RESEARCH ARTICLE

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Impact and Control of *Vinca minor* L. in an Illinois Forest Preserve (USA)

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ABSTRACT: *Vinca minor* L., a woody evergreen vine of Eurasian origin, is a sporadic invader of forest understories in Illinois. We studied understory composition in a mature southwestern Illinois *Quercus–Carya* forest to evaluate the effect of *V. minor* invasion and test the efficacy of a combined cutting and herbicide (glyphosate) control treatment. *Vinca minor* presence did not reduce species richness, evenness, or combined diversity compared to the reference area in either spring or summer. One to two years after treatment, *V. minor* was still prominent in the understory at its original location. In the treated area, *V. minor* frequency was approximately 50% less than in the untreated invaded area. The treated area had a higher proportion of nonvegetated surface and higher species diversity during summer. Understory species composition differed among the invaded, reference, and treated areas. Understory composition in the treated area more closely resembled the reference area than the invaded area. This pattern was present with and without the inclusion of *V. minor* in the data set. Use of a combined cutting/herbicide treatment is moderately effective, and an aggressive follow-up program will be required to achieve control of *Vinca minor*.

Index terms: exotic species, invasive species control, understory composition, *Vinca minor*

INTRODUCTION

Vinca minor L. (Apocynaceae), commonly called vinca, is a trailing woody evergreen vine of southern Europe and Asia that has been widely used as an ornamental groundcover in the United States since colonial times (Wyman 1977). Little has been published about the natural history of vinca, but one of its prominent horticultural characteristics is that it is a good competitor in shade (Hottes 1947). The species produces blue flowers in spring, probably dispersing its naked seeds in summer. Although vegetative reproduction appears to dominate, its tendency to escape cultivation, presumably as seed, was recognized at least 40 years ago (Wyman 1956). In west-central Illinois, near St. Louis, Missouri, the species often escapes to woodlots adjacent to residential dwellings (K. Schulz and C. Thelen, pers. obs.). Our field observations of vinca and the documented history of its escape in the eastern United States (Wyman 1977) indicate that the vine could become a significant pest in the Midwest. The fragmented and heavily modified forests of the region are particularly susceptible to invasion (Hobbs and Humphries 1995). We present a case study documenting the effects of vinca invasion in a mature oak-hickory forest in southwestern Illinois, and report the results of a combined cutting and herbicide control technique.

This study was designed to address three concerns. The first concern was to evaluate the efficacy of combined late season top-cutting and herbicide application as a control measure. We were interested in determining if vinca would be completely eradicated by this approach, or if a potential founder population would remain. The second concern was to evaluate the effect of vinca on forest understory composition and diversity. Although vinca is plainly undesirable because it is an exotic species, there is no published quantitative evidence that vinca invasion changes plant community characteristics, or that the spring and summer flora are equally affected. The third concern was to assess how closely the treated community resembled the reference community. Treatment could leave large expanses of open habitat for other exotics. If residual native vegetation was of low species richness and/or cover, or was very different in composition from the natural understory, restoration might be required.

METHODS AND MATERIALS

Study Site

Knobeloch Woods Nature Preserve (14.4 ha; T 1S, R 7W, section 4) is about 32 km southeast of St. Louis, Missouri, in St. Clair County, Illinois. It features numer-

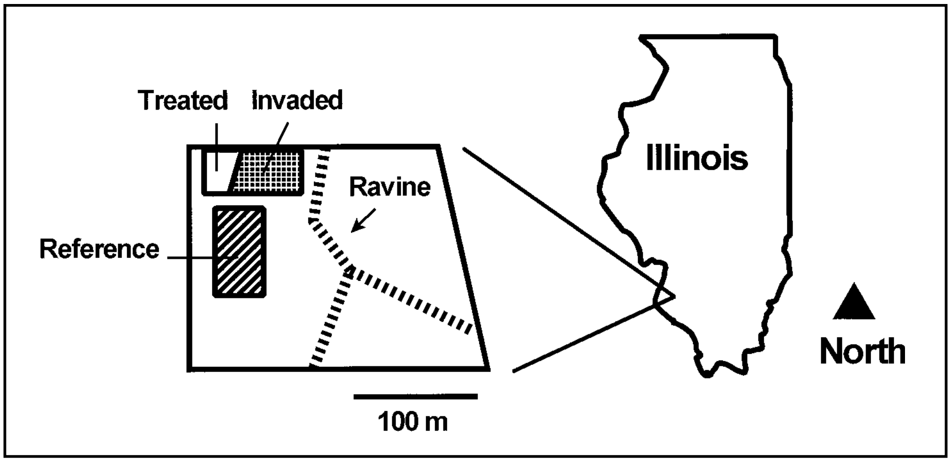

Figure 1. Proximity map and study area layout in Knobeloch Woods Nature Preserve, St. Clair County, Illinois.

ous large-sized hardwoods (predominantly *Quercus alba* L., *Carya cordiformis* [Wang.] K. Koch, *C. tomentosa* Nutt., and *C. ovata* [Mill.] K. Koch), many greater than 60 cm dbh, and there is minimal evidence of selective cutting (mean tree basal area is 29.4 m^2 ha^{-1}; K. Schulz and C. Thelen, unpubl. data). The site has a prominent and diverse herb layer, with a particularly showy display of spring ephemerals. In 1993 *Vinca minor* occupied about 1.2 ha at the northern end of the site, forming a solid mat that was rapidly advancing southward. Before 1993 Illinois Department of Natural Resources personnel unsuccessfully attempted to eradicate vinca using a late-fall foliar spraying treatment with glyphosate and other unidentified herbicides (detailed records are not available).

Knobeloch Woods is situated on a dissected upland in a largely agricultural landscape. Soils are of the Fayette Series (6–12% slopes), deep mixed mesic Typic Hapluldalfs, which are moderately acid (pH 5.1–6.0) silt loams of aeolian origin with substantial water-retaining capacity (0.20–0.22 cm water cm^{-1}) (Wallace 1978). The regional climate is temperate continental averaging 96.3 cm annual rainfall. Average midwinter (January) minimum temperature is -5.6° C, and average midsummer (July) maximum temperature is 32.8° C (Wallace 1978). The study site is in the Southern Till Plain Natural Division of Illinois (Schwegman 1974).

In late autumn (ca. October) 1993, Illinois Department of Natural Resources personnel attempted to kill about 700 m^2 of vinca in the northwest corner of the forest. At the time of treatment all native herbaceous vegetation had senesced and woody species were becoming dormant. Vinca stems were first cut at the base with a manual weed cutter and then sprayed with 5% glyphosate herbicide (Roundup®, Monsanto Company, St. Louis).

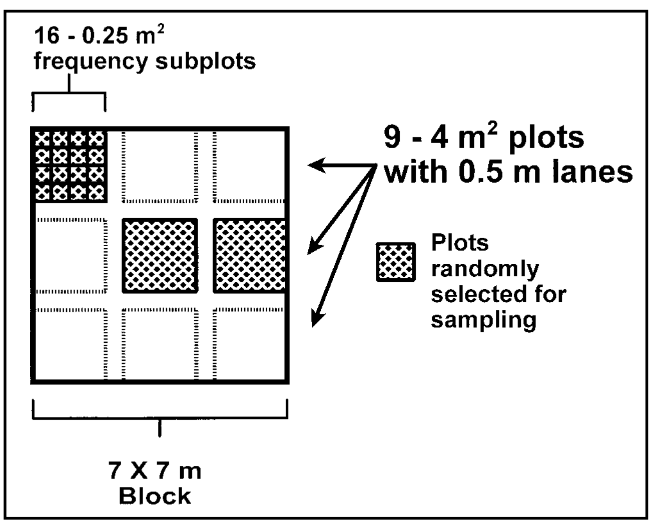

Figure 2. Block and plot layout used in sampling. Three 4-m² (2-m x 2-m) plots were taken at random from each 7-m x 7-m block. Species abundance in each plot was expressed as the frequency of occurrence in 16, 0.25-m² (0.5-m x 0.5-m) plots. Nonvegetated surface was assessed as the percent of 16 unoccupied 10-m x 10-cm plots arrayed at 0.5-m intervals around each 4-m² plot.

Sampling Regime

In 1994 the 14.4-ha stand was divided into four sections (Figure 1). The effects of vinca invasion ("invaded area") were investigated within a 60- to 75-m-wide band along the northern forest edge (ca. 1 ha), which was the area solidly occupied by vinca in summer 1994. Reference ("reference area") vegetation was sampled in a level, undisturbed area within the western third of the stand (ca. 1.6 ha), which was topographically identical to the invaded area. The treated area (ca. 0.07 ha) was in the northwest corner of the invaded region and abutted the reference area to the south. The zone in the south-central and southeast part of the stand encompassed a ravine system and was excluded from sampling. Sampling was conducted in summer (July through mid-August) 1994 and spring (May through June) 1995, 9–10 and 17–18 months, respectively, after herbicide treatment.

Vegetation was sampled using a hierarchically randomized design to make sure that (1) variation between plots was assessed at a uniform spatial scale in all areas (ANOVA error term is "blocks within study areas," see below), and (2) that the larger invaded and reference areas were sampled broadly enough to accurately represent the ground layer. A series of nonoverlapping 7-m x 7-m blocks were designated at random along transects within the invaded (2 transects, 20 m apart), treated (2 transects, 15 m apart), and reference (2 transects, 20 m apart) areas of the stand. The number of blocks differed between areas and seasons owing to the differing sizes of the areas and constraints on the time available for field work (see Table 3). Most blocks sampled in 1994 had to be relocated in 1995 because vandals removed markers (loss of permanent plots precluded a repeated measures statistical design). Each 7-m x 7-m block was divided into nine 4-m^2 (2-m x 2-m) plots, with a 0.5-m walkway between plots. Three of the plots were randomly selected from each block for vegetation sampling (Figure 2).

Species frequency was recorded within the 4-m^2 plots by tabulating the number of square 0.25-m^2 subplots in which all herbaceous and woody species < 1 m tall were rooted (maximum species frequency = 16 subplots). We used frequency (%F) within 4-m^2 plots as measure of abundance because field trials had shown that cover could not be precisely estimated in the morphologically diverse, tangled vegetation of the understory. Relative frequency (%RF) for each species in each 4-m^2 plot was calculated as the percentage of subplots occupied by the species over the total number of occupied subplots for all species. Species presence was also tabulated for each 4-m^2 plot. Woody species > 1.0 m tall were not sampled because they were not widespread in the understory. For each 4-m^2 plot, we estimated the amount of nonvegetated surface (predominantly exposed soil and leaf litter) as the proportion of 16 10-cm x 10-cm squares not shaded or occupied by vegetation < 1 m tall. Squares were arranged at the plot corners, with three squares at 0.5-m intervals along each side. Taxonomy follows Steyermark (1969).

Data Analysis

Shannon-Wiener (H′) combined richness/evenness species diversity indices were calculated for all plots (Ludwig and Reynolds 1988). The modified Hill's ratio (H_5) was calculated to assess evenness (Ludwig and Reynolds 1988). H_5 ranges from 0 to 1 as evenness increases. The Hill's ratio is preferred over Pielou's evenness index [H′ / ln(species richness)], because it is truly independent of species richness (Ludwig and Reynolds 1988). Comparisons of diversity measures for summer and spring were made using nested ANOVA with the effects STUDY AREA and BLOCK within STUDY AREA (Zar 1996). The significance of block effects was tested first using the statistic

$$F = MS_{\text{BLOCK within STUDY AREA}} / MS_{\text{residual}}$$

If block effects were significant ($P \leq 0.10$), differences between areas were subsequently tested with the statistic

$$F = MS_{\text{STUDY AREA}} / MS_{\text{BLOCK within STUDY AREA}}$$

If BLOCK within STUDY AREA was not significant, its sums of squares were pooled with residual error to increase statistical power (Carmer et al. 1969). Differences between areas were then tested with the statistic

$$F = MS_{\text{STUDY AREA}} / MS_{\text{residual}}$$

The Systat® Version 6.0 GLM routine was used to calculate ANOVAs (SPSS Inc. 1996). Post-hoc comparisons of different areas were conducted using the Bonferroni procedure. For vinca frequency and percent nonvegetated surface, ANOVA was conducted on ranked data to help equalize variances. A $P \leq 0.05$ significance level was used for all tests comparing study areas.

Vegetation comparisons were conducted separately for summer and spring data sets. Data were compiled in two ways within 4-m^2 plots, as relative frequency values or as species presence/absence. (Relative frequency data reveal differences in the abundance relations of species within the plots [i.e., community composition], whereas presence/absence data depict differences in species occurrence between plots.) To provide a graphical presentation of understory composition, Beals' (1984) "variance regression" modification of Bray-Curtis ordination was employed with the city block distance measure (D):

$$D = 1 - 2w / (a + b)$$

where:

w = is the sum of the minimum abundance values observed for all species observed in communities 1 and 2

a = the sum of abundance values for community 1

b = the sum of abundance values for community 2

The Bray-Curtis method performed better than local nonmetric multidimensional scaling and detrended correspondence analysis because it accurately represented variation in only two, as opposed to three, dimensions. (The second dimension derived by these procedures revealed no structure in the data.) All ordinations were conducted using PC-ORD (McCune 1993). Comparisons between study areas were made with the Multiple Response Permutation Procedure (MRPP, McCune 1993), using D as a dissimilarity measure and group size as a weighting factor (suggested by McCune 1993). MRPP was conducted on data aggregated to summarize blocks, as opposed to plots. For the purposes of the MRPP statistical test, this conservative approach eliminates any possibility that adjacent plots within blocks might not be completely independent. To eliminate the possibility that significant group separations would pivot on the presence of vinca, MRPP was also conducted on data sets from which vinca data were removed.

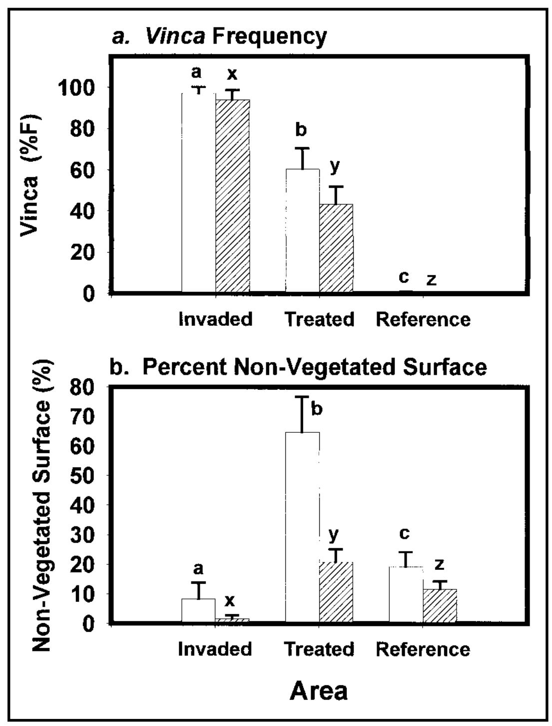

Figure 3. (a) Frequency of *Vinca minor* and (b) percent nonvegetated surface across study areas in summer 1994 and spring 1995. Values are means and SE calculated on 4-m^2 plots. Open bar is summer 1994; hatched bar is spring 1995. Bars followed by same letter are not different at the $P \leq 0.05$ level by Bonferroni adjustment (letters a, b, c are summer; x, y, z are spring). Seasons were tested separately.

RESULTS

Vinca Frequency and Nonvegetated Surface

In both summer and spring, vinca frequency was nearly 100% in the invaded area, significantly more than in the treated area (40–60%) or the reference area (ca. 1%) (Figure 3a). Cutting/herbicide treatment reduced but did not destroy the vinca population. Nonvegetated surface was negatively associated with the frequency of vinca: nonvegetated surface was <10% in the invaded area, 25–65% in the treated area, and < 20% in the reference area (Figure 3b). Nonvegetated surface decreased by two-thirds in the treated area from summer 1994 (65%) to spring 1995 (21%). In the reference area, nonvegetated surface decreased by less than half (19% to 12%) over the same period (Figure 3b).

Species Diversity

Average plant species richness varied from 6 to 14 species per 4-m^2 plot. Species diversity patterns varied by area and season (Table 1). In the reference and invaded areas, combined species diversity (H′) was higher in spring than summer, reflecting both greater evenness and species richness (Figure 4). In contrast, the treated area showed little seasonal change (Figure 4). In summer, combined species diversity and richness were similar in the invaded and reference areas, but were significantly higher in the treated area (Table 1, Figure 4). No significant differences in plant diversity measures were detected for the following spring (Table 1, Figure 4).

MRPP Analysis

Multiple response permutation procedures for both summer and spring showed highly significant differences in species composition (presence/absence) and relative frequency between the three areas—with and without vinca in the data set (Table 2).

Composition in Summer 1994

Ordination of summer species presence (Figure 5a) showed an overlap of reference and treated plots. Invaded plots were

Table 1. Nested analysis of variance results for summer 1994 and spring 1995 sampling periods in Knobeloch Woods, Illinois. Analyses were conducted on raw data, except vinca frequency and nonvegetated surface, which were calculated on ranks (see Methods). # denotes F-ratios calculated using pooled error terms (block + residual for the effect of study area, see Methods).

Effect	SS	df	MS	F	P
SUMMER VINCA FREQUENCY					
Study area	3109.389	2	1554.694	181.218#	< 0.001
Block in study area	112.111	9	12.457	1.748	0.132
Residual	171.000	24	7.125		
SUMMER NONVEGETATED SURFACE					
Study area	1881.140	2	940.570	10.715	0.004
Block in study area	790.010	9	87.779	1.935	0.095
Residual	1088.500	24	45.354		
SUMMER COMBINED DIVERSITY (H′)					
Study area	5.617	2	2.809	9.235	0.007
Block in study area	2.737	9	0.304	2.851	0.019
Residual	2.560	24	0.107		
SUMMER EVENNESS (H_5)					
Study area	0.122	2	0.061	3.651	0.069
Block in study area	0.151	9	0.017	1.960	0.091
Residual	0.205	24	0.009		
SUMMER RICHNESS					
Study area	300.306	2	150.153	16.740#	< 0.001
Block in study area	104.000	9	11.556	1.444	0.225
Residual	192.000	24	8.000		
SPRING VINCA FREQUENCY					
Study area	12648.400	2	6324.200	323.069#	< 0.001
Block in study area	330.405	16	20.650	1.080	0.406
Residual	726.667	38	19.123		
SPRING NONVEGETATED SURFACE					
Study area	4568.060	2	2284.030	14.599#	< 0.001
Block in study area	3290.330	16	205.646	1.521	0.144
Residual	5001.670	37	135.180		
SPRING COMBINED DIVERSITY (H′)					
Study area	0.346	2	0.173	1.155	0.340
Block in study area	2.398	16	0.150	4.922	< 0.001
Residual	1.157	38	0.030		
SPRING EVENNESS (H_5)					
Study area	0.002	2	0.001	0.400#	0.673
Block in study area	0.052	16	0.003	1.243	0.283
Residual	0.099	38	0.003		
SPRING RICHNESS					
Study area	60.067	2	30.033	1.781	0.200
Block in study area	269.863	16	16.866	3.535	0.001
Residual	181.333	38	4.772		

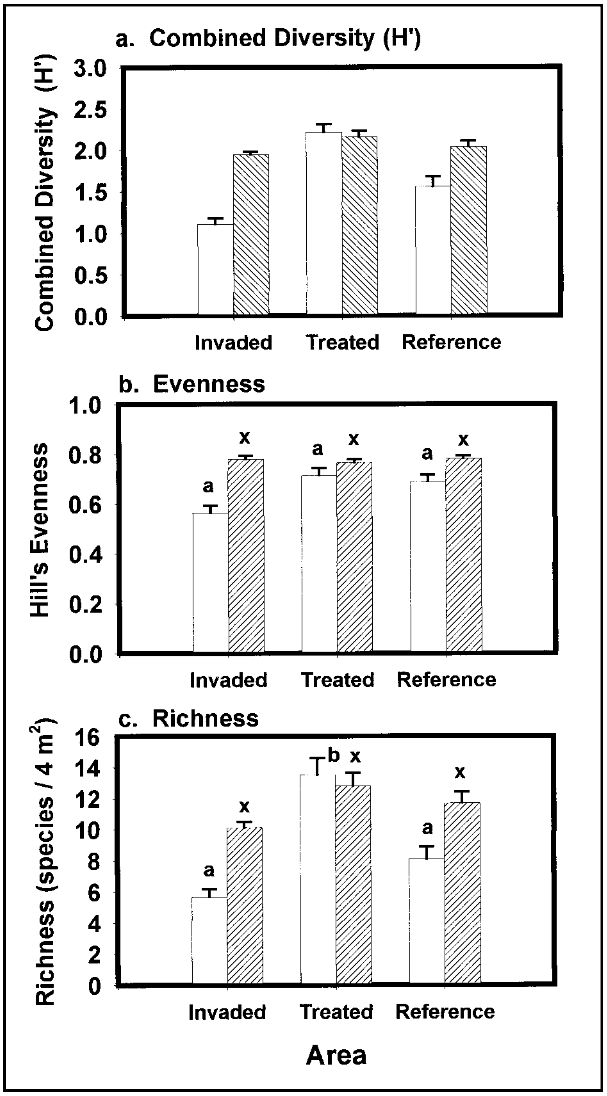

Figure 4. Diversity measures across study areas in summer 1994 and spring 1995. (a) Shannon-Wiener combined diversity (base e), (b) Hill's evenness, (c) species richness per 4-m^2 plot. Values are means and SE calculated on 4-m^2 plots. Open bar is summer 1994; hatched bar is spring 1995. Bars followed by same letter are not different at the $P \leq 0.05$ level by Bonferroni adjustment (letters a and b are summer; x is spring). Seasonal data were tested separately.

arranged in two groups, one of which overlapped the reference and treated plots. The same ordination conducted on relative frequency data arranged invaded, treated, and reference plots in a continuum running diagonally across the figure (Figure 5b), with an outlying group of reference plots in the lower right corner. *Circaea quadrisulcata* was dominant in the reference plots in the upper middle of the ordination; *Rhus radicans* was dominant in the reference plots in the lower right corner (Figure 5b).

In summer, vinca was the dominant species in both the invaded and treated areas, but was at lower relative frequency in the treated area (65% versus 23% RF, respectively; Table 3). In the invaded area, all other species had low frequency (< 8% F) and low relative frequency (<5% RF) (Table 3). In the treated area, *Prunus serotina* was the secondary dominant (16% RF), and all other species had low relative frequency (3–7% RF). In the reference area, four species shared dominance (10–22% RF): *Circaea quadrisulcata, Rhus radicans*, and seedlings of *Ulmus rubra*, and *Prunus serotina*. The naturalized exotic *Galinsoga ciliata* was present in the reference area. Vinca was the only nonindigenous species recorded in the treated area.

Composition in Spring 1995

Ordination of spring species presence data (Figure 5c) also separated invaded, treated, and reference plots. Grouping of the reference plots was less compact in spring than in summer; reference plots were spread along the second axis in spring but were clustered in summer. Ordination of relative frequency data also separated invaded, treated, and reference plots (Figure 5d). Vinca was less dominant in spring in the invaded and treated areas (28% and 11% RF, respectively) because other species were more abundant. Dominance relations among other species were more uniform than in summer, with four species sharing dominance (8–16% RF) in each area (Table 3). In all three areas *Podophyllum peltatum, Osmorhiza claytonii*, and *Galium aparine* were codominants. *Prunus serotina* was abundant in the treated area (> 14% RF), and *Circaea quadrisulcata* was abundant in the reference area (> 60% RF).

Competitive Effect of Vinca

We wanted to statistically test whether vinca reduced the frequencies of individual dominant species in the invaded area, but variability within study areas limited the power of statistical tests. To conduct an exploratory test, we assumed that percent frequencies of each species held in common between the invaded and reference areas were independent, and used a paired t-test to compare the areas. Invaded plots showed a significant reduction in average species frequency (summer, -9.9% F, t = -2.57, df = 13 [N = 14 species in common], P = 0.012; spring -5.2% F, t = -1.93, df = 19 [N = 20 species in common], P = 0.034).

DISCUSSION

This research was a case study in which only one forest stand was examined. Moreover, we have no data describing the forest understory before vinca invasion or at the time of herbicide treatment. Although we consider the study sites to generally represent the effects of vinca invasion, herbicide treatment, or natural understory dynamics, these results are only indicative. Additional replicate studies providing detailed baseline information are desirable.

The objective of invasive species management is to eliminate the invader without

Table 2. Significance levels of multiple response permutation procedures comparing vegetation of invaded, treated, and reference areas in Knobeloch Woods, Illinois.

	Species Presence	Relative Frequency
SUMMER 1994		
V. minor present	0.002	< 0.001
V. minor absent	0.007	0.009
SPRING 1995		
V. minor present	< 0.001	< 0.001
V. minor absent	< 0.001	0.001

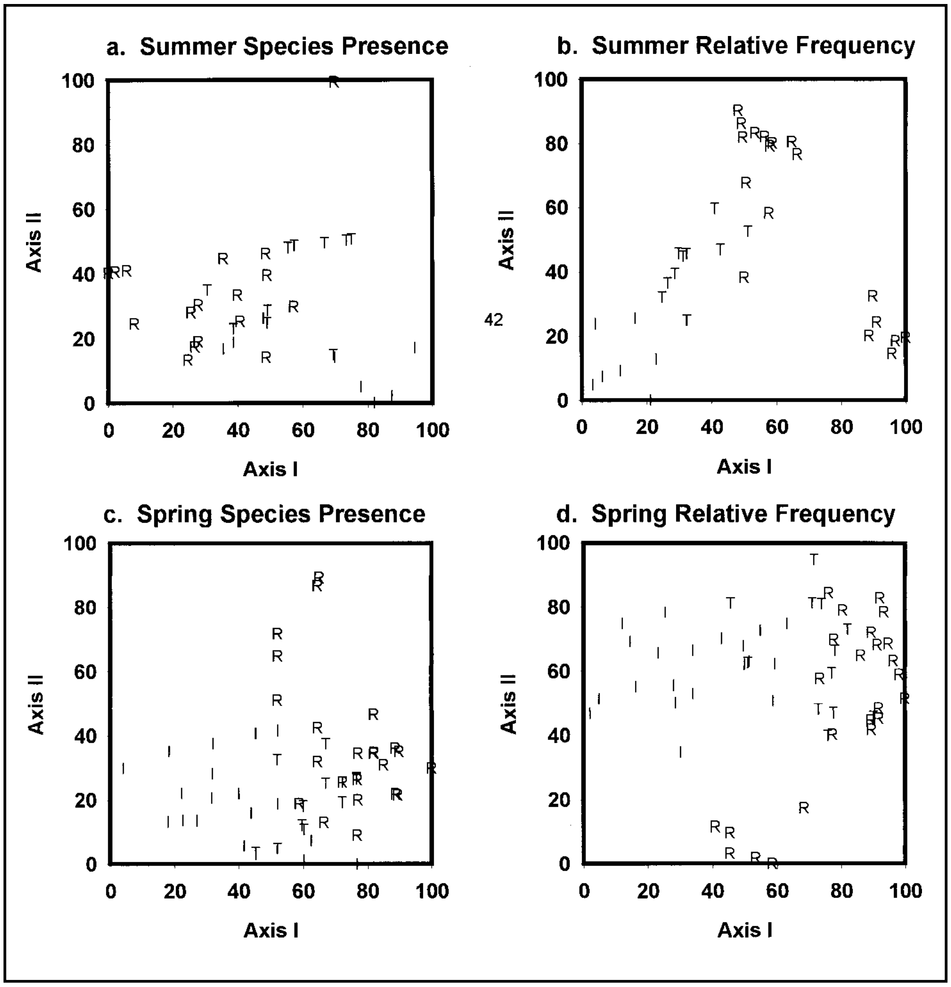

Figure 5. Modified Bray-Curtis ordinations of plots in summer 1994 and spring 1995. (a) Summer species presence, (b) summer species relative frequency, (c) spring species presence, (d) spring species relative frequency. I = vinca-invaded plots, T = cutting/herbicide-treated plots, R = reference plots.

harming native species. Our data, taken 1–2 years after treatment, show that treatment only reduced vinca frequency by about 50%, leaving a sizeable remnant population. Retreatment of these plants will be more difficult because the vinca mat has been fragmented, making surviving ramets more difficult to find in the leaf litter. Cutting and herbicide treatment had not visibly damaged native species at the time of sampling. Damage was not expected because at the time the vinca was treated, native herbaceous species had died back to the ground, and most woody species were dormant.

The effect of vinca invasion on understory vegetation was similar in both summer and spring. In both seasons, vinca dominated the flora and apparently reduced the amount of nonvegetated surface. There was no difference in H' diversity, evenness, or richness between the invaded area and the reference area. In this forest, a single species (e.g., *Circaea quadrisulcata* or *Rhus radicans* in summer; *Podophyllum peltatum* or *Osmorhiza claytonii* in spring) usually dominated each 4-m^2 plot. Dominance by single species (whether native or exotic) by definition reduces species evenness and may limit species richness through competition. Our limited case study provides little evidence that vinca invasion poses a threat to plant species diversity.

Ordination analysis separated plots in the invaded and reference areas in both seasons. This indicates sharply different composition in the two areas. One explanation for this separation is that vinca is dominant in invaded plots and almost absent in reference plots. However, the separation also existed in the ordination of presence/absence data, which do not weight abundance differences among species. Concordant results between the two data sets demonstrates that invaded and reference understories differ as a whole. The reduction in average species frequency in the invaded area suggests that vinca hinders the growth of most native species, which would ultimately cause differences in plant community composition. Differences in composition may not necessarily change species diversity indices because the indices do not take species identity into account.

Treatment caused significant reductions in vinca frequency and increases in nonvegetated surface during both summer and spring. This could be caused by the death of both vinca and nontarget species. Dead plant parts, malformed plants, and other evidence of herbicide damage were not visible the summer after treatment. However, since glyphosate has a short period of activity in soil (planting of crop species is possible within 7–30 days; label instructions for Roundup®, Monsanto Company, St. Louis), it is unlikely that enough herbicide remained active in the soil to cause damage the next growing season. The reasonable similarity of the flora in the treated and reference areas motivates us to conclude that treatment primarily killed vinca, exposing the soil surface. The two-thirds reduction in nonvegetated surface from summer 1994 to spring 1995 probably reflects herb canopy recovery superimposed on the seasonal increase in herb canopy cover visible in the reference area.

There was significantly higher summer combined (H′) species diversity and richness in the treated areas as compared to the invaded and reference areas. The greater richness in summer (no difference was present the subsequent spring) might reflect a pulse of colonizing species after the vinca mat was reduced. The disturbance-dependent species *Prunus serotina* and *Ulmus rubra* were more frequent in the treated area, as this interpretation would predict.

Table 3. Species composition of study areas in Knobeloch Woods, Illinois. Species list is a composite of leading ten species in each area. %F is percent frequency of 0.25-m^2 subplots occupied in 4.0-m^2 plot. %RF is relative frequency. %P is percent of plots where present.

	Reference (6 blocks, 18 plots)			Invaded (3 blocks, 9 plots)			Treatment (3 blocks, 9 plots)		
Species	**%F**	**%RF**	**%P**	**%F**	**%RF**	**%P**	**%F**	**%RF**	**%P**
SUMMER 1994									
Botrychium virginianum (L.) Sw.	8.7	4.1	27.8	5.6	3.7	55.6	7.6	2.9	55.6
Celtis occidentalis L.	1.0	0.5	11.1	3.5	2.3	11.1	-	-	-
Circaea quadrisulcata (Maxim.) Franch. & Sav.	46.9	22.1	66.7	2.8	1.9	33.3	9.0	3.5	66.7
Eupatorium rugosum Hout.	0.7	0.3	11.1	-	-	-	11.8	4.5	55.6
Galinsoga ciliata (Raf.) Blake	11.1	5.2	11.1	1.4	0.9	11.1	-	-	-
Lindera benzoin (L.) Blume	-	-	-	4.9	3.3	22.2	-	-	-
Parthenocissus quinquefolia (L.) Planch.	11.8	5.6	44.4	2.8	1.9	44.4	14.6	5.6	55.6
Prunus serotina Ehrh.	21.2	10.0	77.8	4.2	2.8	55.6	42.4	16.2	100.0
Rhus radicans L.	35.8	16.9	61.1	4.2	2.8	33.3	6.9	2.7	55.6
Ribes missouriense Nutt.	8.7	4.1	27.8	-	-	-	-	-	-
Rubus occidentalis L.	0.7	0.3	11.1	4.2	2.8	22.2	5.6	2.1	11.1
Sanicula canadensis L.	0.7	0.3	11.1	-	-	-	16.7	6.4	77.8
Sassafras albidum (Nutt.) Nees	10.1	4.8	77.8	0.7	0.5	11.1	13.2	5.1	77.8
Smilax tamnoides L.	7.3	3.4	44.4	7.6	5.1	55.6	2.1	0.8	33.3
Ulmus rubra Muhl.	24.3	11.5	94.4	0.7	0.5	11.1	7.6	2.9	55.6
Vinca minor L.	0.3	0.2	5.6	97.2	65.4	100.0	60.4	23.1	100.0
Vitis L. sp.	0.3	0.2	5.6	-	-	-	9.7	3.7	77.8
Species ranking > 10		10.5			6.1			20.5	

	Reference (8 blocks, 24 plots)			Invaded (9 blocks, 21 plots)			Treatment (4 blocks, 12 plots)		
Species	**%F**	**%RF**	**%P**	**%F**	**%RF**	**%P**	**%F**	**%RF**	**%P**
SPRING 1995									
Circaea quadrisulcata (Maxim.) Franch. & Sav.	60.7	16.0	79.2	24.7	7.3	76.2	33.9	8.6	91.7
Dentaria laciniata Muhl.	16.4	4.3	54.2	-	-	-	-	-	-
Galium aparine L.	41.9	11.1	95.8	39.9	11.8	95.2	36.5	9.3	100.0
Jeffersonia diphylla (L.) Pers.	0.5	0.1	8.3	-	-	-	8.9	2.3	25.0
Osmorhiza claytonii (Michx.) Clarke	42.7	11.3	87.5	36.0	10.6	95.2	57.8	14.7	100.0
Parthenocissus quinquefolia (L.) Planch.	17.2	4.5	70.8	17.0	5.0	76.2	13.0	3.3	58.3
Podophyllum peltatum L.	52.3	13.8	87.5	35.7	10.5	66.7	64.6	16.5	100.0
Prunus serotina Erhr.	26.0	6.9	79.2	3.3	1.0	28.6	55.2	14.1	100.0
Rhus radicans L.	25.8	6.8	37.5	25.0	7.4	71.4	2.6	0.7	25.0
Ribes missouriense Nutt.	10.2	2.7	20.8	-	-	-	-	-	-
Rubus occidentalis L.	0.3	0.1	4.2	18.2	5.4	52.4	-	-	-
Sanicula canadensis L.	1.8	0.5	25.0	-	-	-	17.7	4.5	83.3
Sassafras albidum (Nutt.) Nees	3.4	0.9	37.5	5.1	1.5	33.3	7.8	2.0	41.7
Smilax herbacea L.	6.3	1.6	41.7	12.2	3.6	76.2	1.0	0.3	16.7
Ulmus rubra Muhl.	28.6	7.6	95.8	1.2	0.4	14.3	6.2	1.6	58.3
Vinca minor L.	-	-	-	94.0	27.7	100.0	43.2	11.0	100.0
Species ranking > 10		11.8			7.9			11.2	

Ordinations of relative frequency data situated the treated plots between the invaded and reference plots (Figures 5b, d). This is partly caused by the intermediate importance of vinca in the treated plots, as opposed to absence in the reference plots and ubiquity in the invaded plots. Ordinations of species presence, which do not weight abundance, show the treated plots to be between invaded and reference plots in spring, and nearer the constellation of reference plots in summer (Figure 5a,c). If the treatment area flora was converging on the reference area flora, this configuration would be predicted. The possibility of such rapid recovery is worthy of additional study.

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