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Life History Studies on *Microstegium vimineum*, an invasive exotic in southern Illinois.

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Summary

1. The seed dynamics of *Microstegium vimineum*, an invasive exotic grass, were investigated in a secondary oak-hickory forest in Dixon Springs State Park, Illinois. *M. vimineum* occupies a central core population and several satellite populations in the park.
2. The objective of the study was to determine the size and role of the seed bank.
3. Soil samples were collected in fall, 1999 before flowering, and in the subsequent spring. The size of flowering and non-flowering individuals was determined as the plants set seed. Seed dispersal was assessed by counting seeds caught in seed traps.
4. A late summer drought severely impacted the population and few plants flowered before senescing. The plants which did flower were significantly larger than non-flowering plants and limited to one small patch at the edge of the core population. Fifty-eight vascular plant taxa co-occurred within or adjacent to the *M. vimineum* populations, Fall, 1999.
5. Germinable seed emerged from soils placed out in a greenhouse only from samples collected in the spring. No samples emerged from fall collected samples. Germinable seed had a 10 times higher density in samples collected from close to the soil surface than from samples collected > 5 cm depth. Dispersing seed were only found in seed traps placed within the core population. Seedlings emerged from all but one satellite population and from the core population, with the highest densities occurring below the fall flowering patch.
6. The data collected indicate the presence of a large and persistent soil seed bank for *M. vimineum* sufficient to maintain the population for 7-8 years. Even following the

severe summer drought and discounting for spring emergence, the size of the seed bank increased by ~25% in 1999. Control methods for *M. vimineum* would have to include limiting seed recruitment to the seed bank (not allowing plants to flower and set seed) for over 7 years.

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Introduction

Invasive exotic species make up 28% of the Illinois flora and are one of the most pernicious threats to the integrity of natural areas in the state (Illinois Department of Energy and Natural Resources 1994). Understanding their basic population biology is a first step for developing methods of control and integrated pest management for these species.

Microstegium vimineum (Trin.) A. Camus (Eulalia, Japanese grass, stiltgrass, Nepal microstegium) is one of the 25 exotic weeds considered to pose the greatest threat to Illinois forests (Illinois Department of Energy and Natural Resources 1994). A native of Asia, *M. vimineum* was first discovered in the United States in 1919 in Knoxville Tennessee and is now widespread east of the Mississippi (Fairbrothers and Gray 1972; Hunt and Zaremba 1992; Redman 1995; Ehrenfeld 1999). In southern Illinois it is reported in Pope, Union, Saline, Johnson, Hardin, Alexander, Gallatin, Williamson, and Massac Counties (Mohlenbrock and Voigt 1959; Mohlenbrock and Schwegman 1969; Shimp 1996). It is of special concern in a number of State Parks and Illinois Natural Area Inventory Sites.

M. vimineum is an annual grass which spreads into shady stream-side forest habitat (Redman 1995). Despite possessing the C4 photosynthetic pathway, this species is well adapted to low light environments and sunflecks (Winter et al. 1992; Horton and Neufeld 1998). It spreads rapidly into disturbed areas but can invade undisturbed upland areas by forming satellite populations brought in by animals or flooding (Barden 1987). On fertile mesic sites it can replace competing ground vegetation within 3-5 years (Tennessee Exotic Pest Plant Council and Great Smoky Mountains National Park 1997). Hardwood forests in New Jersey invaded by *M. vimineum* were observed to have a thinner litter and O_{e+a} horizons and higher mineral soil pH (Kourtev et al. 1998). A perennial form of *M. vimineum* has recently been reported (Ehrenfeld 1999) from New Jersey, but has not been observed in Illinois.

There is a lack of basic life history information on this species. Illinois currently has no control method listed in the Illinois Vegetation Control Manual for *M. vimineum*.

Project Objectives

The overall project objective was to assess the importance of the seed bank (soil seed reserve) for *M. vimineum*:

As an annual grass, *M. vimineum* is dependent upon germination and establishment from seed every year. In areas where *M. vimineum* has already established, we do not know how dependent it is upon germination from the last seasons crop of seed (i.e., if it has a transient seed bank). Alternatively, populations may develop a persistent (long-term) seed bank. A transient seed bank occurs when there is no carry over of germinable seed from one season to the next. A persistent seed bank occurs when the reserve of seed of species accumulates over a number of years. If a transient seed bank occurs, then effective control might be possible by limiting seed production. If a persistent seed bank occurs, then seed production in any one year would be relatively unimportant, and control needs to focus upon limiting germination and seedling establishment. Anecdotal accounts suggest that each individual plant produces 100-1000 seeds that can persist in the soil for upwards of 5 years (Tennessee Exotic Pest Plant Council and Great Smoky Mountains National Park 1997). Many annual species develop persistent seed banks, and this was our expectation for this species.

Ho: *M. vimineum* develops an extensive, persistent seed bank.

Materials and Methods

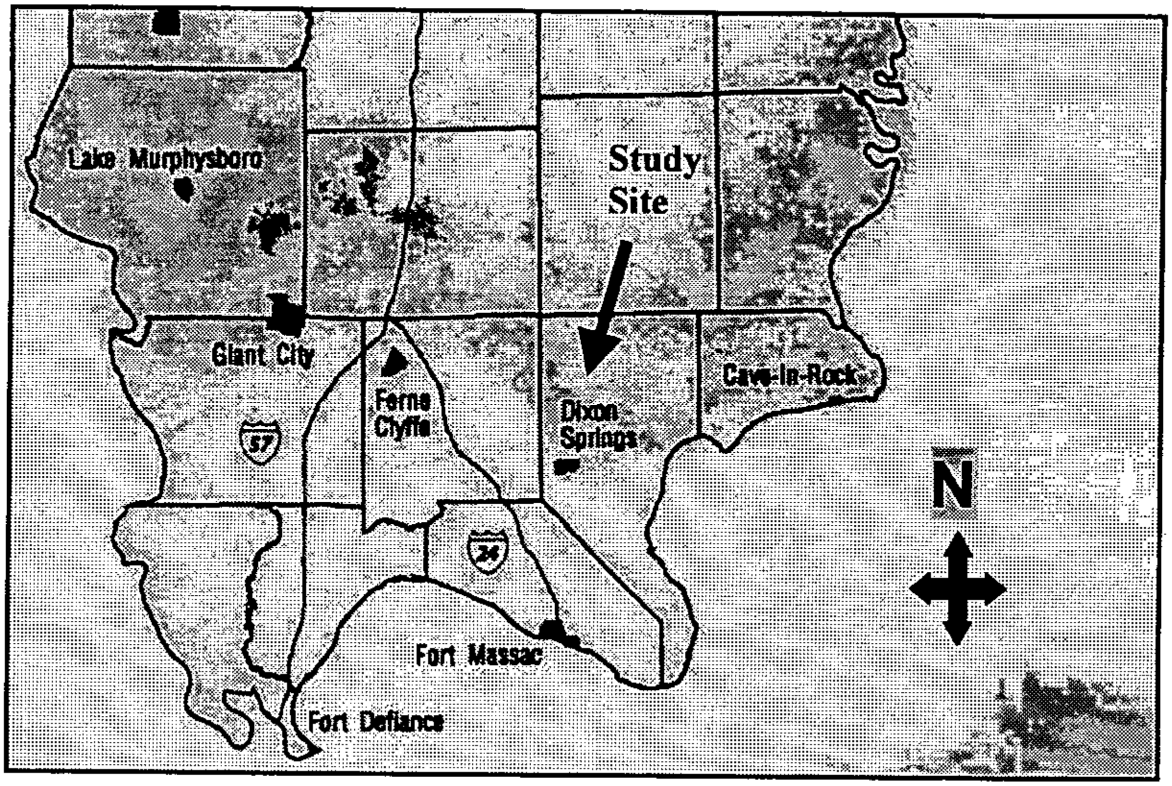
Site Description

Our study was conducted at Dixon Springs State Park in Pope County (Figure 1). This park lies within the Illinois Shawnee Hills Physiographic Region, and is characterized by plant communities ranging from mature secondary Oak-Hickory forest, to early successional woods. We chose to work in an early successional dry/mesic woods encompassing the east half of the park because of its heavy *Microstegium* infestation.

Intermittent streams dissect the area, which is gently sloping. Poor soil horizon development indicates historical agricultural use, followed by abandonment 35 years ago. The area is dominated by young *Quercus velutina, Q. stellata*, and *Carya* spp., with an understory of *Juniperus virginiana, Cornus floridia, Diospyros viriginiana*, and *Sassafras albidum*. Typical shrubs and vines include *Symphiocarpus orbiculatus, Lonicera japonica, Toxicodendron radicans,* and *Vitis* spp.

An initial survey of the distribution of *M. vimineum* at site showed that it is represented by a dense core population within the interior of the park. This 'core' is immediately surrounded by small, isolated peripheral patches. Additionally, a few small, widely scattered satellite patches occur further south along the entrance trail towards the park entrance, away from the large interior core populations.

Figure 1. Southern Illinois State Parks with Dixon Springs Study Site

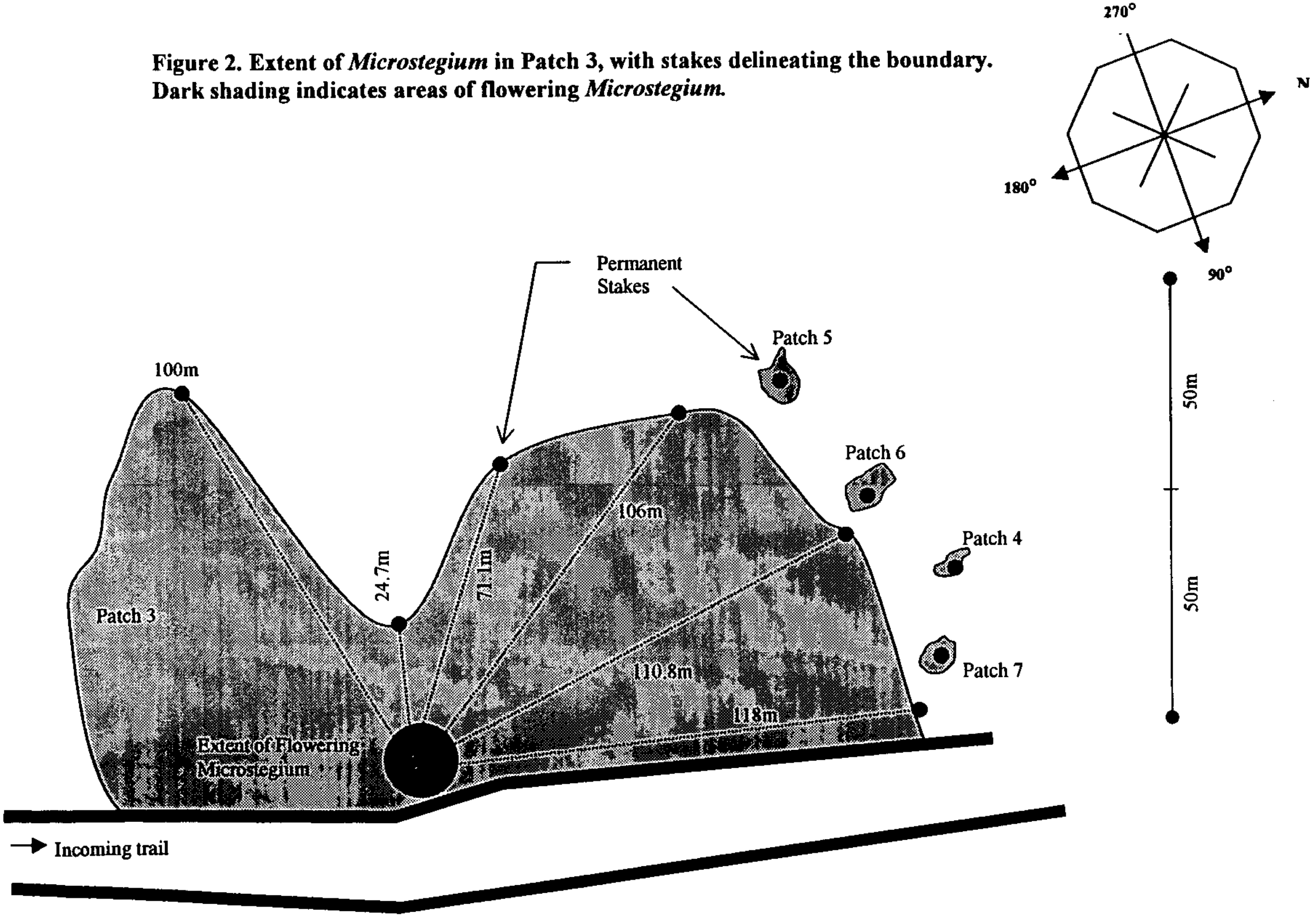


Measurement of Patches

Seven patches of *Microstegium* were studied. Patches 1 and 2 were small satellite patches adjacent to the incoming trail, which likely originated from seed brought in by pedestrian traffic, or grading tractors (Shimp 1999). Patch 3 was the largest, interior, 'core' patch. Patches 4-7 were small patches peripheral to patch 3 (Figure 2). On September 24th, 1999, the length and width of all patches were measured to obtain an estimate of their size. The extent of patch 3 was also delineated using metal stakes around the edge of the patch at 20° compass bearings (Figure 2). This was done in order to establish a baseline of it's size, so that in subsequent years we might determine how fast, and how the grass is spreading through the park.

Additionally, a visual estimate of the percentage cover of *Microstegium* within each patch was taken. Co-associate vascular plants were recorded. Overhead canopy cover was measured using a Spherical Densiometer, taken in the four cardinal directions, within the center of all patches (except patch # 3, where no denisiometer measurements were taken). Densiometer readings were also taken directly outside the patches for a within/outside patch shade comparison.

Figure 2. Extent of *Microstegium* in Patch 3, with stakes delineating the boundary. Dark shading indicates areas of flowering *Microstegium.*



Seed Bank Sampling

Soil samples were collected before anthesis from within and outside *M. vimineum* patches on September 11th, 1999. A total of four (12.5 X 12.5cm) soil samples from the upper (0-5cm), and four from the lower (>5cm depth), soil horizons were taken randomly within each of the seven patches. Four samples were also taken from an area directly outside and downslope of each patch, for an inside patch/outside patch comparison. Samples from each patch were composited (mixed in the field in the soil sample bag) providing four samples from two depths from inside and outside of each patch; i.e.,

a) 4 inside patch < 5 cm depth

b) 4 inside patch 5-10 cm depth

c) 4 outside patch < 5 cm depth

d) 4 outside patch 5-10 cm depth

All soil samples were cold treated for 6 weeks at 10 C°. Samples were placed out in the Plant Biology Greenhouse at SIUC (October 18), in randomly arranged 12.5 X 12.5cm plastic flats. Obvious root fragments, stones, etc. were removed from the soil samples. Control flats with sterile soil were interspersed with the samples to test for greenhouse seed contamination. Samples were rotated periodically to control for heterogeneity in environmental conditions within the greenhouse. Trays were watered as needed and fertilized monthly with N-P-K (20-10-20). In March 2000, the surface layer of soil in the flats was lightly broken up, and stirred with a tongue depressor to break a crust which had developed, and to initiate subterranean seed germination. The presence of viable seed was determined by counting emerging seedlings. Once taxa were identified they were removed from the flats. Vouchers were mounted and deposited within the SIUC Herbarium.

The seed bank study was repeated by collecting a second set of soil samples on March 26, 2000. The sampling procedure in patch 3 was modified slightly to incorporate the very small area of fecund plants. Patch 3 soil samples were taken from within the small group of flowering plants, and then outside samples were taken within patch 3, but outside of the flowering group of plants.

Seed Dispersal Sampling

Thirty-four seed traps were placed within and outside of the 7 *M. vimineum* patches at anthesis (September 25, 1999), and collected after seed shed (December 15, 1999) to determine seed rain. Two seed traps were each placed randomly within patches 1,2, and 4 - 7. Additionally, 2 seed traps were placed directly outside and downslope of each patch to determine the extent of seed rain. To obtain a representative estimate of seed rain in the very large (patch 3) ten traps were placed randomly within it.

The traps consisted of plastic plates (201cm^2) coated with Tanglefoot™ adhesive. Traps were held securely in the soil by nails. *Microstegium* seed collected within the traps was tested for viability using Tetrazolium on excised embyros (0.1 % 2,3,5-Triphenyltetrazolium Chloride).

Seedling Density

The density of *Microstegium* seedlings germinating in 2000 were estimated in May, 2000 by counting the number of seedlings in 1 m radius circular plots centered on the permanent plot marker in patches 1, 2, and 4 – 7. Seedling densities were counted in areas outside of the 7 patches by centering plots in the areas where the 'outside patch' seed bank samples were collected. In patch three, seedling density was counted in six 1 m radius plots. One plot was located in the center of the 1999 flowering area, the other three plots were located at random in a gully (plot F2), an area of high 1999 *Microstegium* density (plot G2), and two additional areas located at random (plots G1, F1).

Plant Morphology

Within our study area flowering tillers were only observed from a very small area within Patch 3 (figure 2). Therefore, we focused on measuring morphological characteristics of these flowering plants. Seed production was assessed by counting seed on 20 plants surveyed at random from within the flowering population in patch 3 before seed shed (October 1, 1999). These plants were compared with 20 plants chosen at random in the area surrounding the group of plants in flower. The following measurements were taken on every plant from both groups.

1. The number of inflorescences - both cleistogamous and chasmogamous (see Ehrenfeld 1999).
2. Number of spikelets.

3. Number of seeds (viable and not determined using Tetrazolium test).
4. Length of the plant measured as the sum of all tiller lengths (cm).
5. Dried biomass of the plant (g dw at 80 ° C).
6. Dried biomass of the spikelets with seed (g dw at 80 ° C).
7. Total biomass of the seed (g dw at 80 ° C).
8. Number of tillers.
9. Number of prop roots.
10. Number of leaves (functional, and undeveloped non-functional). Functional leaves were defined as leaves > 2 cm in length.
11. Number of nodes (including # of rooting and stoloniferous nodes).

Results

The seven *Microstegium* patches ranged in size from 2.3 to 16,706 m^2 with *Microstegium* cover ranging from 35 to 100% (Table 1). The patches occurred under a forest canopy of > 80% cover (patch two at 44% cover was an exception. Overhead canopy cover immediately outside the patches was similar to the canopy cover directly over (inside) the patches.

Fifty-eight taxa were observed co-occurring in or at the margin of the *Microstegium* patches in Fall, 1999 (Table 2). The number of taxa per patch ranged from 12 to 28. On a unit area basis, the smallest patch had the largest number of co-occuring taxa, whereas the largest patch had the smallest. However, there was no statistical relationship between patch size and the number of taxa (Spearman Rho = 0.23, P = 0.61). Of the co-occurring taxa, the fern *Asplenium platyneuron,* the tree *Juniperus virginiana,* and the exotic vine *Lonicera japonica* were the most frequently occurring in all patches. The understory tree *Cornus florida* occurred in six patches. Additional exotic species included *Lespedeza cuneata* and *Rosa multiflora*. Our list is not exhuastive as taxa noted in a spring, 2000 survey of patch 1 included the following taxa not recorded in Fall, 1999 (* denotes exotic): *Agrimonia* sp., *Bromus pubescens, Carex blanda, C. cephalophora, C. hirsutella, Desmodium* spp., *Galium aparine, G. circaezans, Panicum boscii, Pilea pumila, Rosa multflora**, *Smilax* spp., *Sphenopholis obtusata, Triodanis perfoliata, Triticum aestivum**, and *Viola arvensis.*

Plants in the flowering patch were larger than plants outside the flowering patch with respect to all characters measured (Table 3). The most substantial difference was in total biomass; flowering patch plants were almost eight times larger than non-flowering patch plants. The flowering patch plants were 1.7 – 4.0 times larger than non-flowering patch plants for the other characters measured. Sixteen of 21 plants from within the flowering patch flowered, and of these only 4 produced seed.

On the flowering patch plants, there was a mean of 9.5 inflorescences of 70 mostly cleistogamous spikelets. Seed production was very low with only 2.8 (0.71 viable) seeds per plant (14.5 seeds per plant of the four that produced seed). Very few inflorescences had released their seed, indicating that additional immature seed may have been still retained on the plants at the time of sampling (note that the biomass of seed reported included the immature seed). Mean reproductive allocation measured as the biomass of reproductive structures (spikelets plus seed) as a percentage of the total biomass (Bazzaz and Ackerly 1992) was 1.9%. In those plants which flowered, spikelet plus seed biomass was not correlated with total plant biomass (Spearman's Rho = 0.02, P = 0.92).

Seed traps placed inside and outside *M. vimineum* patches retained seed in three traps that were placed inside patch 3 (Table 4). Overall, 104 seeds m^{-2} were being dispersed and reaching the soil surface in this patch. Of these, 34.8 seeds m^{-2} (33%) were viable. Across the whole *M. vimineum* population the seed rain was 10.2 viable seeds m^{-2}.

No seedlings of *M. vimineum* emerged from the seed bank samples collected prior to flowering in Fall, 1999 (Table 5). Forty-three seedlings m^{-2} emerged from upper soil horizon (0-5 cm depth) samples collected in spring, 2000. An order of magnitude fewer seedlings emerged from samples collected from 5-10 cm depth (4.6 m^{-2}).

Seedling emergence of *M. vimineum* in the field in Spring, 2000 varied widely among the 7 patches with a mean of 5.8 seedlings m^{-2}. (Table 6). The highest density of seedlings was emerging within the area of the flowering patch from 1999. Seedlings were only observed emerging outside of the patches adjacent to patch 4. This patch is in a moist, sloping gully, and the outside patch location is downslope of the *M. vimineum* patch. No seedlings emerged inside patch 2.

Table 1: Characteristics of *Microstegium vimineum* patches. Patch dimensions were measured as length by longest orthogonal width.

Characteristic	Patch						
	1	2	3	4	5	6	7
M. vimineum cover (%)	85	95	75-100	35	65	70	65
Dimensions (m)	5.8 x 3.7	9.9 x 3.7	See Fig 2	0.9 x 2.5	4.8 x 2.9	7.1 x 3.7	3.4 x 6.8
Area (m^2)	21.7	36.5	16,706.0	2.3	14.0	26.2	23.0
Overhead canopy cover (%) Fall, 1999							
Inside patch	90.6	80.2	*	82.3	91.7	95.8	88.6
Outside patch	90.6	86.5	*	87.5	89.6	93.7	90.6
Overhead canopy cover (%) Spring, 2000							
Inside patch	85.5	44.0	89.6	95.8	96.9	96.9	95.8
Outside patch	*	*	95.1	94.8	96.9	97.9	96.9

* Not measured

Table 2: Co-associates of *Microstegium vimineum* at Dixon Springs State Park in Fall, 1999. The species listed occurred inside *M. vimineum* patches, or within 1 m of the patch margin. * exotic species.

Species	**Patch**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Acalypha virginica	x						
Acer rubrum			x			x	
Acer saccharum		x			x	x	
Ambrosia artemesifolia		x					
Amelanchier arborea					x	x	
Asplenium platyneuron	x	x	x	x	x	x	x
Bidens bipinnata		x				x	
Bromus spp.					x		
Carex glauca				x			
Carex spp.					x		x
Carya cordiformis			x				
Carya spp.					x		
Celtis occidentalis			x				
Chasmanthium latifolia		x					
Cinna arundinacea	x		x				
Corydalis flavula			x				
Cornus florida	x		x	x	x	x	x
Diospyros virginiana	x	x		x		x	x
Elymus canadensis	x		x				x
Erechtites hieracifolia		x					
Eupatorium perfoliatum						x	
Eupatorium rugosum			x		x	x	x
Eupatorium serotinum		x					
Euphorbia corollata	x						
Fraxinus americana	x	x					
Fraxinus pennsylvanica				x	x	x	
Galium sp.					x		
Geum canadensis				x	x	x	x
Glyceria striata				x			
Ilex decidua						x	
Juglans nigra			x				
Krigia dandelion			x				
Juniperus virginiana	x	x	x	x	x	x	x
*Lespedeza cuneata**		x			x	x	
Liquidambar styraciflua						x	
*Lonicera japonica**	x	x	x	x	x	x	x
Lycopodium digitatum						x	
Muhlenbergii sobolifera				x			x
Ostrya virginiana					x	x	
Panicum laxiflorum					x	x	
Prunus serotinum					x		
Quercus velutina			x		x	x	x
Rhus copalina						x	
*Rosa multiflora**			x	x			
Rosa carolina or *setigera*							x
Rubus occidentalis			x				
Sanicula gregaria			x		x		x
Sassafras albidium			x	x	x	x	x
Smilax glauca			x				

Smilax spp.				x	x	x	x
Solidago canadensis		x					
Symplocarpus orbiculatus	x		x		x	x	
Toxicodenron radicans			x		x	x	
Ulmus alata		x	x	x		x	x
Ulmus americana					x	x	x
Vaccinium arboreum			x				
Ulmus rubra	x		x	x			
Vitis spp.			x		x	x	x
Number of taxa	12	14	25	15	25	28	18
Taxa m^{-2}	0.55	0.38	0.001	6.64	1.78	1.07	0.78

Table 3: Morphology of *Microstegium vimineum* plants (mean ± 1 se) at Dixon Springs State Park collected inside and outside the flowering patch (n = 20 plants per patch). A 1-way ANOVA tested the effect of patch type (inside versus outside) on log transformed values of plant growth (df = 1/39). The test was not performed when all values in one patch type were zero (n/a). Units are numbers per plant except where indicated otherwise.

Character	Inside	Outside	F	P
Leaves				
Functional	28.6 ± 4.4	13.8 ± 1.7	15.26	0.0004
Total	56.7 ± 7.3	20.3 ± 2.6	34.98	<0.0001
Nodes				
Total	44.9 ±4.5	16.2 ± 1.4	66.63	<0.0001
Aboveground	42.1 ± 4.5	14.9 ± 1.3	64.58	<0.0001
Rooting nodes	6.0 ± 0.7	3.6 ± 0.4	4.87	0.03
Tillers	5.7 ± 0.9	1.9 ± 0.3	18.68	0.0001
Prop roots	5.1 ± 0.7	2.0 ± 0.3	8.31	0.006
Inflorescences	9.5 ± 2.8	0	n/a	
Cleistogamous infloresences (%)	62	0	n/a	
Dispersed infloresences	0.5 ± 0.2	0	n/a	
Spikelets	65.9 ±18.5	0	n/a	
Seeds	2.8 ± 1.6	0	n/a	
Viable seed	0.71	0	n/a	
Total length (cm)	150.4 ± 22.8	37.6 ± 5.1	68.38	<0.0001
Biomass (g)				
Seed & spikelets	0.03 ± 0.01	0	n/a	
Seed	0.003 ± 0.002	0	n/a	
Total plant	1.6 ± 0.21	0.20 ± 0.04	75.67	<0.0001

Table 4: Dispersed seed of *Microstegium vimineum* collected in seed traps (201 cm^2 each) at Dixon Springs State Park. Three of 10 traps in the large flowering patch (patch 3) had spikelets collected in the seed traps. 24 traps placed either inside (12 traps) or outside (12 traps) of patches 1, 2, and 4 – 7 did not contain spikelets or seed.

Seed trap	No. spikelets	No. seed	No. viable seed	% viable seed	Seed m^{-2}	Viable seed m^{-2}
A	2	2	1	50.0	99.4	49.7
B	6	3	1	33.3	149.1	49.7
C	75	16	5	31.3	795.2	248.5
Total	83	21	7		1043.7	347.9
Mean of three	27.7	7	2.3		347.9	116.0
Mean of 10 traps in patch 3	8.3	2.1	0.7		104.4	34.8
Mean of 22 traps in patches 1-7	3.8	1.0	0.3		47.4	15.8
Mean of all 34 traps	2.4	0.6	0.2		30.7	10.2

Table 5: Germinating seed of *Microstegium vimineum* (number m^{-2}) from soils collected inside and outside *M. vimineum* patches and at 0 – 5 and 5 – 10 cm depth in Dixon Springs State Park. No *M. vimineum* seed germinated from samples collected in Fall, 1999.

Patch	Inside		Outside	
	0 –5 cm	5 – 10 cm	0 – 5 cm	5 – 10 cm
1	16	16	0	0
2	0	0	0	0
3	64	16	0*	0 *
4	80	0	0	0
5	0	0	0	0
6	96	0	0	0
7	48	0	0	0
Mean	43.4	4.6	0	0

* denotes outside of flowering patch but within the rest of patch 3

Table 6: Density of *Microstegium vimineum* (number m^{-2}) seedlings inside and outside 1999 *M. vimineum* patches in spring, 2000.

Patch	Inside	Outside
1	7.3	0.0
2	0.0	0.0
3		
Flowering patch	23.9	-
F1	3.2	-
F2	0.3	-
G1	2.2	-
G2	1.3	-
4	16.2	1.6
5	1.6	0.0
6	1.9	0.0
7	2.2	0.0
Mean	5.5	0.1

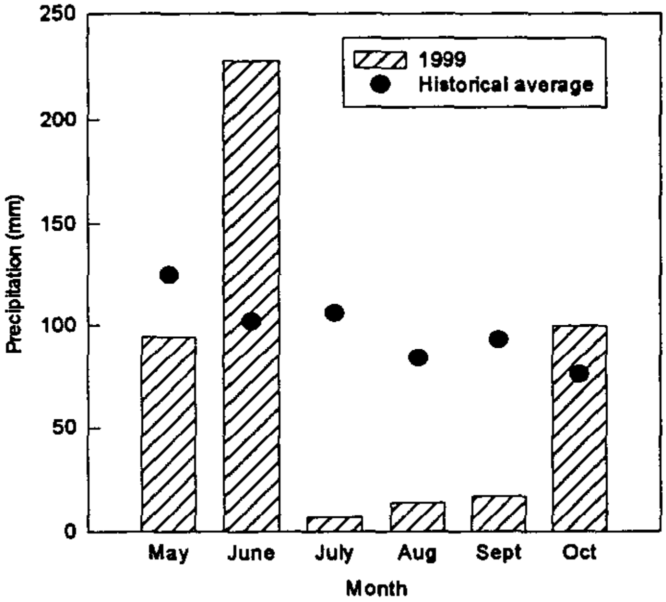
Discussion

Based upon a single year of observations, we can construct a preliminary population dynamics picture for *Microstegium vimineum* at Dixon Springs State Park, IL. *M. vimineum* formed dense cover in both a central core and in several satellite populations. Fifty-eight other vascular plant taxa, including three other exotics, were observed to co-occur with *M. vimineum* in these populations. Cover of these associated taxa was substantially lower than that of *M. vimineum* (D. Gibson, Observation).

Despite the high abundance of *M. vimineum*, plants in only one small location survived to flower and set seed. The plants in the flowering patch were significantly larger in all morphological features measured (number and size of leaves, tillers, internode length) than those outside this patch. The flowering patch was located in a high light environment adjacent to a trail. Although adapted to shady habitats, *M. vimineum* grows best and allocates the greatest amount of resources to reproduction under high light conditions (Claridge 2000).

Microstegium vimineum is reported to flower prolifically and produce large numbers of viable seed (Williams 1998). With only 14.5 seeds per flowering plant, the plants in the flowering patch at Dixon Springs were producing less seed than observed on plants in 4 of 6 populations in the Great Smoky Mountains National Park (Williams 1998). Our observations of poor flowering of the Dixon Springs population in 1999 suggest that such high fecundity may not always be the case. We suggest that the poor flowering of our plants was due to low soil moisture. The southern Illinois region suffered a severe drought in July – September 1999, receiving only 13% of the normal precipitation (Fig 3). Temperatures during this time were not above normal. The plants

Figure 3. Monthly precipitation at Paducah, KY (source: National Weather Service)



that did flower were restricted to a small, high-light patch at the edge of the core population. For an annual plant, such as *M. vimineum*, setting viable seed is critical for the long-term persistence of the population. Although *M. vimineum* is adapted to low light conditions (Winter et al. 1992; Horton and Neufeld 1998), flowering, it appears, may be restricted in times of moisture stress to high light microhabitats.

Our data on seed production, seed dispersal, seed bank germination, and seedling emergence allows a simple model of seed dynamics for *Microstegium vimineum* at Dixon Springs State Park to be developed (Fig. 4). Our model provides a contrast of seed dynamics among all populations and within the flowering patch. Data on potential seed losses to herbivory or pathogens are unavailable but would likely be important too (Crawley 1988).

Consistent with Barden's (1991) account , *M. vimineum* appears to possess a persistent seed bank. We believe this to be the case despite the lack of emergents from the soil samples collected prior to flowering in the fall and the occurrence of seedlings emerging only from the spring samples. The density of emergents from the spring seed bank samples (43.4 m^{-2}) was greater than the seed rain the preceding fall (15.8 m^{-2} viable seed in traps inside patches) indicating carry over from earlier years. Although nothing is known about seed dormancy of *M. vimineum*, we suspect that induced (secondary) dormancy (Bradbeer 1988) precludes germination of seed from soil collected in the late summer. Winter cold likely allows (some) seed to become non-dormant and germinable in the spring. We found no evidence of seed dispersal outside of the *M. vimineum* patches, although the presence of emerging seedlings downslope of one satellite patch in Spring, 2000 suggests that limited dispersal can occur (or has occurred in the past). The limited seed production in the year of our study may underestimate normal seed dispersal outside of populations. Since this species has to spread through the dispersal of seed, it is likely that dispersal to new sites occurs principally in good seed production years (years without a summer drought, perhaps). In North Carolina, Barden (1987) suggested that *M. vimineum* spreads through dispersal to new satellite populations during flooding. Some type of opening or disturbance in the existing ground vegetation also appeared to be necessary to allow establishment.

The viable seed rain density was almost triple the seedling emergence density (15.4 m^{-2} versus 5.5 m^{-2} among all populations; Fig 4) indicating that there was no depletion of the seed bank despite the drought year and low seed set. *M. vimineum* was extirpated following the drought year in only one of six satellite populations (patch 2).

Persistence of the *M. vimineum* population at Dixon Springs occurred despite the lack of flowering and seed production at all other patches and in all but a portion of the main, core patch. The plants in the core patch were large, and an extremely thick layer of thatch (litter from last year's senesced plants) in the spring may have been limiting seedling emergence.

The density of germinable seed in the seed bank (43.4 m^{-2}) coupled with an emergence rate of 5.5 viable seed m^{-2} per year would allow the population to persist for almost 8 years even if new seed input through dispersal ceased. Paradoxically, the higher rate of seedling emergence in the flowering patch (23.9 m^{-2}) compared with emergence among all populations would limit persistence of the flowering patch population for less than 3 years despite the larger germinable seed bank. Nevertheless, the flowering patch population is maintained by a density of seed dispersal over twice that among all populations (Fig 4). A North Carolina population of *M. vimineum* persisted for only three years when input to the seed bank was halted (Barden 1991). In that study, the density of seedlings emerging in the spring was 429-500 m^{-2} following years when seed production was allowed.

Applicability of findings for population control and future needs

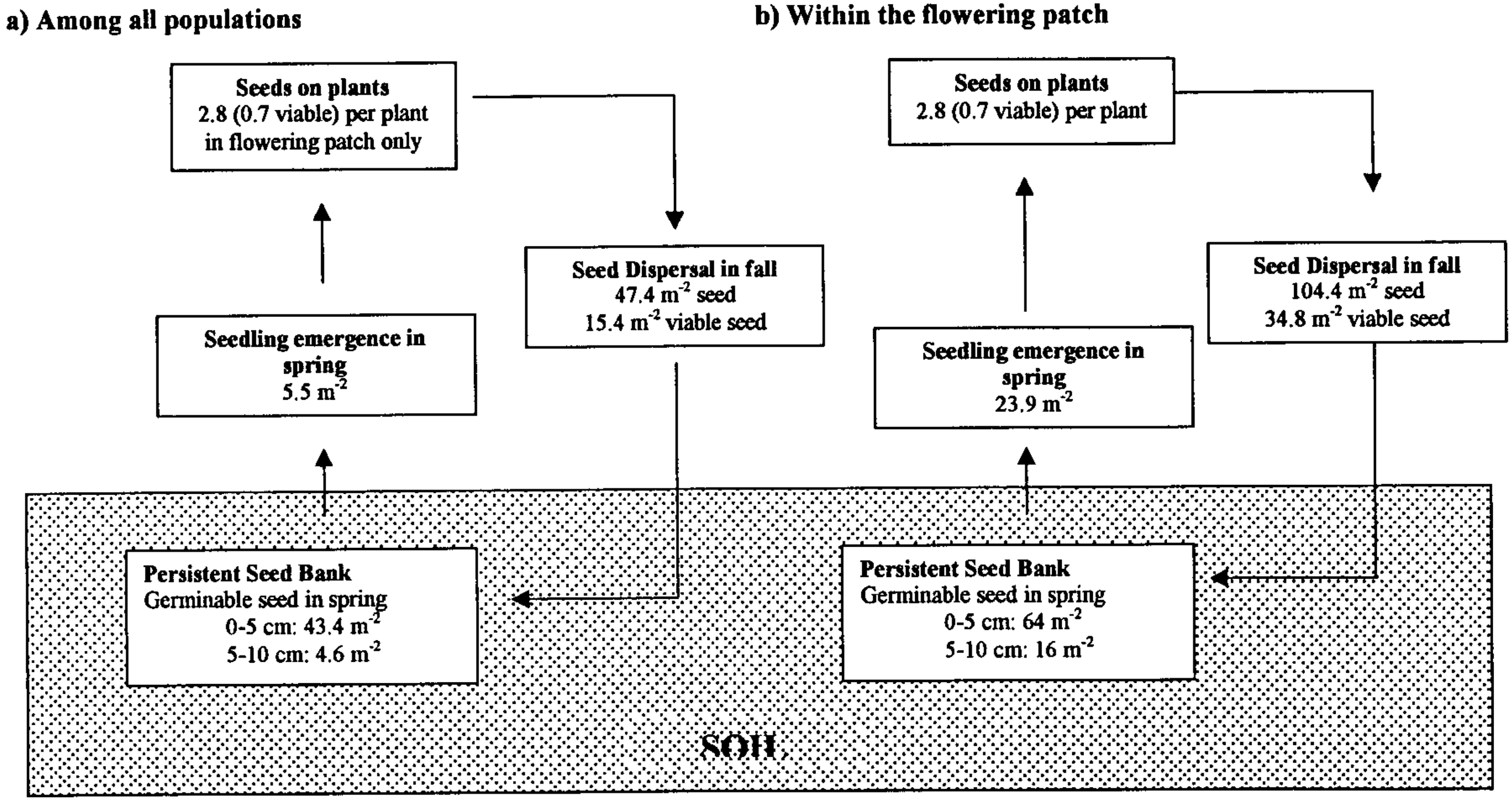
Our recommendations have to be limited by the single season of data, and the effect of the summer drought. Nevertheless, it is clear that *M. vimineum* will continue to persist at Dixon Springs State Park, even though flowering and seed production is susceptible to drought. The presence of the soil seed bank means that new populations of

M. vimineum can reestablish annually. Repeated annual efforts must be made to stop flowering. We concur with others that the best strategy for controlling *M. vimineum* is removal of the plant by hand or mechanical means late in the growing season before seed production (Virginia Natural Heritage Program ; Tennessee Exotic Pest Plant Council and Great Smoky Mountains National Park 1997).

Information on the drought tolerance of *M. vimineum* would be important to obtain as it appears to be best suited to mesic sites. Soil moisture status may be as, or more, important than light and soil nutrients for success and spread of this species (Horton and Neufeld 1998; Claridge 2000). Additionally, we noted no difference in canopy cover inside or outside of *M. vimineum* patches, suggesting shade will not limit this plant.

Further data are needed at other sites and at this site in subsequent years to test the generality of the findings presented here.

Fig 4. Seed dynamics of *Microstegium viminium* at Dixon Springs State Park, 1999-2000, a) among all populations, b) within the flowering patch.



a) Among all populations

b) Within the flowering patch

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