IMPACTS OF ELECTRIC DEER EXCLUSION FENCING AND SOILS ON PLANT SPECIES ABUNDANCE, RICHNESS, AND DIVERSITY FOLLOWING CLEARCUTTING IN PENNSYLVANIA

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Abstract: Electric deer exclusion fencing has become a widely used management tool to promote hardwood regeneration in high deer browsing intensity areas. To assess the impacts of deer browsing on hardwood regeneration and vegetation patterns on clearcuts, six clearcuts with paired electric fenced and unfenced treatments were investigated. Additional data were collected on 10 sites with only fenced clearcut treatments. Overall browse damage on fenced treatments was lower than unfenced treatments, but there were substantial species-specific variability. The vegetation patterns on clearcuts were strongly influenced by pre-harvest ground covers of herbaceous and woody species. Comparisons between fenced and unfenced treatments showed that species richness was not significantly different for any site and that woody species diversity (Shannon Index) was significantly higher on a fenced versus unfenced clearcut on only one site. Observed vegetation patterns may also be influenced by soil nutrient and acidity status. Species richness was significantly related to exchangeable Ca and Al levels in the subsoil and organic horizon pH.

INTRODUCTION

There has been much concern surrounding the difficulties in regenerating desirable hardwood species following clearcutting in Pennsylvania and throughout the eastern hardwood region. There is also growing interest in evaluating clearcut plant communities in light of recent efforts to manage forests for biodiversity (Gove and others 1992; Hansen and others 1991; Niese and Strong 1992). Interpreting causal factors responsible for observed vegetation patterns, however, requires detailed analysis of an array of biotic and abiotic factors that may be influencing the structure and composition of vegetation on any given site. In Pennsylvania, excessive browsing by white-tailed deer (*Odocoileus virginianus virginianus* Boddaert) has been widely cited as the primary agent responsible for depleting advance regeneration stocks, reducing hardwood regeneration on clearcuts, and influencing species composition (Jordan 1967; Marquis 1981). However, ground covers of competing species (Drew 1988; Horsley 1977; Horsley and Marquis 1983; Kolb and others 1990), rodent damage and seed predators (Marquis and others 1976), poor seed production (Tryon and Carmean 1958), low levels of soil N and P (Auchmoody 1982), and soil acidity and soil nutrient imbalances (Tomlinson and Tomlinson 1990) may all play a role in determining the success of hardwood regeneration and the overall community that is regenerated after clearcutting.

Deer exclusion fencing has been used for many years as a research and management tool to both ascertain and ameliorate the impacts of deer browse on regeneration and revegetation of clearcuts (Frontz 1930; Grisez 1959; Marquis and Brenneman 1981; Marquis and Grisez 1978; Shafer and others 1961; Tilghman 1987; Trumbull and others 1989). Research results indicating the potential value of wire mesh fences in promoting hardwood regeneration have led to the development and widespread use of less expensive electric deer fencing in high deer density areas. Despite the expanded use of electric exclusion fencing , however, there have been few quantitative studies on the value of these fences in promoting hardwood regeneration (George and others 1991; Kochel and Brenneman 1987) and fewer studies on plant species richness and diversity. The current study was undertaken to obtain additional information on the effectiveness of electric exclusion fencing in reducing deer influence on the composition of plant

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communities, species richness, and woody plant diversity on clearcuts. The study also focused on the assessment of soil chemical factors at each site to determine if and how soil chemistry might be influencing vegetation patterns. Specifically, the study was designed to analyze three components of clearcut revegetation: (1) comparisons of woody and non-woody species density, height, and cover across a range of different sites, (2) comparisons of overall vegetation patterns, species richness, and woody species diversity, and (3) the potential influence of soil acidity factors in influencing hardwood regeneration and vegetation patterns.

METHODS

Study Areas

One of the aims of this study was to undertake a field evaluation of the effectiveness of electric fencing on clearcut sites that were representative of typical fencing efforts currently employed in Pennsylvania. The study areas were carefully chosen from a large pool of clearcuts located on Pennsylvania Bureau of Forestry lands. The 16 study sites supported even-aged stands, were approximately the same age when cut, had minimal slopes (0-5%), and were from 2 to 4 years old. Six primary sites had paired fenced and unfenced clearcut treatments, of which four were located on oak forest sites and two on northern hardwood sites. Ten secondary clearcut sites scattered across north-central Pennsylvania with only fenced treatments were used to provide supplemental information. The fencing used on each clearcut was a multi-strand electric fence after the design of Brenneman (1982). Fences were constructed soon after harvest operations and were maintained by Bureau of Forestry personnel. At each site, all vegetation plots were located on the same soil series and soil sample results are based on analysis of the specific soil series. To ascertain any potential influence of soil chemical factors, the sites chosen also represented a range in soil conditions. General characteristics of the study sites are given in Table 1.

Study Design and Field Measurements

Each of the six primary study sites was divided into three treatments: a fenced clearcut, an unfenced clearcut, and an understory of an adjacent uncut forest stand similar in composition to the original, pre-clearcut stand. A stratified sampling design was used for vegetation analysis. Nine, 1.828 m radius (6-ft radius), sample plots were located within each treatment at each site (3 treatments x 9 plots = 27 plots per site). Bureau of Forestry field data on the composition of the over- and understories at each site prior to clearcutting were used to verify the validity of using vegetation data from understory plots adjacent to clearcuts as a proxy for pre-clearcut vegetation data in this study. The locations of all vegetation plots were restricted to a single soil type within each site. Soil types at each site were identified using SCS soil maps with ground verification using small, hand excavated soil pits. Vegetation plots were laid out on a 25 m x 25 m grid over the specific soil type on each of the 3 treatments with certain restrictions; plots had to be at least 30 m from the exclusion fences and not to be located on areas with major disturbance such as skid trails, uprooted trees or exposed mineral soil.

Vegetation plots were established during the spring of 1992. Full scale quantitative sampling was conducted on each site in August of 1992. On each of the fenced and unfenced clearcut plots, the number, height, and browse status of each species of woody plant were recorded. On the uncut, unfenced forest plots, the number, height, and browse status of each species of woody seedling and sapling were recorded. Cover of both shrubs and herbaceous species was also determined using the Braun-Blanquet system (7 cover categories). Browse damage on hardwood seedlings and saplings was noted if the top or lateral stems showed browse damage. No separation was made between deer browse and other mammal browse due to difficulties in distinguishing browse damage in the field. However, the high population of deer, and widespread evidence of deer activity at each site, suggest that deer were likely to have been responsible for most of the browse damage observed.

Table 1. General characteristics of six primary, and ten secondary study sites.

Site	Location State Forest	Size (ha)	Elev (m)	Stand Age When Cut	Year Cut	Date Fenced	Preharvest Overstory	Soil Series
				PRIMARY SITES				
1	Bald Eagle	10.1	510	80	1988	5/89	CO,RO,WO	Laidig
2	Bald Eagle	19.8	520	82	1990	6/90	RO,CO,WO	Hazleton
3	Forbes	6.1	830	65	1989	7/89	RO,RM	Dekalb
4	Moshannon	40.5	695	78	1989	8/89	BC,RO,RM	Cookport
5	Susquehannock	29.9	680	84	1990	7/90	BC,BE,RM	Clymer
6	Tioga	23.8	640	90	1989	4/89	SM,BC,BE	Lordstown
				SECONDARY SITES				
7	Moshannon	19.0	695	82	1989	8/89	RO,RM	Hazleton-Clymer
8	Moshannon	12.1	600	78	1989	9/89	RM,RO	Hazleton-Clymer
9	Moshannon	8.1	620	80	1989	9/89	RO,RM	Hazleton-Clymer
10	Moshannon	8.2	525	88	1990	7/90	RO,WO	Berks
11	Moshannon	21.9	680	85	1988	5/89	RO,RM	Cookport
12	Tioga	6.9	720	90	1990	9/90	RO,WO	Clymer
13	Tioga	12.5	730	80	1987	5/88	RO,RM	Oquaga
14	Elk	15.8	520	68	1989	8/89	RM,RO,WO	Wharton
15	Susquehannock	26.3	660	84	1989	5/90	BC,RM,SM	Leetonia
16	Tiadaghton	27.5	680	75	1989	5/90	RM,BE	Wurtsboro

Overstory Species Codes:

RO - Red Oak (*Quercus rubra* L.)
CO - Chestnut Oak (*Quercus prinus* L.)
SM - Sugar Maple (*Acer saccharum* Marsh.)
RM - Red Maple (*Acer rubrum* L.)
WO - White Oak (*Quercus alba* L.)
BC - Black Cherry (*Prunus serotina* Ehrh.)
BE - American Beech (*Fagus grandifolia* Ehrh.)

Soil samples from all horizons to a depth of 30 cm were collected from a random sub-sample of 4 of the 9 vegetation plots. Soils were analyzed by horizon, and soil analysis was performed at The Pennsylvania State University and included pH (glass electrode with 1:1 [w:v] H_2O), soil texture, CEC and base saturation (North Dakota State University 1988), organic matter, total N , and exchangeable Ca, Mg, K, Mn, and Al using a 0.01M $SrCl_2$ extraction (Joslin and Wolfe 1989). The latter analysis was performed in order to estimate the "plant available" fraction of these cations. Table 2 provides a summary of the mineral horizon soil conditions (15-30 cm depth) at each of the six primary sites.

Data Analysis

Differences in vegetation and soil parameters across treatments for each site were analyzed by ANOVA and mean separations were performed using Fisher's LSD test. Herbaceous cover was analyzed after the methods of Bannister (1966). Species richness comparisons were based on the mean number of species per plot within each treatment. Total species richness was measured as the sum of all species found within a treatment. Woody plant diversity was measured using the Shannon-Weiner Index (Magurran 1988). Herbaceous species diversity was not assessed because the Braun-Blanquet cover estimates employed in the study were not amenable to diversity measures (Magurran 1988). All significant differences are reported at the alpha ≤ 0.05 level. Regression and multiple regression analyses were used to determine relationships between plant composition and the soil parameters being studied.

Table 2. Soil characteristics (15-30 cm depth) of the six study sites.

SITE	pH[1]	C:N	%BS	CEC[2]	------ ppm[3] ------ Ca	Mg	K	Al	molar Ca:Al
1 Understory	4.13	44.3	7.2	6.4	2.0	0.3	3.1	9.7	0.14
Clearcut[4]	4.20	36.3	7.5	8.9	2.4	0.4	2.7	9.2	0.18
2 Understory	4.05	30.0	8.1	9.8	4.4	3.2	8.2	8.1	0.37
Clearcut	4.13	31.3	6.1	11.9	5.6	4.4	9.4	7.3	0.52
3 Understory	4.02	26.7	6.5	11.3	3.6	3.7	7.4	21.3	0.11
Clearcut	4.08	30.9	5.2	14.3	3.2	4.1	7.8	19.7	0.11
4 Understory	4.65	32.2	12.3	8.9	5.2	4.9	16.0	11.1	0.32
Clearcut	4.59	27.9	14.6	7.6	6.0	4.6	17.2	10.5	0.38
5 Understory	4.60	22.2	11.1	10.1	8.4	7.1	15.2	15.6	0.36
Clearcut	4.56	28.3	13.0	11.3	11.6	7.3	17.2	11.3	0.69
6 Understory	4.51	21.3	6.9	16.1	14.0	6.8	21.9	13.8	0.67
Clearcut	4.49	24.6	7.5	16.1	12.4	6.1	22.7	12.7	0.66

[1] pH in 1:1 (w:v) H_2O [2] CEC in cmol(+) kg^{-1}
[3] Using 0.01 M $SrCl_2$ extraction (Joslin and Wolfe 1989)
[4] Clearcut soil values refer to fenced clearcut sites

RESULTS

Pre-Clearcut Vegetation Versus Understory Vegetation

In most cases, the composition of the over- and understory on the pre-clearcut stands paralleled the 1992 sampling plots located adjacent to the existing clearcuts (Table 3). Based on this information, the assumption was made that the pre-harvest clearcut vegetation was similar to the adjacent uncut, unfenced plots before cutting. Nonetheless, caution is warranted in interpreting the results based on this assumption.

Fencing Impacts on Browse Damage

Based on the single year (1992) browse damage survey, the overall level of browse damage on woody species was significantly lower within fenced clearcut treatments than on either the unfenced or non-clearcut, unfenced treatments. Species-specific browse damage, however, exhibited substantial variation across sites and treatments. Northern red oak (*Quercus rubra* L.) and sweet birch (*Betula lenta* L.) were the only species that consistently had significantly higher percentages of browsed stems in unfenced treatments (61-82% and 45-100% for red oak and sweet birch respectively), compared to fenced treatments (16-43% and 6-38%). Browse on pin cherry (*Prunus pensylvanicum* L.) and black cherry (*Prunus serotina* Ehrh.) was not significantly different on fenced versus unfenced treatments indicating deer penetration through the fence or other mammal browsing inside the fence. Red maple (*Acer rubrum* L.) browse damage was highly variable ranging from 0-100% on both fenced and unfenced treatments across the six study sites. There were no significant correlations between species-specific stem densities and the proportion of those stems browsed.

Table 3. Comparison of pre-clearcut regeneration information[1] versus 1992 understory vegetation survey.

	SITE 1		SITE 2		SITE 3	
Seedlings/ha	pre-cut	1992 survey	pre-cut	1992 survey	pre-cut	1992 survey
Hardwood seedlings	11600	18890	10280	14850	<3000	1810
Oak seedlings	3700	3890	7410	8100	<500	100
Vaccinium cover	67%	82%	37%	49%	sparse	0%
Kalmia cover	40%	46%	53%	44%	<5%	5%
grass cover	3%	1%	sparse	2%	<5%	5%
fern cover	sparse	1%	sparse	0%	70%	95%
	SITE 4		SITE 5		SITE 6	
Seedlings/ha	pre-cut	1992 survey	pre-cut	1992 survey	pre-cut	1992 survey
Hardwood seedlings	25700	18500	29100	23000	140000	195000
Oak seedlings	2500	3200	0	0	0	0
Prunus serotina L.	15000	7500	12000	8530	24000	29100
Vaccinium cover	15%	23%	sparse	0%	sparse	0%
Kalmia cover	0%	0%	sparse	0%	0%	0%
grass cover	10%	12%	>15%	20%	0%	0%
fern cover	65%	81%	>20%	19%	0%	1%

[1] Based on Bureau of Forestry records. All data presented are based on mean densities or mean % cover on vegetation plots except for values with < or > signs which indicate maximum or minimum estimates.

Woody Stem Densities and Importance Values

Total woody stem densities varied across sites and treatments (Table 4). Stem densities on fenced treatments differed significantly from unfenced treatments on sites 2 and 6; the former with lower density on the unfenced treatment and the latter with higher density on the unfenced treatment. Woody stem densities on the 10 supplemental sites ranged from $41x10^3$ ha^{-1} to $351x10^3$ ha^{-1} in the adjacent forest understory and from $23x10^3$ ha^{-1} to $369x10^3$ ha^{-1} on fenced clearcuts. Based on pooled data from the 6 primary and 10 supplemental sites, understory stem densities were a poor, nonsignificant predictor of stem densities on fenced clearcuts (r^2 = 38.2 %). Table 4 shows calculated importance values (IV = relative density + relative frequency) for all woody species encountered in the sampling on the six primary sites. Site specific comparisons across treatments show widespread similarity in IV's for most woody species, with some key exceptions. The IV's for red maple (*Acer rubrum* L.) in the adjacent understory were significantly greater than those in the clearcut treatment for sites 3, 4, and 6. The same pattern was observed for American beech (*Fagus grandifolia* Ehrh.) on site 5. IV's for pin cherry were significantly higher on unfenced versus fenced treatments on sites 3, 5, and 6 while sweet birch showed the reverse trend on those same sites. The IV's for laurel (*Kalmia latifolia* L.) and *Vaccinium* spp. varied little; however, on site 2, laurel showed a decrease in IV on the clearcut treatments and on site 4, exhibited an increase in IV on the clearcut treatments.

Table 4. Comparison of importance values[1] (IV) for woody vegetation by treatment. N (not cut, unfenced), F (fenced clearcut), U (unfenced clearcut).

SITE	1			2			3			4			5			6		
	N	F	U	N	F	U	N[2]	F	U	N	F	U	N	F	U	N	F	U
TREES																		
Quercus alba L.	2	-	-	5a	2a	5a	-	-	-	3a	4a	3a	-	-	-	-	-	-
Quercus prinus L.	16a	10a	13a	21a	19a	17a	-	-	-	-	-	-	-	-	-	-	-	-
Quercus rubra L.	12a	9a	6a	5a	5a	3a	*23*	-	-	25a	22a	15a	-	-	-	-	-	-
Quercus velutina Lam.	-	-	-	-	2	-	-	-	-	-	2	-	-	-	-	-	-	-
Acer rubrum L.	22a	19a	17a	35a	24a	39a	*115a*	14b	16b	99a	57b	77b	44a	32b	19b	55a	30b	13c
Acer saccharum Marsh.	-	-	-	-	-	-	-	-	-	-	-	-	5a	4a	7a	-	-	-
Fagus grandifolia Ehrh.	-	-	-	-	-	-	-	-	-	-	-	-	97a	23b	26b	15a	24a	18a
Sassafras albidum (Nutt.) Nees	-	13a	14a	-	-	-	*40a*	82a	84a	-	2a	2a	-	-	-	-	-	-
Liriodendron tulipifera L.	-	-	-	-	-	-	-	10a	5a	-	-	-	-	-	-	-	-	-
Acer pensylvanicum L.	-	-	-	-	-	-	-	-	4	-	-	-	-	8a	4a	12a	31a	29a
Prunus serotina Ehrh.	-	-	-	-	-	-	-	-	-	24	32a	29a	-	19a	8a	34a	20a	25a
Prunus pensylvanica L.f.	-	-	-	-	7	-	*23a*	41a	58b	-	7	-	19a	66b	103c	68a	44b	82a
Betula lenta L.	-	-	-	-	-	-	-	28a	4b	-	-	-	38a	40a	20b	14a	45b	31a
Betula alleghaniensis Britton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
Pinus strobus L.	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Tsuga canadensis (L.) Carr.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-
Populus tremuloides Michx.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-
SHRUBS																		
Kalmia latifolia L.	21a	24a	23a	30a	14b	11b	-	19a	21a	-	-	-	-	-	-	-	-	-
Vaccinium spp.	107a	107a	107a	91a	111a	102a	-	-	5	14a	28b	33b	-	-	-	-	-	-
Amelanchier spp.	-	-	-	3	-	3	-	6	4	19a	23a	28a	-	3a	4a	-	-	-
Myrica asplenifolia L.	-	-	4	-	-	5	-	-	-	-	2	-	-	-	-	-	-	-
Hamamelis virginiana L.	20a	19a	16a	12a	15a	13a	-	3	-	-	2a	2a	-	5a	2a	-	-	-
Viburnum spp.	-	-	-	-	-	-	-	-	-	17a	20a	12a	-	-	-	-	-	-
Hardwood seedling density[3]	19a	14a	6a	22a	23a	32a	*1*	4a	3a	78a	52a	59a	23a	78b	99b	195a	41b	71b
Total stem density[3]	29a	22a	7b	32a	27a	38a	*1*	5a	4a	87a	78a	84a	23a	79b	100b	196a	41b	71b

Different letters denote significant differences ($P \leq 0.05$) in means within each site using Fisher's LSD test.

[1] IV = (relative density + relative frequency)

[2] IV values for the uncut forest are of limited value due to the extremely low stem density

[3] (1000 / ha)

Fencing Impacts on Seedling Heights

Figure 1 illustrates differences in mean heights of the dominant (tallest), non-stump sprout origin, tree seedling stems of each tree species found on fenced versus unfenced treatments. On sites 1 and 3 the dominant seedling heights were greater in the fenced than in the unfenced treatments. The relatively tall dominant seedling heights on site 4 reflected the dominance of black cherry growth at the site. However, if black cherry was not included in the mean determinations, there were still no significant differences in dominant seedling heights between the fenced and unfenced treatments. Overall growth performance of hardwood seedlings appeared to be poor relative to that of other published height data. On the oak forest sites, northern red oak seedling height was also found to be positively and significantly related to covers of *Vaccinium* spp. ($r^2 = 32.4\%$).

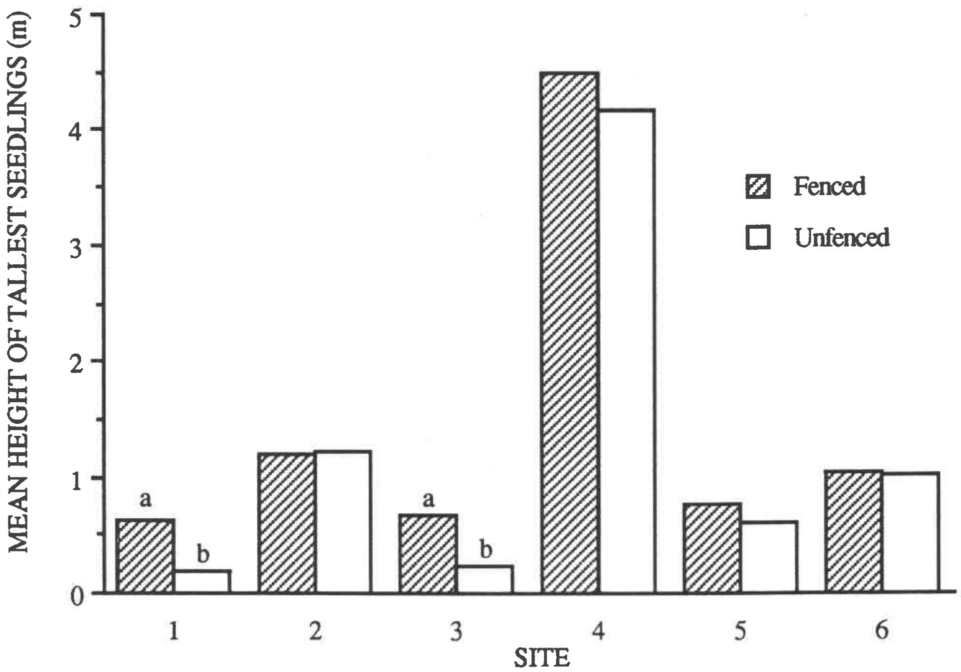

Figure 1. Mean height of the dominant commercial tree seedlings in fenced vs. unfenced clearcuts. Letters denote significant differences ($P \leq 0.05$).

Fencing Impacts on Herbaceous Species

Table 5 provides a condensed summary of herbaceous species cover on the six primary study sites. Ground covers of fern, grass and sedge were found across all sites and treatments. Fern cover was generally higher on unfenced versus fenced treatments, although significant differences were found only on sites 3 and 6. Site 6 also had significantly greater fern cover on the clearcut treatments compared to the adjacent understory. Grass and sedge covers on clearcut treatments were generally higher than in the understory. The only significant difference in grass and sedge cover on clearcut treatments was observed on site 5. Cover of ***Rubus*** on unfenced treatments was significantly lower than the fenced treatment on sites 3 and 5. The remaining covers of herbaceous species were highly variable across sites and treatments, yet the herbaceous cover at each site was generally dominated by a single herbaceous species.

Fencing Impacts on Species Richness and Diversity

Total and woody species richness comparisons are summarized in Table 6. Total species richness ranged from 9 to 26 species across sites and treatments. Total species richness on the 10 supplemental sites ranged from 9 to 29 species. Comparisons of the mean number of species per plot between fenced and unfenced clearcut treatments showed no significant differences in either total or woody species richness. Sites 4 and 5 did have significantly lower total species richness in the understory compared to the clearcut treatments. Regression analysis was performed to predict species richness using herbaceous covers on fenced clearcuts (pooled from the six primary and 10 supplemental study sites). Significant negative relationships were found between total species richness and grass and sedge cover ($r^2 = 31.6\%$) and fern cover ($r^2 = 34.4\%$), although the variation explained by these variables is modest.

Table 5. Percent cover[1] of dominant herbaceous species.
N (not cut, unfenced), F (fenced clearcut), U (unfenced clearcut).

SITE	1			2			3			4			5			6		
	N	F	U	N	F	U	N	F	U	N	F	U	N	F	U	N	F	U
Ferns[2]	0.5	4.0	1.0	0.0	1.7	0.0	95.1	74.2	91.5	81.0	47.7	73.0	18.9	18.7	28.1	5.0	5.8	29.0
Grass/Sedge	0.7	1.6	0.0	1.7	3.3	1.0	5.1	16.3	14.5	12.1	48.6	53.3	20.0	27.6	14.1	2.5	8.1	14.1
Rubus	1.0	0.0	0.0	0.0	7.0	0.4	0.0	31.4	16.3	3.1	12.3	12.1	2.0	27.6	14.5	4.0	19.7	17.2
Other Herbs	12.0	64.9	18.6	16.3	19.9	53.6	51.7	16.3	57.3	27.5	44.3	51.7	4.2	9.1	5.3	3.7	9.6	9.7

[1] % covers listed have been back transformed from Domin values (Bannister 1966).
[2] predominantly hay-scented fern (*Dennstaedtia punctilobula* [Michx.] Moore)

Table 6. Species richness[1] comparisons for three treatments at each site.

SITE	1	2	3	4	5	6
total species richness						
Not cut (adjacent forest understory)	9	14	16	19	9	12
Fenced Clearcut	13	16	19	26	14	15
Unfenced Clearcut	11	13	18	26	18	17
woody species richness						
Not Cut (adjacent forest understory)	7	8	4	7	4	7
Fenced Clearcut	7	9	8	12	8	6
Unfenced Clearcut	8	10	9	9	10	7

[1] Species numbers represent total number of species tallied at each site

Computed Shannon-Weiner diversity index values (H') are listed in Table 7. Comparison of diversity indices showed no significant difference in diversity between fenced and unfenced treatments on five of the six primary sites. Only site 5 had a significantly lower H' value on the unfenced treatment. This low H' value can largely be attributed to the influence of a high proportion of pin cherry seedlings on the unfenced site.

Table 7. Shannon diversity values (H') for treatments on all sites.

SITE	1	2	3	4	5	6
Not Cut (adjacent forest understory)	0.52a[1]	0.96a	0.95a	0.89a	0.98a	1.15a
Fenced Clearcut	0.55a	0.47b	1.20a	1.67b	1.54b	1.40a
Unfenced Clearcut	0.41a	0.68b	1.18a	1.26b	0.68a	1.24a

[1]Letters denote significant differences ($P \leq 0.05$) in means within each site.

Potential Impacts of Soil Parameters

To test the potential direct and/or indirect influence of soil parameters on species richness, soil and species richness data from the 10 supplemental sites were added to the six primary study site data. Only data on fenced clearcuts were used in this analysis due to the lack of unfenced treatments on the supplemental sites. Regression and multiple regression analysis indicate that species richness on fenced clearcuts covaried with some of the soil parameters investigated. As shown in Figure 2, a significant positive relationship was found between species richness and exchangeable Ca levels in the subsoil ($r^2 = 61.0\%$). A significant positive relationship was also found between species richness and organic horizon pH. ($r^2 = 22.4\%$). Significant negative relationships between species richness and exchangeable Al ($r^2 = 33.4\%$) and the molar Ca:Al ratio in the mineral soil horizons ($r^2 = 35.1\%$)

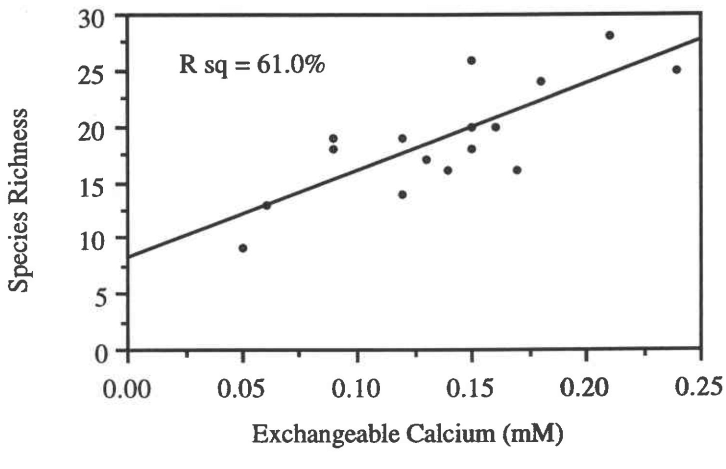

Figure 2. Regression between species richness on fenced clearcuts and exchangeable Ca in the mineral subsoil (15-30 cm depth).

DISCUSSION

No accurate data were available as to deer densities at the different study sites during the study period. Thus, comparisons with previous deer exclusion and enclosure studies must take into account potential differences in deer browsing pressure as well as differences in foraging patterns. Historically, most exclusion studies have employed woven wire mesh fencing. It is likely that the five- and six-strand electric exclusion fencing present on the study sites discussed here provided less protection than woven mesh fencing. George and others (1991) reported increased deer penetrations through electric fencing after two years of service. The results of the present study also are based on a single sampling period (1992); and the results must be interpreted within that limited framework. These caveats notwithstanding, comparisons of the results of the present study with woven mesh studies can provide useful information in ascertaining the effectiveness of the electric fencing.

Overall, electric exclusion fencing treatments provided limited improvement in promoting increased stocking of desirable hardwood species, enhancement of total species richness or woody species diversity compared to non-fenced treatments. Based on the assumption that the vegetation data collected on adjacent, uncut stands in the current study is representative of the pre-clearcut vegetation on the site, the composition of clearcut vegetation was strongly influenced by the composition of species prior to clearcutting. This result implies that the influence of fencing must be assessed within the framework of vegetation cover prior to harvest. Similar patterns in post-clearcut vegetation composition were noted by Hughes and Fahey (1991). In addition, the results of the current study showed few differences in shrub densities and IV's between understory, fenced and unfenced treatments at each site similar to results presented by Martin and Hornbeck (1989). Few significant differences in absolute woody stem densities were found between fenced and unfenced treatments in this study and by other investigators (Jordan 1967; Marquis 1981). The present study also found significant browse damage and IV declines for sweet birch on unfenced versus fenced treatments as reported by Marquis (1981) and Shafer and others (1961). Other tree species densities and IV's showed variable patterns across treatments and sites. Lack of consistent increases in fern cover in unfenced versus fenced treatments in the current study was also reported by Trumbull and others (1989). Also, paralleling their results, we found a general increase in grass cover following clearcutting on half the study sites.

Contrary to previous studies that found pin cherry nearly eliminated by browse in unfenced clearcut treatments (Marquis 1981), the current study found no differences in mean seedling height or dominant seedling height for pin cherry between fenced and unfenced treatments. In addition, the IV of pin cherry significantly increased in unfenced clearcut treatments on 3 of the 5 sites where it was present. We also found no significant increases in beech or striped maple density, height or IV on unfenced plots as reported by Marquis (1981). These results indicate first, that browse impacts can be highly site specific and second, that vegetation within electric exclusion fencing did not differ as dramatically from unfenced treatments as reported in previous woven mesh fencing studies. The latter point is further reinforced by comparing our results with the deer enclosure study of Tilghman (1989). Tilghman reported that the mean heights of the tallest woody stems on clearcuts were significantly shorter under higher deer densities. While we do not have accurate deer density estimates in the current study, our results show significantly lower heights for dominant woody stems on only 2 of 6 unfenced plots. Thus, despite increased browse pressure on unfenced seedlings, on 4 of the 6 study sites we investigated, some stems were able to reach heights comparable to those within the exclusion fencing.

The present study sites were from 2 to 4 years old and the low woody species richness and diversities observed could be considered an artifact of clearcut age (Gove and others 1992). The improbable recruitment of new seedlings into the clearcuts, however, suggests that woody species richness will show few gains in the short-term. It is difficult to make meaningful comparisons in species richness and diversity across geographical regions which support very different assemblages of species and where different sampling designs have been employed. Nonetheless, the range in woody species richness (4-12 species) and the range in Shannon diversity values reported here (0.41-1.67), although low, fall in the range of values reported by other authors (Locasio and others 1991; Niese and Strong 1992; Tilghman 1989). In terms of herbaceous species richness, the current study showed few differences on fenced versus unfenced clearcuts and only modest gains in numbers of herbaceous species on 2 to 4 year old clearcuts when compared with the understory. This is in contrast to Stransky and others (1986) who reported a greater than doubling of herbaceous species following the first year after clearcutting of a loblolly pine-hardwood forest and a peak in species richness after 3 years.

Regression analysis of soil variables and species richness on clearcuts in this study provides some preliminary evidence that soil acidity factors may be directly or indirectly influencing plant species growth and composition. Similar to the present study, studies on the North Carolina Piedmont have noted a strong correlation between calcium and magnesium levels in soil and species richness (Palmer 1990; Peet and Christensen 1980). Sharpe and others (1991) also reported increased diversity following liming in a forest understory in western Pennsylvania. In the current study, the low pH's and the low base saturations observed point to potential increased solubility of Al which might play a role in inhibiting cation availability and uptake and ultimately reducing root and shoot growth. In fact, we found significant negative relationships between species richness and both exchangeable Al in the subsoil and the molar Ca:Al ratio in the subsoil. The potential negative impacts of high Al and low Ca levels in subsoils on root uptake, root growth, and overall vigor have been addressed by Tomlinson and Tomlinson (1990). The combined impact of the predisposing stress of extremely acidic soils and the contributing stress of herbivory by deer may be too severe for regenerative success on some sites and indicate that soil evaluation should be considered as an integral component when formulating forest management strategies on extremely acidic forest soils.

SUMMARY

The influence of electric deer exclusion fencing on vegetation patterns, species richness, and woody species diversity were investigated on 16 clearcut sites across Pennsylvania. Many site specific and interacting factors are likely to have influenced hardwood regeneration success and the growth and development of plant communities on these sites. The results of this study indicated that hardwood seedling density, species richness, and woody species diversity were not enhanced by the use of electric deer fencing on the hardwood clearcuts studied. Some additional conclusions can be drawn from the current study.

1. Pre-harvest (understory) ground covers of both woody and herbaceous species appeared to have had an impact on species composition in clearcuts regardless of the presence of electric exclusion fencing as evidenced by a high degree of overlap between pre- and post-harvest plant communities. In addition, comparisons of the importance values of woody species (especially shrubs) across fenced versus unfenced treatments on all sites showed few significant differences.

2. Electric deer fencing did reduce browse damage but did not promote increased species richness on clearcuts. No significant differences in total or woody species richness were observed across treatments. Computed Shannon diversity values for woody species on fenced, versus unfenced, clearcuts were significantly higher on only 1 of 6 fenced clearcut treatments.

3. On sites with extremely acidic soils, soil acidity/nutrient factors may be influencing both hardwood regeneration success and the overall composition of plant communities. Because of the variable effectiveness of electric exclusion fencing, it was difficult in this study to separate the effects of deer browse pressure from acidity/nutrient problems. It was clear that use of electric exclusion fencing did not guarantee acceptable hardwood regeneration in terms of relative density and frequency of seedlings or diversity of woody stems. Furthermore, significant positive relationships were found between species richness and soil Ca levels, organic horizon pH, and Ca:Al ratios in the mineral subsoil. A significant negative relationship was found between species richness and exchangeable Al levels in the subsoil.

4. The combined impact of the predisposing stress of extremely acidic soil and the contributing stress of herbivory by mammals (primarily deer), may be too severe for regeneration success on some sites. This indicates that soil chemical evaluation, and possibly remediation through liming and fertilization, should be added to the management equation when formulating forest management strategies on sites with extremely acidic soils, even when deer exclusion fencing is to be utilized.

LITERATURE CITED

Auchmoody, L.R. 1982. Response of young black cherry stands to fertilization. Can. J. For. Res. 12:319-325.

Bannister, P. 1966. The use of subjective estimaes of cover-abundance as the basis for ordination. J. Ecol. 54:665-674.

Brenneman, R. 1982. Electric fencing to prevent deer browsing on hardwood clearcuts. J. For. 80(10):660-661.

Drew, A.P. 1988. Interference of black cherry by ground flora of the Allegheny uplands. Can. J. For. Res. 18:652-656.

Frontz, L. 1930. Deer damage to forest trees in Pennsylvania. Pa. Dept. For. and Waters Res. Circ. 3.

George, D.W., T.W. Bowersox, and L.H. McCormick. 1991. Effectiveness of electric fences to protect planted seedlings in Pennsylvania. 8th Central Hardwoods Forest Conference, pp. 395-401.

Gove, J.H, W. Martin, G.P. Patil, D.S. Solomon, and J.W. Hornbeck. 1992. Plant species diversity on even-aged harvests at the Hubbard Brook experimental forest. Can. J. For. Res. 22:1800-1806.

Grisez, T.J. 1959. The Hickory Run deer exclosure. U.S. For. Serv. Res. Note NE-87, 4 pp.

Hansen, A.J., T.A. Spies, F.J. Swanson, and J.L. Ohmann. 1991. Conserving biodiversity in managed forests. BioScience 41(6):382-392.

Horsley, S.B. 1977. Allelopathic inhibition of black cherry by fern, grass, goldenrod, and aster. Can. J. For. Res. 7:205-216.

Horsley, S.B. and D.A. Marquis. 1983. Interference by weeds and deer with Allegheny hardwood reproduction. Can. J. For. Res. 13: 61-69.

Hughes, J.W. and T.J. Fahey. 1991. Colonization dynamics of herbs and shrubs in a disturbed northern hardwood forest. J. Ecol. 79:605-616.

Jordan, J.S. 1967. Deer browsing in northern hardwoods after clearcutting: effect on height, density, and stocking of commercial species. U.S. For. Serv. Res. Pap. NE-57, 15 pp.

Joslin, J.D. and M.H. Wolfe. 1989. Aluminum effects on northern red oak growth in six forest soil horizons. Soil Sci. Soc. Am. J. 53: 274-281.

Kochel, J. and R. Brenneman. 1987. Use and effectiveness of electric fencing in protecting clearcuts from deer browsing. Proc, Deer, forestry, and agriculture: interactions and strategies for management, June 15-17, pp. 118-123.

Kolb, T.E.,T.W. Bowersox, and L.H. McCormick. 1990. Influences of light intensity on weed-induced stresses of tree seedlings. Can. J. For. Res. 20: 503-507.

Locasio, C.G., B.G. Lockaby, J.P. Caulfield, M. B. Edwards, and M.K. Causey. 1991. Mechanical site preparation effects understory plant diversity in the Piedmont of the southern USA.

Magurran, A.E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, NJ, 179 pp.

Marquis, D.A. 1981. Effect of deer browsing on timber production in Allegheny hardwood forests of northwestern Pennsylvania. U.S. For. Serv. Res. Pap. NE-475, 10 pp.

Marquis, D.A. and T.J. Grisez. 1978. The effect of deer exclosures on the recovery of vegetation in failed clearcuts on the Allegheny Plateau. U.S. For. Serv. Res. Note NE-270, 5 pp.

Marquis, D.A. and R. Brenneman. 1981. The impact of deer on forest vegetation in Pennsylvania. U.S. For. Serv. Res. Gen. Tech. Rep. NE-65, 7 pp.

Marquis, D.A., P.L. Eckert, and B.A. Roach. 1976. Acorn weevils, rodents, and deer all contribute to oak-regeneration difficulties in Pennsylvania. U.S. For. Serv. Res. Pap. NE-356, 5 pp.

Martin, C.W. and J.W. Hornbeck. 1989. Revegetation after strip cutting and block clearcutting in northern hardwoods: a 10-year history. U.S. For. Serv. Res. Pap. NE-625, 17 pp.

Niese, J.N. and T.F. Strong. 1992. Economic and tree diversity trade-offs in managed northern hardwoods. Can. J. For. Res. 22:1807-1813.

North Dakota State University. 1988. Recommended chemical soil test procedures for the north-central region. North Dakota Ag. Exp. Sta., NDSU, Bulletin No. 499 (revised). 37 pp.

Palmer, M.W. 1990. Spatial scale and patterns of species-environment relationships in hardwood forests of the North Carolina Piedmont. Coenoses 5:89-96.

Peet, R.K. and N.L. Christensen. 1980. Hardwood forest vegetation of the North Carolina Piedmont. Veršff. Geobot. Inst. Eidg. Tech. Hochsch. Stift. RŸbel, ZŸr. 69:14-39.

Shafer, E.L., T.J. Grisez, and E. Sowa. 1961. Results of deer enclosure studies in northeastern Pennsylvania. U.S. For. Serv. Res. Note NE-121, 7 pp.

Sharpe, W.E., B.R. Swistock, and D.R. DeWalle. 1991. Response of an Appalachian mountain forest soil, soil water and associated herbaceous vegetation to liming. 8th Central Hardwoods Forest Conference, pp. 489-499.

Stransky, J.J., J.C. Huntley, and W.J. Risner. 1986. Net community production dynamics in the herb-stratum of a loblolly pine-hardwood forest: effects of clearcutting and site preparation. U.S. For. Serv. Gen. Tech. Rep. SO-61, 11 pp.

Tilghman, N.G. 1989: Impacts of white-tailed deer on forest regeneration in northwestern Pennsylvania. J. Wildl. Manage. 53(3):524-532.

Tomlinson, G.H. and F.L. Tomlinson. 1990. Effects of Acid Deposition on the Forests of Europe and North America. CRC Press, Boca Raton, Fla., 281 pp.

Trumbull, V.L., E.J. Zielinski, and E.C. Aharrah. 1989. The impact of deer browsing on the Allegheny forest type. N. J. Appl. For. 6:162-165.

Tryon, E.H., and K.L. Carmean. 1958. Regeneration under oak stands. W. Va. Univ. Ag. Exp. Sta. Bull. 424T. 22 pp.