mean plot S, E, and H' also did not differ significantly from those recorded on the control area ($p>0.05$). Since none of the parks in this natural region 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 is dominated by *Athyrium pycnocarpon* (narrow-leaved spleenwort), *Jeffersonia diphylla* (twinleaf), *Alliaria officinalis* (garlic mustard), and *Asarum canadense* (wild ginger). These species accounted for 54% of the total percent cover at the park versus 3% of the total percent cover at the control site in 1997. The mean plot S, E, and H' were lower at Versailles than at the control, but these differences were not significant under the constraints of this study. *Alliaria officinalis* accounted for approximately 16% of the total percent cover of herbaceous species in Whitewater State Park while only accounting for 3% of the coverage at the control area. *Athyrium pycnocarpon, Jeffersonia diphylla,* and *Asarum canadense* were not common in the park. At Clifty Falls State Park *Asarum canadense* accounted for approximately 25% of the total percent cover of herbaceous species. This species was not present on transects sampled at the control area. *Podophyllum peltàtum* 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. Spring Mill and McCormick's Creek State Parks had lower mean percent cover of herbaceous species than their control area in 1996, but the differences were not significant ($p>0.05$, 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 was not significantly lower than the control area ($p>0.05$, Table 2). Mean plot S was significantly less in both parks than in the control area ($p<0.05$). Mean plot E and H' of these parks did not differ significantly ($p>0.05$) from the control area.

In 1997 the same situation existed at Spring Mill and McCormick's Creek (Table 1 - 2), with the exception of species richness, which was slightly higher in the parks in 1997 and no longer significantly different from the control area ($p>0.05$). Also, woody stem density was not sampled in Spring Mill during the 1997 field season. Three plots sampled in Yellowwood State Forest in May of 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 than the control area ($p<0.05$, Table 1 - 2). Mean plot S was also significantly different from that of the control areas for this Natural Region ($p<0.05$). Mean plot H' was lower in Brown County State Park than the control areas, but this difference was not significant ($p>0.05$). Mean plot E was slightly higher in the park than in the control, but this difference was not significant ($p>0.05$).

In this natural region *Asarum canadense, Podophyllum peltàtum,* and *Urticastrum divaricàtum* (wood nettle) accounted for more of the percent cover than any other single species in 1997. *Asarum canadense* accounted for 32% of the total herbaceous cover at Spring Mill State Park and 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 comprised about 1% of the herbaceous coverage at Morgon Monroe State Forest. *Urticastrum divaricàtum* was only recorded at McCormick's Creek where it accounted for approximately 20% of the total herbaceous cover. *Podophyllum peltàtum* was recorded at Spring Mill and McCormick's Creek where it accounted for approximately 13% and 26% of the total herbaceous cover respectively. This species was not present on any of the transects at Yellowwood State Forest and only made up 10% of the herbaceous coverage at Morgon Monroe State Forest. The most abundant species by coverage in Brown County State Park was *Arisaema triphỳllum* which accounted for approximately 14% of the total herbaceous cover. *Arisaema triphỳllum* accounted for approximately 5% of the total herbaceous coverage at Yellowwood State Forest and 11% of the herbaceous coverage at Morgon Monroe State Forest.

Central Till Plain Natural Region. The two parks sampled in this Natural Region (Turkey Run and Shades State Parks) had lower mean percent cover of herbaceous species than the control area in 1996, but these differences were not significant ($p>0.05$, Table 1). No significant differences were found between these parks and their control area for density of woody stems in 1996 ($p>0.05$, Table 2). Mean plot S, E, and H' of the parks in this Natural Region did not differ significantly ($p>0.05$) from their control area.

With the exception of wood stem density (not recorded in 1997 for these parks) the same relationship existed in 1997. No significant differences in percent cover of herbaceous species were detected ($p>0.05$, Table 1) and the mean plot S, E, and H' did not differ significantly from the control area (p>0.05). Shades State Park had a slightly greater species richness than that of the control area during both field seasons, but these differences were not significant (p>0.05).

Polystichum acrostichoides, *Podophyllum peltàtum, Sanicula spp* (snakeroot spp.) and *Parthenocissus quinquefolia* (Virginia creeper) are common in the herbaceous layers of Turkey Run State Park and Shades State Park. *Polystichum acrostichoides* accounts for approximately 8% and 4% of the total herbaceous cover in Turkey Run State Park and Shades State Park, respectively. This species accounted for <1% of the herbaceous coverage at the control area. *Podophyllum peltàtum* is the most abundant species in terms of coverage. It accounted for approximately 16% and 34% of the total herbaceous coverage in these parks while only accounting for 3% of the total herbaceous coverage at the control area. *Sanicula spp.* are most abundant in Turkey Run State Park where they comprise 19% of the total herbaceous cover. This group accounted for 6% of the total heracous coverage at the control area. *Parthenocissus quinquefolia* is moderately abundant and makes up approximately 4% and 7% of the total herbaceous cover respectively, in these parks while accounting for <1% at the control area. *Urticastrum divaricàtum* is common in Shades State Park where it accounted for 10% of the total herbaceous coverage. This species accounted for 2% of the coverage on the control area.

Northern Lakes Natural Region. All three parks (Chain O' Lakes, Pokagon, and Potato Creek State Park) sampled during 1996 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 their control area (p<0.05, Table 2). Chain O' Lakes State Park also had fewer woody stems 50-200 cm in height per hectare than the control area, but this difference was not significant (p>0.05, Table 2). The mean plot S of Potato Creek State Park was significantly less than that of the control area (p<0.05). The mean plot S of the other parks in this region did not differ significantly from the control area (p>0.05). Mean plot E and H' of the parks in this Natural Region did not differ significantly (p>0.05) from those found on the control area.

Deer reductions were conducted during the winter of 1996 in Pokagon State Park and Potato Creek State Park, but not in Chain O' Lakes State Park. So with the exception of woody stem density in Chain O' Lakes (not recorded in 1997), the same differences were observed in 1997 as 1996 (Table 1). While the herbaceous cover at Pokagon State Park is significantly less than that of the control area, the extent of the reduction in herbaceous cover may be masked by the extensive coverage of the exotic *Alliaria officinalis* (garlic mustard) in this park (Figure 4). *Alliaria officinalis* accounts for approximately 32% of the total.

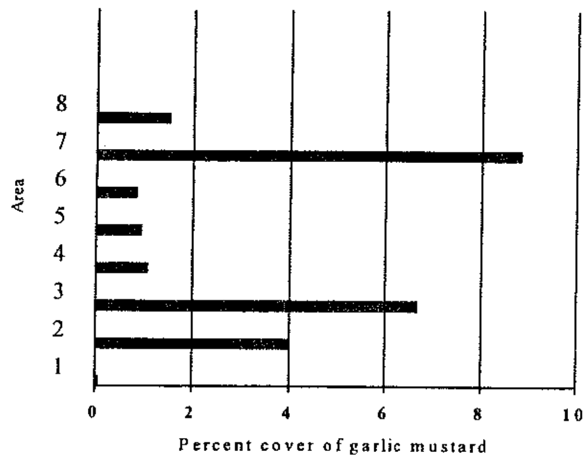

Figure 4. Percent cover of garlic mustard in state parks and control areas (1=Clifty Falls, 2=Versailles, 3=Whitewater, 4=Webster Farm (control), 5=Martell (control), 6=Chain O' Lakes, 7=Pokagon, and 8=Tippecanoe River) sampled during May and June of 1997.

herbaceous cover in Pokagon State Park while not showing up on any transects within the control area. This species is not often consumed by deer and tends to increase in importance as deer abundance increases (McShea and Rappole 1997). Several parks across the state have high coverages of *Alliaria officinalis* (Figure 4). However, it should be noted that these differences in coverage of *Alliaria officinalis* are not statistically significant ($p>0.05$). *Podophyllum peltàtum* is also abundant in these northern parks and accounts for 11%, 29%, and 26% of the total herbaceous cover in Chain O' Lakes, Potato Creek, and Pokagon, respectively. This species accounted for 9% of the total coverage of herbaceous species on the control area.

Grand Prairie and Northwestern Morainal Natural Regions. Tippecanoe River State Park lies in the Grand Prairie Natural Region and Indiana Dunes State Park is in the Northwestern Morainal Natural Region. Due to the difficulty of finding comparable control areas within these Natural Regions we opted to compare these parks to a mean derived from all of the control areas sampled. Indiana Dunes State Park had significantly less percent cover of herbaceous species than the mean control area ($p<0.05$, Table 1). This park also had fewer woody stems per hectare than the mean control area, but this difference was not significant ($p>0.05$, Table 2). Indiana Dunes had significantly lower mean plot S and H' than the mean control area ($p<0.05$). Tippecanoe River State Park did not differ significantly from the mean of control areas in percent herbaceous cover, density of woody stems, S, E, or H'($p>0.05$, Table 1).

Sanicula spp. are common in Tippecanoe River State Park and account for approximately 16% of the total herbaceous cover within the park. This species accounted for approximately 3% of the coverage of herabaceous species on control areas. *Prenanthes altissima* (white lettuce) and *Geranium maculàtum* (wild geranium) were both common in the limited herbaceous layer at Indiana Dunes State Park. *Prenanthes altissima* accounted for 19% of the total herbaceous cover while *Geranium maculàtum* accounted for 21%. These species accounted for 2% and 1%, respectively, of the total herbaceous coverage on control areas throughout the state.

DISCUSSION

These data suggest some Indiana state parks are being negatively impacted by their resident populations of white-tailed deer. Areas where hunting historically has been permitted generally have higher mean percent covers of herbaceous species than areas where hunting historically has been prohibited. Hunted areas also tend to have higher densities of woody stems 50-200 cm in height. It does not appear that deer have significantly reduced the diversity or evenness of the herbaceous plant communities in the majority of the parks sampled during this study. However, they have significantly reduced the mean percent cover of herbaceous species and the densities of woody stems in several parks. This may indicate that most species are being utilized in proportion to their abundance or that composition of the herbaceous layer has shifted to less palatable species.

The plant communities within the parks have been demonstrated to be dominated by a few rather common species in each park. These species, and species that actually increase as browse intensity increases on the remainder of the plant community (i.e.

Alliaria officinalis) may mask the impacts of overbrowsing in its early stages. Some of the more severely impacted parks such as Brown County and Harmonie appear to attain higher mean plot species evenness and diversity (Shannon-Weiner) than less impacted parks in their respective natural regions. White-tailed deer are selective browsers when resources are abundant, but switch to a generalist diet when resources become scarce (Nudds 1980). Therefore, it is possible that in the most severely impacted parks deer have shifted to a generalist foraging strategy and are utilizing the limited plant resources in the park in proportion to their abundance. Further collaboration comes from the patchy distributions of species found in the less severely impacted parks such as Spring Mill, Turkey Run, and Shades. As deer remove the more preferred species, less preferred species may increase in abundance. Removal of preferred 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 extinction of plant species when deer densities are in excess of their carrying capacity (Anderson 1997). This results from disproportionately intense browsing of 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, and Westoby 1974). The significant declines in species richness in six parks may indicate that parks are losing some of their more rare herbaceous species.

The apparent differences in plant community condition between parks suggests that the native plant species within the parks sampled are being damaged at varying levels. Some parks such as Spring Mill are just starting to show evidence of overbrowsing. Other parks, such as Harmonie State Park, had approximately 85% less herbaceous cover than its control area which is located just outside of the park boundary. Several variables may contribute to the uneven distribution of damage in parks that have not allowed hunting for similar lengths of time. These may include, but are not limited to, park shape and size, landscape context, and attitudes of local land owners about hunting (Hansen et al. 1997). The location of control areas outside of the parks may also increase variability due to past landuse and microsite variations. Exclosures have now been established in all of the parks sampled and may over time improve the understanding of the dynamics of these 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 reduce populations of other animals such as song birds (MacGowan and Weeks 1998 (see chapter 3), 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 identification of overabundance can be difficult to interpret in the early stages.

Research is needed to identify the point when a deer population is beginning to exceed the capacity of its habitat and what predisposes some areas to develop more severe problems with deer overabundance than others. Chapter two of this report develops a method for early detection of deer overbrowsing.

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Evaluation of *Osmorhiza claytoni, Arisaema triphyllum*, and *Actaea pachypoda* asPotential Indicators of White-tailed Deer Overabundance

published as:
CR Webster & GR Parker. 2000.
Eval of.... Natural Areas Journal
20(2): 176-188.

ABSTRACT

The heights of *Osmorhiza claytoni* (sweet cicely), *Arisaema triphyllum* (jack-in-the-pulpit), and *Actaea pachypoda* (white baneberry) were measured in fifteen state parks and six control areas during June of 1997 to examine the effects of white-tailed deer (*Odocoileus virginianus*) browsing on the condition of these species. Earlier results suggested that these species may be useful as indicators since all were found to decline in coverage even in the least impacted parks. Heights were measured on ten randomly selected plots in mesic, closed canopy forest communities within each park and control. Percent cover of herbaceous species was determined on line transects in six of the ten plots on all areas except for Indiana Dunes State Park and Yellowwood State Forest (control area) where percent cover was based on the transects within three of the ten plots. All three species were found to be shorter in height on the majority of the parks where they occurred ($p<0.05$). Nonlinear regression analysis was then used to examine this relationship further. Our results suggest that mean heights of these species can be used to identify early over browsing within mesic plant communities.

INTRODUCTION

White-tailed deer (*Odocoileus virginianus*) were extirpated from Indiana by the late 1880s due to habitat destruction and unregulated harvest, but were successfully reintroduced during the 1930s and 1940s. By 1945 deer were causing localized damage to crops and native vegetation. The first modern deer hunt in Indiana was held in 1951 to remove the annual surplus of deer and reduce crop damage (Mumford and Whitaker 1982, Brown County State Park Deer Study Committee 1993). White-tailed deer are highly adaptable and flourish in the agricultural mosaic created by modern land use (Anderson 1997). In the absence of population control by predation, hunting, or disease, populations can increase to numbers exceeding the capacity of their habitat. For the purposes of this study, we define overabundant deer popilations as those which are at a density where they are beginning to have a negative impact on local plant communities.

Overabundant populations of white-tailed deer can have a profound effect on the composition and structure of forest systems (Balgooyen and Waller 1995, Redding 1995, McCormick et al. 1994, Strole and Anderson 1992, Frelich and Lorimer 1985). White-tailed deer have been shown to impact woody vegetation in numerous forests (Deelen et al. 1996, Balgooyen and Waller 1995, Bowersox et al. 1995, Anderson and Kratz 1993, Trumbull et al. 1989, Frelich and Lorimer 1985, Anderson and Loucks 1979, Marquis 1974, Telfer 1972), resulting in a composition shift towards less browsed species and species that can withstand repeated browsing. Changes in composition and coverage of woody and herbaceous browse species also have been documented in Indiana state parks (Parker and Van Kley 1993, Parker and Brown 1994). Dramatic understory alterations resulting from excessive deer browsing are becoming more frequent and may lead to the local extinction of some highly preferred plant species (Strole and Anderson 1992). The foraging strategy of white-tailed deer may be permanently altering the composition and structure of Midwestern forest communities.

The differential use of plant species within and between seasons may, in the early stages of deer overabundance, make it difficult to identify damage to plant communities. White-tailed deer are selective browsers when resources are abundant, but switch to a generalist diet in the winter when resources become scarce (Nudds 1980). The selective use of preferred species by white-tailed deer can lead to the local extinction of plant species when deer densities are in excess of their carrying capacity. This results from disproportionately intense browsing of relatively uncommon species (Strole and Anderson 1992). Deer continue to consume preferred species until those species become very rare before switching to less preferred species (Gillingham and Bunnell 1989, Westoby 1974). Highly preferred herbaceous species could serve as indicators of damage, thus providing an early indication of imminent damage.

Until recently, herbaceous plants were not widely used to estimate foraging pressure, because loss of vegetative parts makes the identification of browsed species difficult (Balgooyen and Waller 1995). Shelton and Inouye (1995) found that wild lettuce (*Lactuca canadensis*) is an indicator species in Minnesota, where browsing by deer has caused a seven-fold reduction in reproductive output by reducing plant height. Variation in species frequency or percent cover may prove more useful as an indicator of excessive deer browsing (Balgooyen and Waller 1995). Anderson (1994) suggested that unbrowsed stem height of white-flowered trillium (*Trillium grandiflorum*) was reduced by browsing, since deer selectively consumed flowering plants which were also the largest plants in the population. Balgooyen and Waller (1995) found that the stem height and frequency of yellow clintonia (*Clintonia borealis*) decrease in areas of current or historically high deer densities. These studies suggest that sensitive herbaceous plants may provide an index of forest health as affected by deer overabundance.

To work well as an indicator, a species must be common and easy to identify in the field (Balgooyen and Waller 1995). The three species evaluated in this paper as indicators of deer overabundance in Indiana are all common throughout the state and relatively easy to identify in the field. With increasing population levels of deer and more and more restrictions on hunter access, indicator species specific to Indiana are needed to identify deer problems before significant damage occurs to the plant community and the health of the deer.

Over the last decade, damage from heavy deer browsing has been observed in Indiana State Parks (Parker and Van Kley 1993, Parker and Brown 1994), and controlled hunts have been initiated to reduce deer populations within selected parks. Here we present the results of a study initiated to identify a set of species that could be monitored in Indiana to determine when browsing by white-tailed deer begins to affect forest communities. Prior experience suggested that three species, sweet cicely (*Osmorhiza claytoni*), jack-in-the-pulpit (*Arisaema triphyllum*), and white baneberry (*Actaea pachypoda*) may be useful as indicator species. We sought answers to the following questions. (1) Are the mature heights of these species being reduced by overbrowsing in areas with historically high deer densities? (2) If so, is there a correlation between the heights of these species and an indicator of overbrowsing, such as percent cover of herbaceous species, that could be used to identify overbrowsing early enough to prevent significant damage to an area?

METHODS

1996 Study Area. Thirteen Indiana State Parks were sampled during May and June to assess the effect of white-tailed deer on plant community condition (Figure 1).

Parks were selected to provide a range of sizes, shapes and landscape contexts. To control for possible regional variations in species and growing conditions the parks were clustered by natural region (Homoya et al. 1985) for sampling. A single control area where hunting is permitted was also sampled within each natural region (Figure 1).

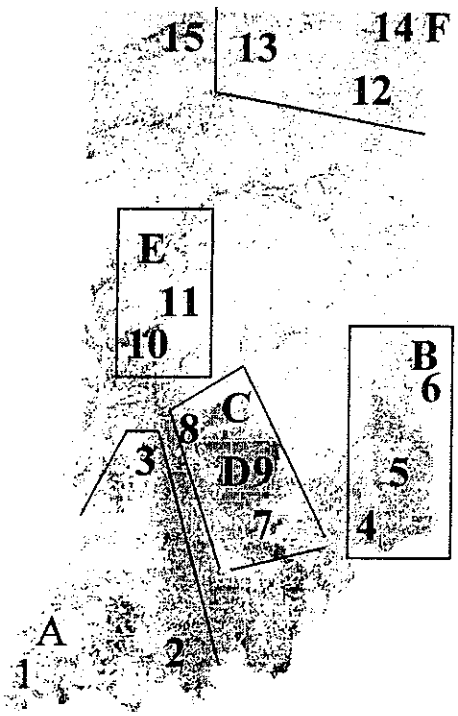

Figure 1. Locations of Indiana state parks (1=Harmonie, 2=Lincoln, 3=Shakamak, 4=Clifty Falls, 5=Versailles, 6=Whitewater, 7=Spring Mill, 8=McCormick's Creek, 9=Brown County State Park, 10=Turkey Run, 11=Shades, 12=Chain O' Lakes, 13=Potato Creek, 14=Pokagon, and 15=Indiana Dunes) and control areas (A=Indian Mounds Farm, B=Webster Farm, C=Yellowwood State Forest, D=Morgan Monroe State Forest, E=Martell

Six interior forest stands were randomly selected for sampling within each park using USGS Quad Maps and ground reconnaissance. Harmonie State Park, Versailles State Park, Spring Mill State Park, McCormick's Creek State Park, Turkey Run State Park, and Pokagon State Park (Brown 1996) all had three existing plots, so three additional plots were selected to provide a total of six sampling sites per area. Sites were permanently marked for future monitoring. Only mesic plant communities with mature closed hardwood canopies were sampled. Plant species and aspect were used to discern mesic sites.

Field Sampling Design for 1996. Ground flora coverage for each site was determined on line transects placed parallel to the slope contour. On each slope we randomly placed a base stake at approximately midslope that served as the end of the center 10m line transect. Two additional 10m line transects were randomly placed parallel to the center transect. The distance of overlap in centimeters along each line transect was recorded for all herbaceous species and woody species less than 50 cm in height. General notes on site conditions were recorded on a $300m^2$ circular plot centered around the base stake.

1997 Study Area. During May and June, the sites sampled in 1996 were resampled, and sites in two additional parks and one control area were sampled for the first time. Two interior forest stands were randomly selected for sampling using USGS Quad Maps and ground reconnaissance within Indiana Dunes State Park, one previously . established plot was resampled. Five previously established permanent plots and one new plot in Brown County State Park (BCSP), and three previously established permanent plots in Yellowwood State Forest (control area) were sampled. Plots were permanently marked for future monitoring.

Field Sampling Design for 1997. Ground flora coverage was determined on all plots from the distance of overlap in centimeters, of all herbaceous species and woody species less than 50 cm in height, along each line transect. Heights of sweet cicely, jack-in-the-pulpit and white baneberry were measured within the established 300 m^2 plots in each park and control. Heights of these species also were measured on four to seven additional, randomly selected $300m^2$ circular plots per area to provide a total of ten replicates per area. All heights were measured during a one month period (June) to reduce variation in heights due to sampling date. The height of sweet cicely was measured at the intersection of the highest leaf whorl and the stem (Figure 2). The height

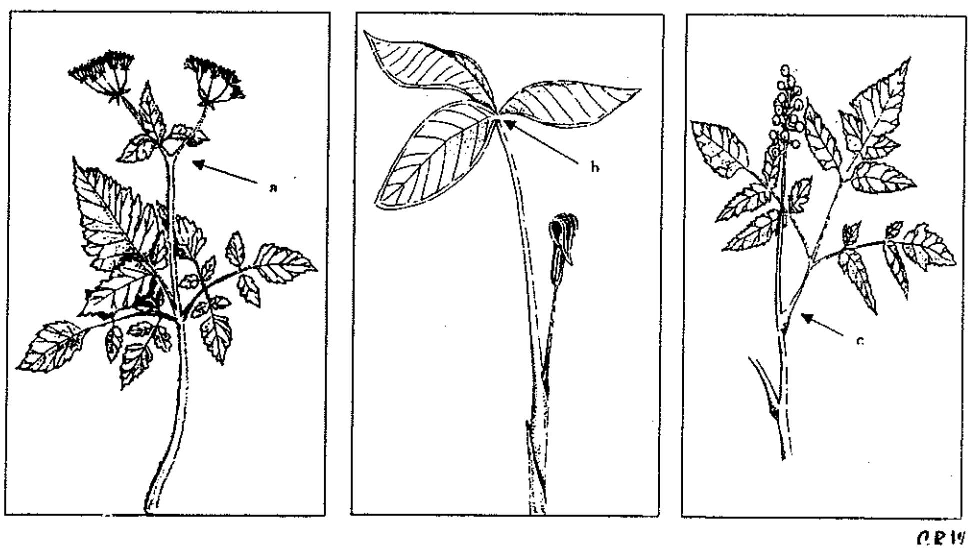

Figure 2. Points of height measuremnets on specimens of (a.) sweet cicely, (b.) jack-in-the-pulpit, and (c.) white baneberry.

of jack-in-the-pulpit was measured at the point of attachment of the leaves to the stem (Figure 2). White baneberry height was measured at the intersection of the highest leaf and the main stem (Figure 2). To obtain mature heights, the ten closest flowering individuals of each species to the center stake of the $300m^2$ circular plot were measured. If ten flowering individuals could not be found, the largest specimens of each species were measured. It was not always possible to find ten individuals of each species per plot. In that case every individual that could be found was measured. Therefore, the plot mean heights are based on ≤ 10 plants measured per species.

Data Analysis. Using the data collected in 1996, parks were divided into damage classes based on their percent reduction in overall herbaceous cover from a statewide mean percent cover of herbaceous species on control areas. Parks were classified as lightly, moderately, or severely damaged based on reductions in cover from the statewide mean of < 25%, 25-49%, and $\geq$ 50%, respectively. T-tests were used to compare the coverage of each herbaceous species between control areas and parks for each damage class. A Mann-Whitney Rank Sum Test was used if the data were non-normal or had unequal variance.

T-tests were used to compare the mean height of each potential indicator species for each park and all controls. A Mann-Whitney Rank Sum Test was used if the data were non-normal or had unequal variance. All control sites were grouped together to provide a better representation of the range of heights of these species.

Pearson product-moment correlations were computed to examine the relationship between sweet cicely height, jack-in-the-pulpit height, white baneberry height, and percent cover of herbaceous species found in 1997. Graphical analysis suggested that the data may be best fit with a sigmoidal curve. Nonlinear regression analysis was then used to further examine this relationship with mean percent cover as a function of the four parameter logistic equation:

$$f(x) = \frac{a}{1+e^{b(x-c)}} + d$$

where x is the mean height of an indicator species and f(x) is the response in the mean percent cover of herbaceous species, and a, b, c, and d are the regression coefficients (Jandel Scientific 1995). When b is less than zero then a + d is equal to the asymptote approaching infinity, d is the minimum approaching negative infinity, c is the point of inflection, and b is the slope. It then follows that when b is greater than zero then a + d is equal to the minimum, d is the asymptote, c is the point of inflection, and b is the slope (Jandel Scientific 1995).

RESULTS

Species Selection. Initial comparison of percent cover by species, from the 1996 data, between parks and controls indicated that five herbaceous and three woody species decrease in coverage with light damage, one herbaceous and one woody species were found to decrease at moderate damage, and fifteen herbaceous and six woody species decreased under severe damage. The three herbaceous species that exhibited the most significant differences at the lowest intensity of damage were selected for evaluation as potential indicators; sweet cicely (p=0.117), jack-in-the-pulpit (p=0.049), and white baneberry (p=0.082). Herbaceous species were selected over woody species since they do not grow above the height that deer can browse during a single growing season. Greenbrier (*Smilax rotundifolia*) was not selected since it does not die back and resprout each year. Once it grows out of the reach of feeding deer it is relatively unaffected by browsing, making height measurements of this species difficult to interpret in the context of deer browsing intensity. Also the three species selected are common throughout the state.

Comparisons of Species Heights. All three indicator species were shorter in height within the majority of parks where they occurred compared to control areas. The mean heights of these species for each plot are based on the number of individuals found on each plot. Some plots had fewer than ten individuals or no individuals present and therefore the low sample size may obscure some significant differences. The mean height of sweet cicely in ten of the thirteen parks where it occurred was significantly less (p=0 05) than the mean height on controls throughout Indiana (Figure 3). By damage class, the mean height of sweet cicely was significantly shorter on all three of the severely damaged parks where it was present, one of two moderately damaged parks, and four of six of the lightly damaged parks. The mean height of jack-in-the pulpit in twelve of the fifteen parks in which it occurred was significantly less (p=0.05) than in control areas (Figure 3). By damage class, the mean height of jack-in-the-pulpit was significantly shorter on all of the severely and moderately damaged parks, and three of the six lightly damaged parks. White baneberry exhibited a similar trend, with significantly shorter heights (p=0.05) in nine of the twelve parks in which it occurred (Figure 3). The mean height of white baneberry was significantly shorter on all five of

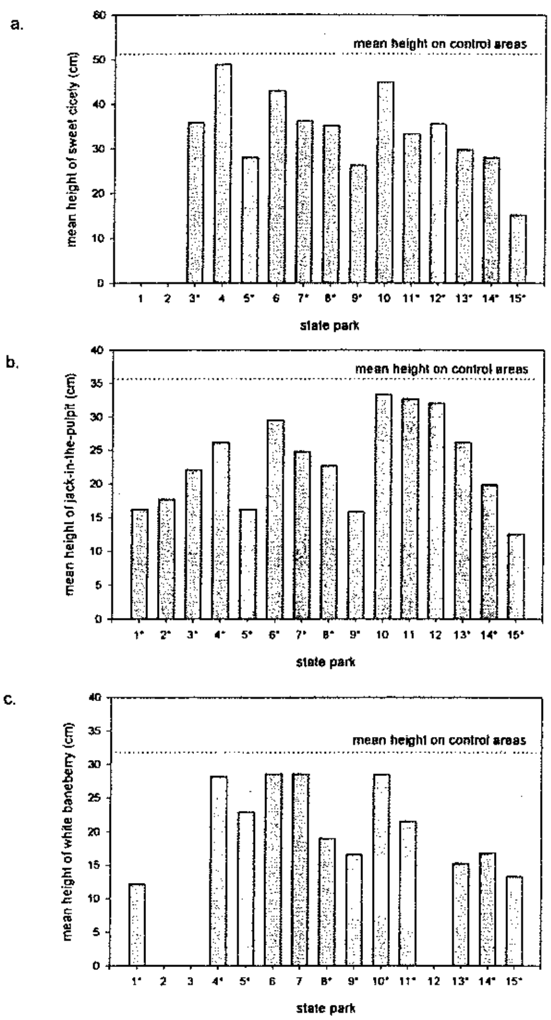

Figure 3. Mean height of indicator species (a. sweet cicely, b. jack-in-the-pulpit, and c. white baneberry) for selected state parks (1=Harmonie, 2=Lincoln, 3=Shakamak, 4=Clifty Falls, 5=Versailles, 6=Whitewater, 7=Spring Mill, 8=McCormick's Creek, 9=Brown County State Park, 10=Turkey Run, 11=Shades, 12=Chain O' Lakes, 13=Potato Creek, 14=Pokagon, and 15=Indiana Dunes) sampled during June of 1997. An (*) denotes a significant difference from the mean height of that species found on control areas throughout Indiana.

the severely damaged parks where it was present, none of the moderately damaged parks where it was present, and three of five lightly damaged parks where it was present. In general mean heights of these species were less in parks than controls, even where significant differences were not found.

Correlation Analysis. The heights of all three species and mean percent cover for each site were positively correlated ($p<0.003$) for all tests. Also, the heights of the three indicator species were correlated with each other, suggesting that the heights of jack-in-the-pulpit, sweet cicely, and white baneberry respond in a similar manner to deer browsing.

Regression Analysis. The most pronounced expression of a sigmoidal relationship was observed for white baneberry ($F_{3,18} = 14.737$, $P < 0.001$, $R^2 = 0.747$, Figure 4). Sweet cicely provided the next best fit to this model ($F_{3,18} = 7.386$, $P = 0.003$, $R^2 = 0.596$, Figure 4) followed by jack-in-the-pulpit ($F_{3,20} = 4.907$, $P = 0.012$, $R^2 = 0.464$, Figure 4). The coverages of all herbaceous species present were included in the mean of percent cover values used in this regression series.

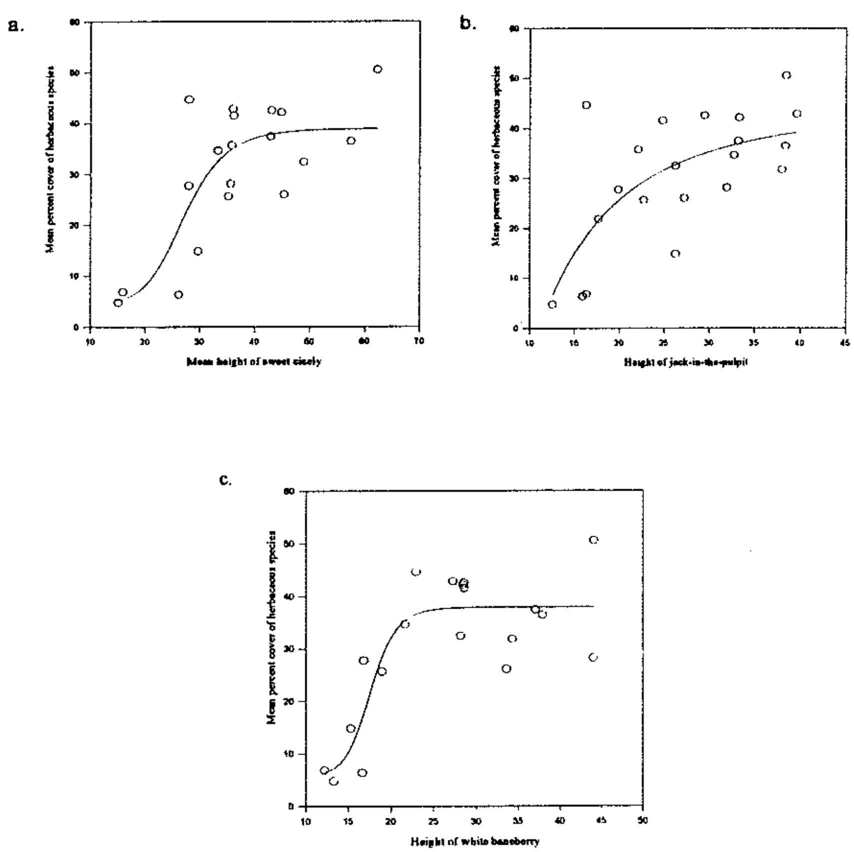

Figure 4. Nonlinear regression of mean height of indicator species (a. sweet cicely, b. jack-in-the-pulpit, and c. white baneberry) versus mean percent cover of herbaceous species found within state parks and control areas during May and June of 1997.

DISCUSSION

Stem height has been shown to be a useful indicator of browsing intensity, because foraging deer seem to select larger plants over smaller ones (Anderson 1994). The consumption of the upper stem region, flowers and leaves decreases storage of carbohydrates in rhizomes (Lubber and Lechowicz 1989). Therefore, a plant's size is reduced with repeated browsing until it become so small that it is no longer browsed (Anderson 1994). This appears to have occurred with the three species examined in this paper, since the coverage and size have decreased, but the species have not disappeared from the majority of Indiana state parks sampled during this study. It also has been suggested that larger flowering plants may contain more nutrients and other essential resources than smaller non-flowering plants (Anderson 1994). Since deer are more limited by processing time than by how fast they can obtain food, they must select a diet with a variety of nutrients from a relatively fixed amount that can be ingested (Westoby 1974). In order for deer to maximize their nutrient intake per unit time, flowering plants should be selected over non-flowering plants within a given taxon.

Brown (1996) found that jack-in-the-pulpit height in twelve central and southern Indiana state parks was significantly shorter than in corresponding control sites and suggested that this difference may be due to repeated browsing. Due to the selective foraging behavior of white-tailed deer (Balgooyen and Waller 1995, Strole and Anderson 1992, Gillingham and Bunnell 1989, Westoby 1974), species may be selected as preferred species and subsequently utilized until they are almost eliminated from an area and only remain in a stunted growth-form. These species would be the first to decline under heavy browse pressure since they are taken disproportionately often compared to their abundance. Therefore, monitoring the size of highly preferred species could allow early identification of potential problems associated with deer population growth.

We found no evidence in the literature that the three species examined in this study are preferred browse species in the Midwest (LaGory et al. 1985, Rose and Harder 1985, Kirkpatrick et al. 1976, McCaffery et al. 1974, Sotala and Kirkpatrick 1973, Nixon et al. 1970, Korschgen 1962). Most research however, has centered on the proportion of a species eaten versus the proportions of other species consumed to determine preference. Fleshy herbaceous plants are difficult to identify in rumen and often are grouped together.

Also, many studies have been done during fall hunting seasons when herbaceous plants are not an important part of the diet. Petrides (1975) defined a principal food as a food that is eaten in the greatest quantity by an animal population and a preferred food as a food that is more frequent in the diet than in the available environment. This indicates that a principal food is not always one that is preferred. Thus, a highly preferred food may not be an important part of the overall diet of a white-tailed deer and may therefore be difficult to detect via rumen samples. It is also possible that in some instances these plants are being selected because more palatable species are no longer abundant enough to add to the nutritional balance of the diet and that these species represent a shift in preference based on availability (Anderson 1997).

These results indicate that the mean height of mature plants of sweet cicely, jack-in-the-pulpit, and white baneberry have been significantly reduced by the excessive populations of white-tailed deer in Indiana state parks. The mean height of mature plants of these species was significantly reduced in most of the state parks sampled compared to control areas where hunting is allowed. Parks where height was not significantly reduced were lightly or moderately damaged based on total reduction in percent cover.

Some significant differences may be obscured by individual plants finding refuge from browsing by growing in fallen branches and trees. We observed this situation in several parks. Thus, plants growing in inaccessible sites should be noted when sampling. Also due to the clumped distribution of herbaceous plants, indicator species were sometimes present on a slope but did not fall within the sample area. A general search for mature individuals of each species throughout mesic communities in a park may provide a better estimate of mean heights than plot sampling.

The sigmoidal relationship exhibited between the mean heights of these plant species and percent cover of herbaceous ground flora may provide a useful tool in predicting when a white-tailed deer population is beginning to negatively impact its habitat. Regression analysis with a logistic function model suggests that species height increases to an asymptote at which point the percent cover of herbaceous species also levels off. Suggesting that after a certain height is reached there is no additional increase in mean percent cover for and an additional increase in mean height. The resulting curves then allow the prediction of browse intensity, before percent cover is greatly reduced, from measurements of sweet cicely, jack-in-the-pulpit, and white baneberry heights. White baneberry provides the best model for predicting percent cover, but in its absence sweet cicely and jack-in-the-pulpit heights also provide good assessments of damage. Percent cover can be a good index of browse intensity especially at high deer densities, but at moderate densities it is often obscured by an increase in non-preferred species such as garlic mustard (*Alliaria officinalis*), twinleaf (*Jeffersonia diphylla*), and paw paw (*Asimina triloba*) seedlings that increase in coverage as the competition from preferred species is reduced. In this case, indicator species may provide a better indication of browse intensity in a park than a direct measurement of percent cover of herbaceous species. Heights of indicator species are also easier to collect than detailed coverage data for all species. Thus, one could estimate a range of mature heights or a minimum height that should be expected for an area that does not have an overabundance of white-tailed deer.

Nonlinear regression results suggest that a mean white baneberry height of at least 25 cm reflects the potential mean height (at the point of measurement) of this species in a mesic closed canopy forest community in Indiana in the absence of excessive deer browsing. The mean percent cover at this point is approximately 38 percent, which is corroborated by the mean percent cover of all control areas sampled (38.4 percent). Mean sweet cicely height plateaus at approximately 42 cm, suggesting that a mean height of at least 42 cm reflects the potential of this species under the above conditions. This plateau of mean sweet cicely height is also reached at approximately 38 percent cover of herbaceous species. This relationship is also pronounced in the mean height of jack-in-the-pulpit. A mean jack-in-the-pulpit height of at least 37 cm appears to reflect the potential of this species. Again, this plateau is associated with a mean percent cover of herbaceous species of approximately 38 percent. For all three species the overall mean percent cover of the control areas corroborates the estimates of mean mature plant height in the absence of excessive browsing. Thus, these minimum mean heights may indicate the point at which a plant community is in balance with the population of white-tailed deer. A drop below these levels in mean indicator species height would indicate that the deer population is beginning to negatively impact the plant community.

Balgooyen and Waller (1995) suggest that assessing the effects of white-tailed deer on vegetation may rely on the monitoring of a common or highly visible species to determine the degree of pressure that deer are exerting on a plant community. Sweet cicely, jack-in-the-pulpit, and white baneberry are all common species in Indiana. Also they are readily identified with minimal training and therefore may prove to be excellent early indicators of plant community response to deer overabundance.

Sweet cicely, jack-in-the-pulpit, and white baneberry are typically found in mesic forest stands. Thus, other sensitive species may need to be identified for more hydric and xeric forest areas. The integration of this type of analysis with ecological classification systems (Van Kley and Parker 1993) could provide a useful management tool and help further the understanding of the long-term impacts of overbrowsing by white-tailed deer on midwestern hardwood forest.

The understanding of how deer impact vegetation at the landscape level is still in the early stages of development. Correlating the heights of indicator species with actual deer population estimates could help validate the use of indicator species to assess browse damage. Measurements of other vegetative characteristics of these species such as fruiting success, fruit weight, and root weight could provide useful insights into the long-term effects of excessive browsing by white-tailed deer. This and other information about the reproductive success of these species at varying intensities of browsing may help further our understanding of the dynamics of recovery for plant communities.

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AVIAN COMMUNITIES IN DECIDUOUS FORESTS DIFFERENTIALLY IMPACTED BY WHITE-TAILED DEER (*ODOCOILEUS VIRGINIANUS*) BROWSING IN INDIANA

ABSTRACT

Through browsing, white-tailed deer (*Odocoileus virginianus*) have the potential to indirectly affect bird abundance by decreasing nesting cover and substrate, as well as prey availability. A deficiency of these factors can impact abundance and productivity of forest avifauna that nest or forage near the ground. During the 1996 and 1997 breeding seasons, we conducted a study on 12 sites throughout Indiana determined to be differentially impacted by white-tailed deer. Sites were divided into light, moderate and heavy browse damage classes based upon differences in vegetation. Percent cover, sapling density and vertical vegetation density were different among damage classes. Light-damage sites averaged 3.8 ground-nesting species per site, while moderate- and heavy-damage sites averaged 1.69 and 1.13, respectively ($P<0.02$). The mean number of species per site of intermediate-canopy-nesting birds within light-damage sites (7.0) differed from moderate- (4.19) and heavy- (4.06) damage sites ($P<0.0006$). High-canopy nesting birds did not exhibit any significant differences. Average daily survival rates of wood thrush (*Hylocichla mustelina*) and acadian flycatcher (*Empidonax virescens*) nests were higher on light-damage sites compared to heavy-damage sites ($P=0.028$ and $P=0.105$, respectively). Light-damage sites had both a greater number of Diptera and biomass of Hymenoptera in sweep net samples compared with heavy-damage sites ($P<0.05$). Rare orders of insects were limited to light-damage sites. Deer have significantly impacted these forest communities. The management of keystone species such as the white-tailed deer is essential when ecosystem management or biodiversity are management goals.

INTRODUCTION

Much concern has been expressed recently regarding the decline in songbird populations, especially those of neotropical migrants (NTM), in the woodland habitats of eastern North America (Robbins et al. 1986, Hutto 1988, Robbins et al. 1989, Sauer and Droege 1992). Several of these species are sufficiently rare in Indiana to be listed as species of special concern (black-and-white warbler (*Mniotilta varia*), broad-winged hawk (*Buteo platypterus*), hooded warbler (*Wilsonia citrina*), worm-eating warbler

(*Helmitheros vermivorus*)); others, while not listed in Indiana, have been classified by Thompson et al. (1992) as of paramount management concern in the Midwest (cerulean warbler (*Dendroica cerulea*), wood thrush (*Hylocichla mustelina*)). This postulated decline has been variously attributed to factors associated with declining quantity and increasing fragmentation of forests, especially in the eastern United States (Litwin and Smith 1992). Factors such as nest predation and nest parasitism by brown-headed cowbirds (*Molothrus ater*) seem to increase directly with the amount of edge habitat, which itself varies directly with woodland fragmentation (Lynch and Whigham 1984, Paton 1994).

Little attention has been given thus far to changes in quality of habitats, apart from those variables attributable to proximity to edge. Many studies have described the relationship between bird species diversity and habitat structure (MacArthur and MacArthur 1961, MacArthur et al. 1962, Karr and Roth 1971, Moss 1978, Mills et al. 1991). Martin (1988) has made a compelling case for the importance of secure nest sites for ground/shrub nesting songbirds, and the importance of vegetative structure in supplying these sites. Changes in structure has the potential of impacting both security of nests and the composition of the avian community using a site. Many forest-inhabiting NTM songbirds in Indiana nest on the ground or in the shrub/sapling layer of the forest (e.g., Kentucky warbler (*Oporornis formosus*), hooded warbler, worm-eating warbler, black-and-white warbler, ovenbird (*Seiurus aurocapillis*), and wood thrush). Quality of nest sites would naturally be compromised by significant changes in composition and diversity of vegetation within these layers. Vertical vegetation density may be important in concealing nests from predators (Wray and Whitmore 1979). Bowman and Harris (1980) found that decreasing heterogeneity was correlated with increased efficiency of raccoon (*Procyon lotor*) predation.

Perhaps equally important, these avian species and others that frequently nest in the lower canopy (e.g., acadian flycatcher *Empidonax virescens*, red-eyed vireo (*Vireo olivaceus*), American redstart (*Setophaga ruticilla*)) forage for insects in the shrub/sapling horizon. Insect abundance can be affected by plant biomass and structure (Holmes and Schultz 1988). Less dense understory cover may result in drier soils and less shade, which could impact soil arthropods (MacKay et al. 1986). Holmes et al.

(1986) found that breeding bird abundance correlated with density of insect larvae within a New Hampshire forest. Within some eastern forests, insect availability is the limiting resource for avian species. Smith and Shugart (1987) hypothesized that birds gauge this resource by assessing the density of the understory. Low prey availability may also impact foraging tactics and success in songbirds (Robinson and Holmes 1984).

The white-tailed deer (*Odocoileus virginianus*) through its browsing has the capability to drastically change the structure (Anderson and Loucks 1979, Alverson et al. 1988, Tilghman 1989, McShea and Rappole, 1992) and composition (Anderson and Loucks 1979, Alverson et al. 1988, Miller et al. 1992) of forestlands. Because of this and its proliferation in the eastern United States, the deer has been termed a "keystone species" in the eastern deciduous forest. There is rising concern that continued, long-term browsing by deer in forested ecosystems can produce "alternate stable states" (Warren 1991, Laycock 1991); once reaching this condition, a forest would never return to its natural state even if browsing pressure were diminished by permanent reduction of deer densities. Browsing at high deer densities has reduced the diversity and size of tree seedlings compared to areas with low deer densities (Tilghman 1989). This can severely inhibit the natural regeneration of a forest ecosystem and may directly affect songbird diversity and abundance.

Deer have increased in Indiana and throughout the Midwest since their reintroduction in the 1930's after several decades of extirpation (McCabe and McCabe 1984). By the 1960's, populations had increased in some areas where they were protected from poaching (principally military areas) to levels that were causing noticeable damage to vegetation. Since that time deer impacts on the forests of Indiana (and the Midwest) have been quite variable. Several factors contribute to this variability, but the strongest factor is undoubtedly deer density. Hunting is a common method used to regulate deer populations. However, deer that are under only light hunting pressure can still deplete the understory and prevent its recovery (Hough 1965). Therefore, much concern is raised in situations where deer numbers cannot be efficiently limited (e.g., state parks, urban areas). Severe damage to plant communities has been documented in several areas in Indiana (e.g., Brown County State Park, Parker unpublished data), and lesser impacts are widespread.

This damage to the floral community undoubtedly has trickle-down effects on the whole ecosystem. Changes in plant community structure and composition may impact food, cover and reproduction requirements for many groups of forest fauna. NTM songbirds is one such group - primarily dependent on vegetation for reproductive success (nest concealment) and secondarily for its production of food in the form of insect biomass. Although some evidence has accumulated indicating a negative effect of heavy browsing on avian communities (Casey and Hein 1983, DeCalesta 1994, McShea et al. 1995, McShea and Rappole 1997a), little information exists on the magnitude and pervasiveness of effects in natural systems anywhere, and especially in the Central Hardwoods Region. We examined avian species richness and relative abundance in forests of Indiana differentially impacted by deer browsing. Areas with high deer densities may be indirectly causing the decline of many sensitive forest songbird species (see above) by direct changes in vegetation structure and composition due to high browse pressure. This pressure may also decrease the diversity and abundance of some forest insect species, an important food source for many birds of concern (red-eyed vireo, Kentucky warbler, acadian flycatcher). The maintenance of high deer densities is not necessarily bad, but may not be optimal for certain conservation goals. Documentation of ecosystem dynamics and identification of potential thresholds will supply administrators and managers vital information in the decision-making process for the maintenance of biodiversity in some of Indiana's most unique systems.

METHODS

Study sites

We established 12 study sites in mature, deciduous woodlands throughout Indiana (Figure 1). Sites ranged in size from small fragments (~100 ha) to large continuous tracts (9,712 ha). Based upon the degree of damage from deer browsing, 4 sites were placed into each of 3 damage classes – light or none, moderate and heavy (Brown and Parker, unpubl. data). Study sites were grouped within the same physiographic region so that each group contained a site from each damage class (Table 1). Three groups were

1. Pokagon State Park
2. Moraine Nature Preserve
3. Oakhill Camp
4. Brown Co. State Park
5. Eagle Creek Park
6. Yellowwood State Forest
7. McCormick's Cr. State Park
8. Big Walnut Nature Preserve
9. Morgan-Monroe State Forest
10. Harmonie State Park
11. Whip-poor-will Nature Preserve
12. Indian Mounds Farm

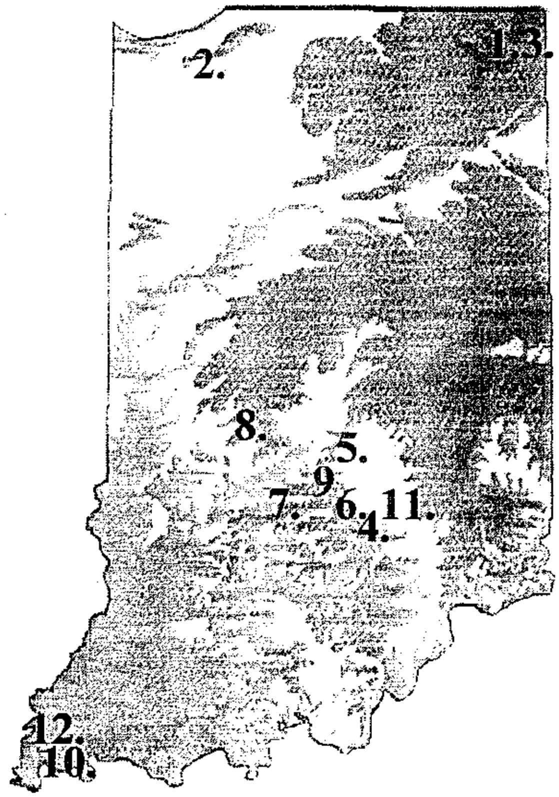

Figure 1. Location of study sites in Indiana (Physiographic groupings: **I** - sites 1-3; **II** – sites 4-6; **III** – sites 7-9; **IV** – sites 10-12).

Table 1. Mean per plot vegetation characteristics of Indiana study sites, 1996-1997.

Group	Damage Class	Site	Site Code	Area (ha)	Percent cover[1] 1996	Percent cover[1] 1997	Seedling denstiy (#stems/ha)[2] 1996	Seedling denstiy (#stems/ha)[2] 1997	Sapling density (#stems/ha)[3] 1996	Sapling density (#stems/ha)[3] 1997	Vertical vegetation density[4] 1997
I	light	Oakhill Camp	OAK	~100	58.72	47.87	24111.11	19444.44	11533.33	6733.33	15.9
I	moderate	Moraine Nature Preserve	MOR	166	20.83	12.32	4000.00	13000.00	1400.00	1466.67	16.4
I	heavy	Pokagon State Park	PSP	487	7.56	10.48	9111.11	23333.33	0.00	0.00	27.4
II	light	Yellowwood State Forest	YSF	9389	19.31	26.11	13777.78	29222.22	2600.00	4733.33	11
II	moderate	Eagle Creek Metro Park	EAG	1578	26.21	15.04	29555.56	19444.44	1266.67	933.33	18
II	heavy	Brown County State Park	BCSP	6358	9.24	8.34	13000.00	3777.78	200.00	66.67	33.4
III	light	Morgan-Morone State Forest	MMSF	9712	36.26	33.87	15111.11	16888.89	5800.00	6666.67	16.3
III	moderate	Big Walnut Nature Preserve	BIGW	495	32.37	10.74	11444.44	11444.44	3000.00	2600.00	19.3
III	heavy	McCormick's Creek State Park	MCSP	742	10.46	15.23	12111.11	6555.56	933.33	1200.00	41.3
IV	light	Indian Mounds Farm	INDM	~100	28.86	28.88	3000.00	5222.22	1066.67	1866.67	21.6
IV	moderate	Whip-poor-will Nature Preserve	WHIP	291	17.62	14.79	37666.67	7555.56	1600.00	2066.67	33.1
IV	heavy	Harmonie State Park	HSP	1403	5.87	8.97	10111.11	9333.33	2466.67	4133.33	13.6

[1] Percent cover includes woody and herbaceous species < 50 cm in height.
[2] Seedlings include all woody stems < 50 cm in height.
[3] Saplings include all woody stems between 50 and 200 cm in height.
[4] Average number of 10 cm sections of 2 m cover pole > 25% covered summed for each of the cardinal directions per point (0-80).

located in southern Indiana, which is the focus of the distribution of several NTM species in the state. One group was located in the more fragmented northern part of the state.

Specific study plots were selected within each site in such a way that the confounding effects of fragment size (ideally > 200 ha) and proximity to edge (no closer than 100 m) will be minimized. Ideally, plots would be at least 300 m from the edge, but this was not possible due to the lack of large tracts of mature forest in Indiana, especially in the northern part of the state.

Vegetation sampling

From May through early-July 1996 and 1997, we sampled vegetation on 3 permanent plots on mesic slopes within each site. Three parallel 10 m line transects were established along the contour of each plot. These line transects also formed the lower edge of 3 belt transects of 1 X 10 m. The middle transect was randomly selected along mid-slope, while the remaining 2 transects were positioned parallel to the first at a random distance of 2-5 m. The amount of overlap (cm) of all herbaceous species and any woody stems <50 cm on all 3 line transects were recorded and summed. The number of seedlings (<50 cm tall) within the belt transects were recorded. All saplings (50-200 cm tall) were recorded within a 50 m^2 circular plot, centered upon the start of the middle line transect. An estimate of relative abundance was calculated for all species. Although we tried to control for landscape variables, each plot is characterized by fragment size, distance to edge, and interspersion (Gustafson and Parker 1992).

In 1997, we measured an index of vertical vegetation density using methods described by Griffith and Youtie (1988). A cover pole 2 m in height and divided into 10 cm sections was placed at each bird survey point. At 15 m, in each of the cardinal directions, an observer counted the number of 10 cm sections > 25% covered by vegetation. These were summed for each point/site. Measurements were made the same day of the last breeding bird survey on each site.

Breeding bird surveys

Using point-count methodology (Ralph et al. 1993), we sampled breeding bird communities twice from May through mid-July in both 1996 and 1997. While point counts do not allow density estimates, they do allow for assessment of presence/absence and relative abundance. Sampling began in the southern portion of the state and progressed northward. This cycle was repeated for the second survey in each year. We conducted fixed-radius (50 m) point surveys on fair weather days (no rain or fog, minimal wind) from sunrise to 1000 hours. Count duration was 10 min so that interspecies differences in singing frequencies and detection probabilities would be minimized (McShea and Rappole 1997b). Points were centered upon the 3 permanent vegetation plots if they met the landscape criteria.

We divided bird species into 4 nesting guilds (ground – 0 to 0.5 m, intermediate-canopy – 0.5 to 5.0 m, high-canopy - > 5.0 m, and other, which included cavity nesters, brown-headed cowbird and any species that do not require vegetation for nesting substrate and cover, see Appendix A) based upon the common heights in which each species nests (Ehrlich et al.1988, Baicich and Harrison 1997). Mean species richness per site and mean number of individuals per plot were calculated for each nesting guild. Means were calculated for each year. Differences between years were examined in a nested factorial ANOVA model for each dependent variable (ground-nesting species per site, ground-nesting individuals per plot, etc.) (see *Statistical analysis* section below).

Avian productivity

During the 1996 and 1997 we conducted nest searches and monitored nest success in songbirds in BCSP, MCSP, MMSF and YSF (see Table 1 for key to site codes). Nests were visited during 3-day intervals in 1996 and 2-day intervals in 1997. Nest daily survival rate (the probability of a nest surviving 1 day) was calculated for wood thrush and acadian flycatcher nests. Nest searches were not limited to plots but were conducted anywhere >100 m from the forest edge.

Arthropod sampling

We sampled arthropods with malaise (Townes 1972) and pitfall traps (Murkin et al. 1994) during the 1996 and 1997 bird breeding seasons on BCSP, MCSP, MMSF and YSF. Logistics prevented use of these sampling methods on all 12 sites. One malaise trap and 9 pitfall traps were set on each vegetation plot for 3, 2-day occasions in 1996 and 2, 2-day occasions in 1997. Pairs of sites within a physiographic group (for instance, BCSP and YSF) were sampled simultaneously. When comparisons between sites are made, simultaneous sampling is best (Disney 1986). Trapping was conducted in fair weather and at 2-week intervals for a given pair of sites. Although long-term sampling may be best since there is no such thing as a "normal" year for insects (Samways 1994), a reasonable picture can be drawn from sampling in a short-time frame (Owen and Owen 1990).

During the 1997 bird breeding season, we sampled foliage-dwelling arthropods on all 12 sites using sweep nets and branch clipping. These methods sampled the foliage-dwelling arthropods that malaise and pitfall traps likely missed (Southwood 1978, Cooper and Whitmore 1990). One 1000-sweep transect was conducted on each site. Surveys were made as close together as possible on sites within a group to avoid any confounding effects (Disney 1986). Transects were along a random azimuth and began from 1 of the vegetation plots, also randomly chosen. The transect was shifted 45 degrees clockwise if it approached within 50 m (estimated) from the edge of the woods. The net was then placed in a trash bag with an ethyl acetate-soaked sponge.

Branch clippings were made from 10 bird survey points. Points were randomly chosen on sites with >10 survey points. From the each point, the observer walked in the 4 cardinal directions until a branch at waist height was found. A bag was placed over the branch as quickly as possible and the branch was cut at its insertion point. If the branch was longer than the bag (folded down to 76 cm), it was cut at the length of the bag. The entire bag was placed in a trash bag with an ethyl acetate-soaked sponge.

All samples were stored in 70% ethyl alcohol. Samples taken in 1996 were summed, dried and weighed to the nearest 0.0001 g for each order (Borror et al. 1989).

In addition, 1997 samples were grouped into "operational species" for each order on a per plot basis. We defined operational species as individuals that looked alike under a dissecting scope. Individuals >5 mm and <5 mm in length were totaled for each order; divisions were based upon recommendations of Poulin and Lefebvre (1997). We assumed larger arthropods were more preferred items of prey for birds.

Statistical analyses

The data was analyzed with SAS®, using a nested factorial model, to compare differences among damage classes within groups (SAS Institute 1988). $Y = GROUP_i + DAMAGE_{(i)j} + YEAR_k + GROUP*YEAR_{ik} + DAMAGE*YEAR_{(i)jk} + \varepsilon_{(jk)l}$ Tukey's multiple comparison procedure was used to analyze significant main effects. Tukey has a smaller type I error rate than either the Duncan or Newman-Keuls procedures, and is therefore more conservative, although not as powerful (Montgomery 1991).

Among-order comparisons were made for all arthropod sampling efforts independently. Between-order comparisons were made for orders found in all sites (Coleoptera, Diptera and Hymenoptera). Shannon-Weiner diversity (H) and evenness (J) indices were calculated per plot for malaise and pitfall trap samples and per site for branch clipping and sweep net samples. These indices recognize differences among species on the basis of abundance only (Cousins 1991). It would be more beneficial to rank species on the basis of feeding preferences by birds (Cousins 1991), but this was not possible when an entire community of birds is composed of 30-50 species.

Significant, uncorrelated vegetation and insect variables were included into a cluster analysis of the study sites using PC-ORD®. In this procedure, similar sites would cluster together in a dendrogram. We expect heavy-, moderate- and light-damage sites to cluster into 3 separate groups. Although the procedure for separating clusters from the dendrogram is subjective (Ludwig and Reynolds 1988), this type of analysis gave us the advantage of comparing many complex communities at once.

RESULTS

Vegetation

Overall, mean percent cover (see Table 1) varied significantly among light-, moderate- and heavy-damage classes (P=0.0017). Mean percent cover was different between years (P=0.0423). Within each physiographic grouping, mean percent cover was higher in light-damage sites compared to heavy-damage sites within 3 of 4 groups (P<0.05) (Table 2). Although not significant, moderate-damage sites were consistently higher in mean percent cover compared to heavy-damage sites (Tables 1 and 2).

Table 2. Variables significantly different among damage classes in a nested factorial ANOVA. Variables with different letters are significant at alpha=0.05 (Tukey's multiple comparison procedure).

Group	Damage Class	Site	Percent cover [1]	Sapling denstiy [2]	Vertical vegetation density [3]
	light	OAK	A	A	A
I	moderate	MOR	B	B	A
	heavy	PSP	B	-	A
	light	YSF	A	A	A
II	moderate	EAG	A	AB	B
	heavy	BCSP	A	B	B
	light	MMSF	A	A	A
III	moderate	BIGW	AB	A	B
	heavy	MCSP	B	A	B
	light	INDM	A	A	A
IV	moderate	WHIP	B	A	B
	heavy	HSP	B	A	AB

[1] Damage(Group) for Percent Cover as dependent variable P=0.0017
[2] Damage(Group) for sapling density^{-1} as dependent variable P=0.0086
[3] Damage(Group) for vertical vegetation density index as dependent variable P=0.0001

Mean sapling density (see Table 1) was also significantly different among damage classes (P=0.0086). Within group differences existed in groups I and II (P<0.05) (Table 2). Light-damage class sites had the highest mean sapling density in all groups but IV.

In this group, HSP, a heavy-damage site, had the highest sapling density, of which the majority was pawpaw (*Asimina triloba*).

Overall, the cover pole index of vertical vegetation density (see Table 1) was significantly different among damage classes (P=0.0001). Significant differences were apparent in 3 of 4 groups (P<0.05) (Table 2). The lack of significance in group I is most likely a consequence of the heavy ground cover of garlic mustard (*Alliaria officinalis*) in PSP. Over 55% of the coverage in PSP was within 0-0.5 m from the ground. Only 1 other site (BIGW) had more than 40% of its coverage at this height.

Avian abundance and diversity

The mean number of species per site and the mean number of individuals per plot of ground-nesting birds were significantly different among damage classes in 1996 and 1997 (P=0.0017 and P=0.0016, respectively) (see Figure 2). Differences between years for both variables were not significant (P>0.3). The number of ground-nesting species per site differed among sites with groups II and IV (P<0.05) (Figure 2). The number of ground-nesting individuals per plot differed among sites within groups II, III and IV (P<0.05) (Figure 2). The absence of many ground-nesting warblers in the northern part of the state (Kentucky warbler, worm-eating warbler), along with more hydric conditions, may explain the lack of significance within group I, although OAK still had many more species per site (Figure 2).

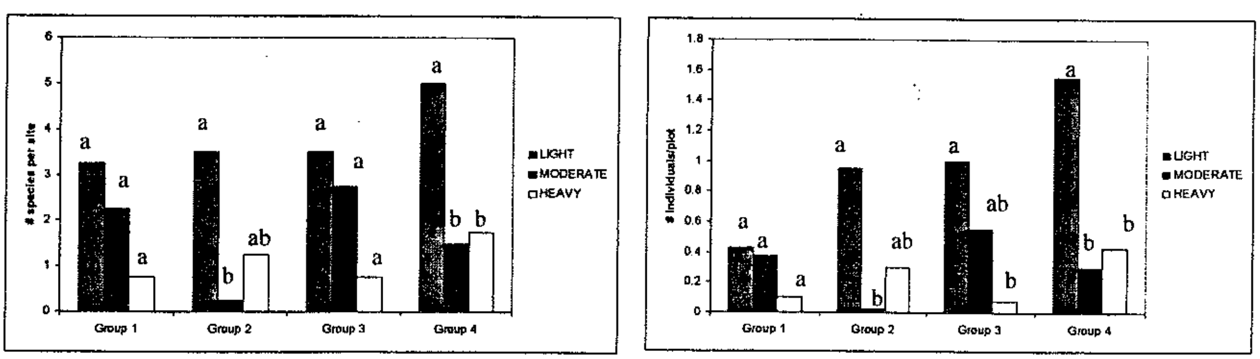

Figure 2. Mean species per site (right) and mean number of individuals per plot (left) of ground-nesting (0-0.5 m) species in deciduous forests of Indiana, 1996 and 1997. Each column represents 1 site. Site names within each group can be found in Table 1. Sites within each group with different letters are significantly different at alpha=0.5 (Tukey's multiple comparison procedure).

For intermediate-canopy-nesting species, the number of individuals per plot was significantly different between years (P=0.0086). No difference existed between years for the number of species per site. Both the number of individuals per plot and the number of species of intermediate-canopy-nesting birds were significantly different among damage classes (P=0.0006 and P=0.0416, respectively) (see Figure 3). Within-group differences existed among sites in groups I, III and IV for the number of species per site, and groups I and II for the number of individuals per plot (Figure 3 and Table 3). For both variables, light-damage sites were higher than heavy-damage sites, except for sites within group III.

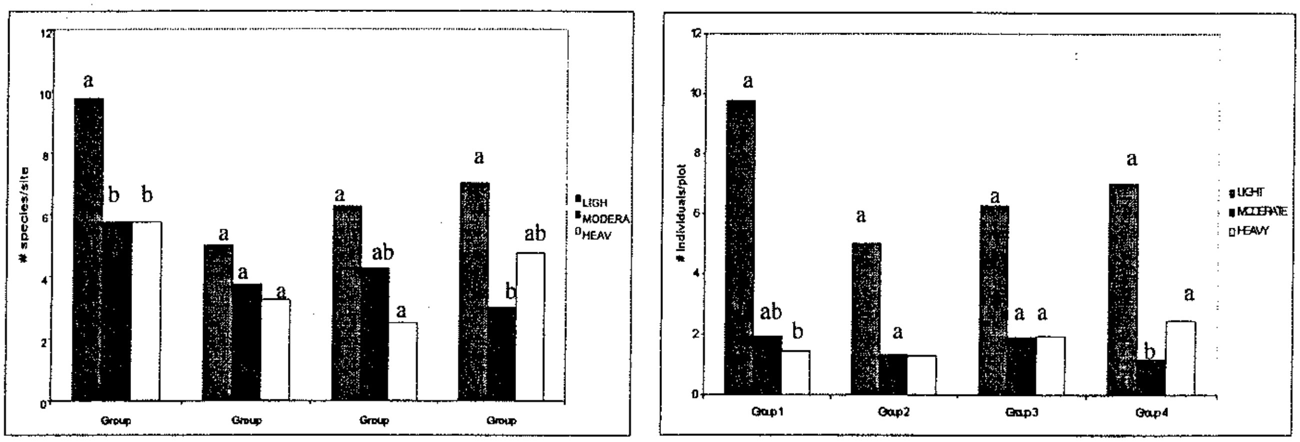

Figure 3. Mean species per site (right) and mean number of individuals per plot (left) of intermediate-canopy-nesting (0.5-5.0 m) species in deciduous forests of Indiana, 1996 and 1997. Each column represents 1 site. Site names within each group can be found in Table 1. Sites within each group with different letters are significantly different at alpha=0.5 (Tukey's multiple comparison procedure).

As expected, no trend was apparent for high-canopy-nesting species. All other species were not considered in analyses because they have different nesting biology than the guilds described above. A list of the mean number of birds per site for all species recorded during breeding birds surveys and the nesting guilds to which they were assigned can be found in Appendix A.

Avian productivity

We defined avian productivity as the daily nest survival rate, or the probability that a nest will survive a given day. This included incubation and brooding periods. Only acàdian flycatcher and wood thrush had a large enough sample size in every site to warrant separate analysis. Wood thrush productivity was significantly higher in MMSF than MCSP (P<0.05) (Table 3). The same was true for sites pooled within each damage class. Survival rates for nests of acadian flycatchers and all bird species together were not significantly different within any of the groups. However, a trend was evident, since all values of productivity were always higher on light-damage sites opposed to heavy-damage sites, pooled or unpooled (Table 3).

Table 3. Daily survival rates (Bart and Robson 1982) of nests in deciduous forests of Indiana, 1996-1997. Pairs in bold italics have P < 0.05. N= number of nest.

Group	Damage class	Site	Woodthrush Productivity (N)	Acadian flycatcher Productivity (N)	All birds Productivity (N)
II	Light	YSF	0.9692(10)	0.9609(17)	0.9577(46)
	Heavy	BCSP	0.9498(27)	0.9253(13)	0.9432(48)
III	Light	MMSF	***0.9911(4)***	0.9667(16)	0.9709(26)
	Heavy	MCSP	***0.9447(17)***	0.9318(13)	0.9325(31)
pooled	Light	YSF/MMSF	***0.9801(14)***	0.9637(33)	0.9643(72)
	Heavy	BCSP/MCSP	***0.9476(44)***	0.9285(26)	0.9378(79)

Arthropod biomass and total numbers

Total arthropod biomass and numbers of individuals per plot caught in malaise and pitfall traps in 1996 and 1997 were not significantly different among damage classes. In malaise traps, biomass and numbers were higher for the light-damage site in group II, but lower in group III (Table 4). No relationship was found for arthropods caught in pitfall traps (Table 5).

Differences in biomass and numbers of individuals of common orders caught in malaise and pitfall traps in 1996 and 1997 were not significant. Diptera and Hymenoptera mass and numbers in malaise traps were higher in YSF than BCSP, but lower in MMSF compared to MCSP (Table 4). Both mass and numbers of Collembola in group III were the only major differences between sites for common orders of arthropods (Table 5). Mass and numbers were approximately 5 and 4 times greater, respectively, in MMSF compared to MCSP.

Table 4. Average biomass and total number of individuals per plot of all arthropods and common orders captured in malaise traps on BCSP, YSF, MCSP and MMSF in 1996 and 1997.

Group	Damage class	Site	All arthropods mass	All arthropods total #	Diptera mass	Diptera total #	Hymenoptera mass	Hymenoptera total #
II	Light	YSF	1.2460	97.6	0.6991	59.5	0.2806	20.8
	Heavy	BCSP	0.4413	72.9	0.2106	48.5	0.0848	9.2
III	Light	MMSF	0.3261	49.2	0.0722	26.5	0.1022	11.07
	Heavy	MCSP	0.4674	77.1	0.2758	51.5	0.1219	14.92

Table 5. Average biomass and total number of individuals per plot of all arthropods and common orders captured in pitfall traps on BCSP, YSF, MCSP and MMSF in 1996 and 1997.

Group	Damage class	Site	All arthropods mass	All arthropods total #	Aranae mass	Aranae total #	Coleoptera mass	Coleoptera total #	Collembola mass	Collembola total #
II	Light	YSF	1.8582	122.6	0.0924	13.1	0.8532	24.9	0.0074	25.8
	Heavy	BCSP	1.9111	127.6	0.0982	16.4	0.6029	33.6	0.0120	26.4
III	Light	MMSF	1.4146	112.2	0.0610	14.9	0.9310	18.3	0.0171	40.8
	Heavy	MCSP	1.5135	55.9	0.0396	8.4	0.8035	14.0	0.0037	9.4

The number and biomass of total arthropods caught in sweep nets and branch clippings on 12 sites in 1997 were not significantly different among damage classes. However, the number of Hymenoptera$^{0.5}$ and mass of Diptera$^{0.5}$ of sweep net samples were significantly different when sites within each damage class were pooled (P=0.0035 and P=0.0279, respectively).

Arthropod size

The proportion of total arthropods that were >5 mm in length were not different among damage classes for all trap types. The total number of Hymenoptera >5 mm were greater in light-damage sites (21.75) than moderate- (6.5) or heavy- (8.5) damage sites (p=0.058).

Arthropod diversity

A total of 18 arthropod orders were caught in sweep nets on 12 sites in 1997. Of these, 16, 12 and 13 were caught on light-, moderate- and heavy-damage sites, respectively. Four orders (Mecoptera, Odonata, Phasmida, and Trichoptera) were exclusive to light-damage sites. However, none of these were found in more than 2 light-damage sites. Acari were exclusive to 1 heavy-damage site (HSP). Collembola were only caught on 1 moderate-damage site (BIGW).

We caught 16 orders of arthropods with branch clippings in 1997. Two orders, Ephemeroptera (INDM) and Phasmida (MMSF and YSF), were found only on light-damage sites. Isoptera was exclusive to heavy-damage sites (BCSP).

We calculated Shannon diversity (H) and evenness (J) for operational species (individuals that looked alike) for arthropods caught in malaise and pitfall traps in 1997. Evenness was very similar for both trap types. In pitfall traps, H in YSF was greater or equal to BCSP. No pattern was apparent in MMSF and MCSP. Diversity in malaise traps was consistently higher in light-damage sites. YSF and MMSF diversity was greater than BCSP and MCSP, respectively, in all but 1 plot within a trapping time. No differences were statistically significant for either malaise or pitfall traps.

The diversity (H) of the mass and numbers of each order caught in sweep nets and branch clippings in 1997 had no apparent trend. The pattern seemed to be almost random.

Cluster analysis

All significant variables from the previous analyses, except for sapling density, were included in the cluster analysis. These included percent cover, index of vertical vegetation denstiy, mass of Diptera caught in sweep nets, and number of Hymenoptera caught in sweep nets. Two main groupings appeared on the dendrogram (Figure 4). Three light-damage sites, OAK, YSF and MMSF, clustered together. The remaining 9 sites formed the second cluster. If the dendrogram was cut at a distance of about 2000, 3 clusters would result. The first cluster would remain and the second cluster would be divided into 2 groups. One group would contain BCSP, HSP and PSP, all heavy-damage sites. The remaining 6 sites would form the last cluster. Any further divisions of the dendrogram would not make sense. Although this procedure cannot compare damage classes within each physiographic region, it does support our site classifications. Therefore, it appears that the state parks we studied vary from other sites in respect to these vegetation and insect variables. Ground- and intermediate canopy-nesting birds are correlated with 1 or more of these variables.

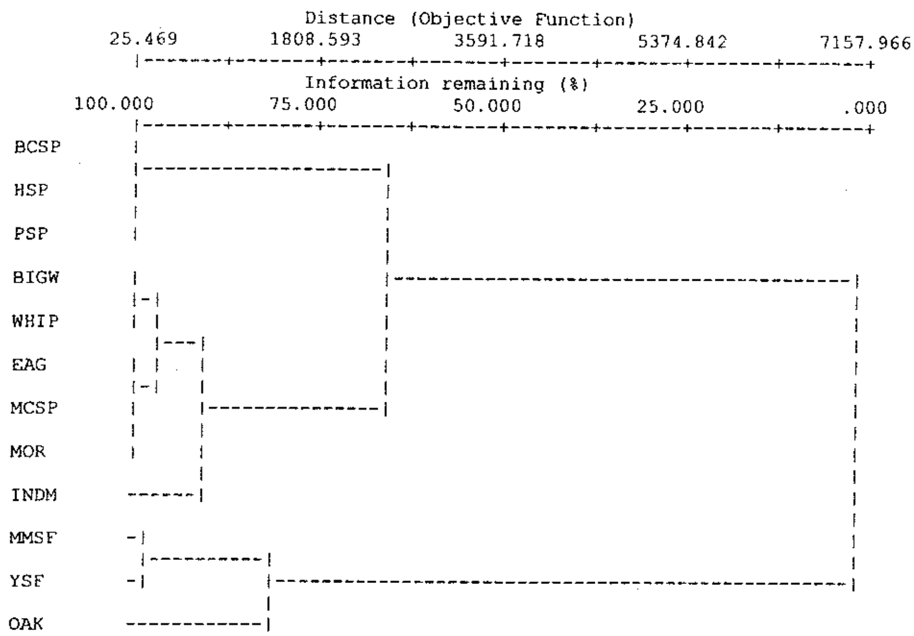

Figure 4. Cluster dendrogram of study sites in Indiana using number Hymenoptera caught in sweep nets, mass of Diptera caught in sweep nets, ground-nesting species per site and individuals per plot, intermediate-canopy-nesting species per site and individuals per plot, an index of vertical vegetation density, and percent cover. Refer to Table 1 for site code definitions.

DISCUSSION

White-tailed deer have significantly impacted songbirds that commonly nest <5 m high in the forest understory the state parks that we studied. Both the number of species per site and the number of individuals per plot of ground-nesting and intermediate-canopy-nesting birds were significantly different among damage classes. These birds were always more abundant on light-damage sites compared to heavy-damage sites. High deer densities have been associated with a decline in intermediate canopy-nesting birds (deCalesta 1994). The 4 state parks studied were all heavy-damage sites. Until recently, they have not been hunted, since their designation as state parks. All 4 light-damage sites have been consistently hunted. Two sites were state forests, and 2 were private land. Apparently, annual population control of deer can reduce their impact on the forest ecosystem.

Daily survival rates of wood thrush and acadian flycatcher nests were higher in light-damage sites compared to heavy-damage sites. Daily nest survival rates for YSF and MMSF were comparable to those found in other forest neotropical migrants (Holmes et al. 1992, Sargent et al. 1997). However, rates for MCSP and BCSP were lower. Large forested areas, such as MCSP and BCSP, are usually considered to be source populations for songbirds because of low rates of brood paratisism and predation compared to small blocks of forest, which are common throughout Indiana. These 4 sites were all large (see Table 1); therefore, forest size should not have affected our results. In a study using artificial nests, predation rates were not a sole function of forest size, but were influenced by vertical vegetation density and herbaceous cover (Leimgruber et al. 1994). Low foliage (1-3 m) may be important for foraging of females and for feeding of fledglings (Steele 1993). However, Tye (1992) found that breeding success was not so much dependent upon the amount of food available during the nestling period, but rather upon the food availability at the time of territory assessment. It seems vegetation structure, as well as forest size, play important roles in the reproductive success of forest songbirds in Indiana.

We found higher species richness in malaise trap samples in MMSF and YSF compared to MCSP and BCSP. However, sweep net sampling seemed to be the best method of assessing and comparing the abundance of arthropod communities in deciduous forests. While sweep nets are inexpensive and allow coverage of a large area with relatively low effort, they have the disadvantage of specimens being lost in crushed vegetation (Matthews and Matthews 1971). It was expected that the malaise and pitfall trap data would better reflect insect community structure than sweep netting and branch clipping. The problem may have been that sampling 3 "clumps" of the forest may have missed patchily-distributed species. Both sweep nets and branch clippings covered a larger area; however, branch clippings typically capture few arthropods per sample (Cooper and Whitmore 1990). Random placement of malaise traps within each site for every trapping occasion may have given us a better overall sample of flying arthropods. We attempted to place every trap 5 m down-slope of the center of each vegetation plot, but this was rarely possible due to a paucity of trees and shrubs on some plots; malaise traps must be anchored to limbs of adjacent shrubs. The height of surrounding vegetation and amount of shade or sun can alter trap efficiency (Matthews and Matthews 1971). Poles could have been used to avoid the possible bias caused by the use of trees to set and fasten the malaise traps. If Diptera do make a good indicator habitat quality (Disney 1986), then random sampling using malaise traps throughout a site may be the most effective means to assess quality.

The question of how to manage for the recovery and maintenance of these systems remains unanswered. A biodiversity approach would ignore the value many park visitors place upon the white-tailed deer. An ecosystem management approach may be best, since it integrates ecological processes and sociopolitical values (Grumbine 1994). Some important themes in ecosystem management are the preservation of community diversity and ecological patterns and processes, coupled with data collection and monitoring (Grumbine 1994). Continuation of some form and intensity of deer population control should be included into any management plan, since deer lack effective natural population control mechanisms. Passive, reactive management of deer may result in reduced species richness, abundance, and community composition of plants and animals (deCalesta 1997). We suggest that an ecological monitoring system may be the best approach in tracking the recovery of these systems. Along with birds, communities of mammals, amphibians and reptiles should be examined, since they all are of interest to many park visitors and are important in the overall function of the ecosystem.

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Appendix A. The mean number of individuals of each species recorded per breeding bird survey, 1996 and 1997. Nesting guild codes: G – ground, I – intermediate-canopy, H – high-canopy, C – cavity, O – other. Site codes: BCSP – Brown County State Park, BIGW – Big Walnut Nature Preserve, EAG – Eagle Creek Metro Park, HSP – Harmonie State Park, INDM – Indian Mounds Farm, MCSP – McCormick's Creek State Park, MMSF – Morgan-Monroe State Forest, MOR – Moraine Nature Preserve, OAK – Oakhill Church Camp, PSP – Pokagon State Park; WHIP – Whip-poor-will Nature Preserve, YSF – Yellowwood State Forest.

Appendix A (page 1 of 2)

Species	Scientific Name	AOU code	nesting guild	PSP 1996	PSP 1997	MOR 1996	MOR 1997	OAK 1996	OAK 1997	BCSP 1996	BCSP 1997
Yellow-billed cuckoo	*Coccyzus americanus*	YBCU	H	-	-	-	-	-	-	-	-
Ruby-throated hummingbird	*Archilochus colubris*	RTHU	I	-	0.5	-	-	1.1	0.5	-	-
Red-bellied woodpecker	*Melanerpes carolinus*	RBWO	C	1.5	0.5	0.5	0.5	2.8	0.5	1.5	1
Northern flicker	*Colaptes auratus*	NOFL	C	0.5	-	-	-	-	-	-	-
Red-headed woodpecker	*Melanerpes erthrocephalus*	RHWO	C	-	-	-	-	-	-	0.5	-
Downy woodpecker	*Picoides pubescens*	DOWO	C	1.5	-	0.5	1.5	0.6	2.5	1	-
Hairy woodpecker	*Picoides villosus*	HAWO	C	-	-	-	-	0.6	-	-	0.5
Pileated woodpecker	*Dryocopus pileatus*	PIWO	C	0.5	-	0.5	0.5	-	-	2	-
Great-crested flycatcher	*Myiarchus crinitus*	GCFL	C	2	1.5	0.5	-	6.1	1	1	1
Eastern wood peewee	*Contopus virens*	EWPE	H	1.5	2.5	1.5	4	3.3	4.5	3.5	2
Eastern phoebe	*Sayornis phoebe*	EAPH	O	-	-	-	-	-	0.5	-	-
Acadian flycatcher	*Empidonax virescens*	ACFL	I	7	5	4.5	7	4.4	6	10	4
Blue jay	*Cyanocitta cristata*	BLJA	H	1.5	1.5	1	0.5	2.8	1	2.5	-
American crow	*Corvus brachyrncos*	AMCR	H	3.5	0.5	0.5	0.5	1.1	1	1	-
Tufted titmouse	*Parus bicolor*	TUTI	C	2	2	1	2	3.3	1.5	0.5	0.5
Black-capped chickadee	*Parus atricapillus*	BCCH	C	1.5	3	1.5	1	1.7	3	-	-
Carolina chickadee	*Parus carolinensis*	CACH	C	-	-	-	-	-	-	1	1.5
White-breasted nuthatch	*Sitta carolinensis*	WBNU	C	0.5	0.5	0.5	0.5	1.1	-	-	-
Carolina wren	*Thryothorus ludovicianus*	CAWR	C	-	-	-	-	-	-	-	-
House wren	*Troglodytes aedon*	HOWR	C	-	1.5	0.5	1.5	1.1	1.5	-	-
Blue-gray gnatcatcher	*Polioptila caerulea*	BGGN	I	0.5	-	1	-	0.6	-	-	-
Wood thrush	*Hylocichla mustelina*	WOTH	I	1.5	1.5	3.5	3	2.8	4	3.5	3.5
Veery	*Catharus fuscescens*	VEER	G	0.5	0.5	1.5	2.5	1.1	2	-	-
American robin	*Turdus migratorius*	AMRO	H	2	1	1	-	2.8	1.5	0.5	-
Gray catird	*Dumetella carolinensis*	GRCA	I	0.5	-	-	1	5.0	2	0.5	-
Cedar waxwing	*Bombycilla cedrorum*	CEWX	H	-	1	-	-	-	-	-	-
White-eyed vireo	*Vireo griseus*	WEVI	I	-	-	-	-	1.1	1.5	-	-
Yellow-throated vireo	*Vireo flavifrons*	YTVI	H	0.5	0.5	-	-	-	-	1	-
Red-eyed vireo	*Vireo olivaceus*	REVI	H	2.5	-	7	5.5	1.1	3	6	2.5
Tennessee warbler	*Vermivora peregrina*	TEWA	G	-	-	-	-	-	-	1	-
Nashville warbler	*Vermivora ruficapilla*	NAWA	G	-	-	-	-	-	-	-	-
Northern parula	*Parula americana*	NOPA	H	-	-	1	-	-	-	-	-
Black-and-white warbler	*Mniotilta varia*	BWWA	G	-	-	-	1	0.6	1	-	-
Black-throated blue warbler	*Dendroica caerulescens*	BBWA	I	0.5	-	-	-	-	-	-	-
Cerulean warbler	*Dendroica cerulea*	CEWA	H	2	0.5	-	0.5	0.6	1	-	-
Black-throated green warbler	*Dendroica virens*	BGWA	H	0.5	-	-	-	-	-	-	-
Yellow-throated warbler	*Dendroica dominica*	YTWA	H	-	-	-	-	-	-	-	-
Yellow warbler	*Dendroica petechia*	YEWA	I	-	0.5	-	-	4.4	2.5	-	-
Kentucky watbler	*Oporornis formosus*	KEWA	G	-	-	0.5	-	-	-	-	-
Hooded warbler	*Wilsonia pusilla*	HOWA	I	-	-	0.5	-	1.1	-	-	-
Worm-eating warbler	*Helmitheros vermivorus*	WOEW	G	-	-	-	-	-	-	3	2
Ovenbird	*Seiurus aurocapillus*	OVEN	G	-	-	0.5	1	1.7	1	-	-
Lousiana waterthrush	*Seiurus motacilla*	LOWA	G	-	-	-	0.5	-	-	-	-
Common yellowthroat	*Geothlypis trichas*	COYE	G	1	-	-	-	1.1	1	-	-
American redstart	*Setophaga ruticilla*	AMRE	I	1	-	5.5	3	1.1	-	-	-
Rose-breasted grosbeak	*Pheucticus ludovicianus*	RBGR	H	1	-	-	-	-	1	-	-
Northern cardinal	*Cardinalis cardinalis*	NOCA	I	4.5	3.5	7.5	1.5	7.2	4	2.5	1.5
Indigo bunting	*passerina cyanea*	INBU	I	0.5	0.5	0.5	0.5	2.8	1	-	-
Eastern towhee	*Pipilo erythrophthalmus*	EATO	I	-	-	-	-	0.6	-	-	-
Swamp sparrow	*Melospiza georgiana*	SWSP	I	-	0.5	-	-	-	-	-	-
Brown-headed cowbird	*Molothrus ater*	BHCO	O	14	2.5	5.5	1.5	4.4	4	5.5	2.5
Scarlet tanager	*Piranga olivacea*	SCTA	H	2	1	3	3.5	0.6	1	2.5	3.5
Summer tanager	*Piranga ludoviciana*	SUTA	H	-	-	-	-	-	-	-	-
American goldfinch	*Carduelis tristis*	AMGO	I	-	1	-	-	1.1	0.5	-	-

Appendix A (page 2 of 2)

AOU code	nesting guild	EAG 1996	EAG 1997	YSF 1996	YSF 1997	MCSP 1996	MCSP 1997	BIGW 1996	BIGW 1997	MMSF 1996	MMSF 1997	HSP 1996	HSP 1997	WHIP 1996	WHIP 1997	INDM 1996	INDM 1997
YBCU	H	-	-	-	-	-	0.5	-	-	-	-	0.5	-	-	0.5	-	-
RTHU	I	-	-	1	-	0.6	-	0.5	0.5	-	-	0.5	0.5	-	-	0.5	2
RBWO	C	-	0.5	-	0.5	1.2	1.5	1	0.5	-	0.5	0.5	0.5	2	1.5	1.5	0.5
NOFL	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
RHWO	C	1	-	-	-	-	-	-	-	0.5	-	1	-	0.5	-	2.5	-
DOWO	C	2	1	-	1.5	-	-	-	0.5	0.5	1	-	-	-	0.5	0.5	1.5
HAWO	C	0.5	-	-	-	1.2	-	1	-	-	-	0.5	1	-	-	-	0.5
PIWO	C	-	-	0.5	0.5	-	-	-	0.5	0.5	1	2.5	0.5	-	1	0.5	1
GCFL	C	2	-	2	1	0.6	1.5	0.5	0.5	-	1	0.5	2.5	0.5	-	-	1
EWPE	H	2	1	-	3	6	3.5	5	2.5	0.5	2	2.5	1.5	2	3.5	2.5	2
EAPH	O	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	0.5
ACFL	I	2	1	1.5	8.5	16.8	9.5	14	8	9.5	7.5	15.5	11.5	9	7.5	15.5	9
BLJA	H	4	-	-	2	1.2	1.5	1	-	1	0.5	0.5	-	-	1	2.5	0.5
AMCR	H	-	1	1.5	-	-	-	-	-	1.5	-	-	-	-	1	-	0.5
TUTI	C	3	2	-	1	1.8	1.5	1.5	3	2.5	1.5	7	3	0.5	1.5	1.5	3
BCCH	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CACH	C	4.5	1.5	-	1.5	0.6	-	0.5	-	2	1	4	1	1	2.5	1.5	1.5
WBNU	C	-	0.5	-	-	1.2	-	1	2	-	1	1	-	0.5	-	-	0.5
CAWR	C	-	-	-	-	-	-	-	-	1.5	-	2.5	-	-	-	2.5	0.5
HOWR	C	-	-	-	-	1.2	-	1	0.5	-	-	-	-	-	-	-	-
BGGN	I	-	-	2	-	-	-	-	-	-	0.5	-	-	-	-	-	-
WOTH	I	0.5	-	-	5.5	1.8	4.5	1.5	3.5	1.5	5	4.5	5	0.5	3.5	5	6
VEER	G	-	-	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-
AMRO	H	4.5	2.5	-	-	-	-	-	0.5	-	0.5	0.5	1	-	-	-	0.5
GRCA	I	1	1	-	-	-	-	-	-	-	0.5	-	-	-	-	-	-
CEWX	H	0.5	1.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WEVI	I	-	-	-	-	-	-	-	-	0.5	0.5	-	0.5	-	-	-	-
YTVI	H	-	-	7	1	-	-	-	0.5	-	1.5	-	-	-	-	2	1
REVI	H	3	4	-	5	8.4	3	7	6	5	5.5	4.5	2	8	7.5	5.5	5
TEWA	G	-	-	-	-	-	-	-	-	-	-	1	2.5	-	-	0.5	4
NAWA	G	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
NOPA	H	1	-	2.5	-	-	-	-	0.5	-	1	0.5	-	0.5	-	1.5	1
BWWA	G	-	-	-	0.5	1.2	-	1	0.5	1	1	0.5	-	-	-	2	0.5
BBWA	I	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5
CEWA	H	0.5	-	-	-	0.6	2	0.5	1.5	0.5	2.5	-	-	-	-	3	2.5
BGWA	H	-	-	-	-	-	-	-	-	-	-	-	0.5	-	-	-	-
YTWA	H	-	-	-	-	0.6	-	0.5	-	-	0.5	1	-	-	-	0.5	-
YEWA	I	-	-	1.5	-	-	-	-	-	-	-	-	-	-	-	-	-
KEWA	G	0.5	-	1.5	1	3	0.5	2.5	1.5	2.5	2	1.5	-	0.5	-	-	3
HOWA	I	-	-	4.5	4	-	-	-	-	2	3.5	-	-	1	-	2.5	-
WORM	G	-	-	2	3.5	-	-	-	-	1.5	3	1	-	1.5	3	5	5
OVEN	G	-	-	-	3.5	4.2	-	3.5	1	4.5	4.5	1.5	-	-	1	1	3.5
LOWA	G	-	-	-	-	1.2	-	1	-	-	-	0.5	-	-	-	0.5	1.5
COYE	G	-	-	1.5	-	-	-	-	-	-	-	-	-	-	-	-	-
AMRE	I	-	-	-	2	-	0.5	-	0.5	-	1.5	-	1	-	0.5	1	4.5
RBGR	H	-	-	1.5	-	0.6	-	0.5	-	0.5	-	-	-	-	-	-	-
NOCA	I	10.5	6	-	1.5	6.6	-	5.5	1.5	3	0.5	5	3.5	0.5	1.5	9	2.5
INBU	I	-	-	-	-	1.2	-	1	1	-	1.5	0.5	-	-	-	1	2.5
EATO	I	0.5	-	-	-	-	-	-	-	2	1.5	0.5	-	-	-	-	0.5
SWSP	I	-	-	5.5	-	-	-	-	-	-	-	-	-	-	-	-	-
BHCO	O	7	5.5	5	4.5	11.4	5.5	9.5	6	13	6	11	9.5	1	1.5	10.5	6
SCTA	H	2	0.5	-	3	4.8	1.5	4	2.5	1.5	2.5	1.5	2	2.5	3	2.5	2.5
SUTA	H	-	-	-	-	1.2	0.5	1	0.5	-	-	-	0.5	-	-	1	0.5
AMGO	I	1.5	3	-	-	-	-	-	0.5	-	-	-	-	-	-	-	-

CONCLUSIONS

This research confirms the belief of many biologists within Indiana that white-tailed deer populations are excessive in most of the state parks and are negatively affecting their habitat and the habitat of other species within these parks. The following summarize the major findings of this research:

- White-tailed deer have reduced the ground cover of herbaceous species to varying degrees in most of the parks examined.
- Regeneration of woody species in the understories of Indiana state parks has been significantly reduced by excessive browsing in eight of the parks examined and tends to be lower in most parks than in similar areas outside the parks.
- Excessive browsing has significantly reduced the species richness within sample areas of six of the parks examined. The species richness in the remaining parks tends to be lower than that of control areas. However, most parks still retain most of the plant species occurring outside the park boundaries. This is due to the reduction in plant size and a more patchy distribution within parks than outside.
- Species evenness and diversity tend to be lower in parks than control areas, but these differences are not significant in the majority of the parks at this time.
- The heights of white baneberry, sweet cicely, and jack in the pulpit appear to be excellent indicators of browing pressure on mesic plant communities within Indiana state parks.
- Abundance and diversity of songbirds that commonly nest >5m above the ground were significantly reduced in areas with excessive browse damage caused by white-tailed deer.
- Daily survival rates of wood thrush and acadian flycatcher nest during incubation and brooding were higher in light-damage sites compared to heavy-damage sites.
- Species richness of arthropods tended to be lower in McCormick's Creek State Park and Brown County State Park than in hunted areas such as Morgan Monroe State Forest and Yellowwood State Forest