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Effects of *Microstegium Vimineum* (Trin.) A. Camus on native woody species density and diversity in a productive mixed-hardwood forest in Tennessee

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Abstract

We investigated the impacts of *Microstegium vimineum* (Trin.) A. Camus, on the density and diversity of native woody species regeneration following canopy disturbance in a productive mixed-hardwood forest in southwest Tennessee. Field observations of *M. vimineum* in the forest understory pre- and post-canopy disturbance led us to believe the species might have an impact on post-disturbance regeneration. Specifically, we noticed what appeared to be a dramatic increase in post-disturbance *M. vimineum* which we hypothesized would compete with native woody species regeneration, negatively impacting species diversity and seedling density. Total native woody species stems per hectare declined with increasing *M. vimineum* cover ($P < 0.001$, $r^2 = 0.80$). Simple species richness of native woody species and Shannon's and Simpson's diversity indecies also decreased with increasing *M. vimineum* percent cover ($P = 0.0023$, $r^2 = 0.47$, $P = 0.002$, $r^2 = 0.47$ and $P = 0.02$, $r^2 = 0.31$, respectively). Our results indicate that *M. vimineum*, may have a negative impact on native woody species regeneration in southern forests.

Keywords: Disturbance; Invasive species; Japangrass; *Microstegium vimineum*; Nepalese browntop; Regeneration

1. Introduction

Non-native invasive species pose a substantial threat to the economy and ecology of Southern forests (Gordon, 1998; Stapanian et al., 1998; Pimental et al., 2001; Jose et al., 2002). Ecological impacts caused by the establishment of non-native invasive species include altered soil biogeochemistry and site moisture (Gordon, 1998; Jose et al., 2002), changes in site hydrology (Gordon, 1998), extinctions via competitive exclusion and site homogenization (Mooney and Cleland, 2001), altered stand structure, and changes in local disturbance regimes like fire frequency and intensity (Jose et al., 2002). The ability of some shade-tolerant non-native species to persist under the canopy of the forest interior with little impact, then experience remarkable growth in response to canopy removal, is of concern to conservationists, ecologists, and forest resource managers (Horton and Neufeld, 1998; Oswalt et al., 2004).

Microstegium vimineum (Trin.) A. Camus (Nepalese browntop) is an annual, shade-tolerant, C_4 grass native to Asia. Seeds from this plant were inadvertently introduced in 1919 in the southern State of Tennessee as packing material for fragile porcelain (Barden, 1987). *M. vimineum* is now considered to be a noxious weed in 14 states in the Eastern United States, frequently invading moist forests and stream banks and displacing native vegetation (Horton and Neufeld, 1998; Swearingen, 2004). Because *M. vimineum* persists in the interior of floodplain forests in the Southeast, it represents a potential threat to native woody species regeneration following disturbance.

Typical C_4 grasses, like corn (*Zea maize* L.) and millet (*Sorghum* spp.) are well suited for hot, arid conditions because of their efficiency in fixing carbon dioxide using nearly half the water of C_3 plants. This characteristic, combined with the ability to efficiently utilize nitrogen, makes C_4 plants highly competitive in dry sites exposed to bright sunlight. Conversely, C_4 plants are typically less competitive in moist, shady sites

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because of the excess energy needed to complete C_4 photosynthesis.

Unlike most C_4 plants, *M. vimineum* successfully invades and persists under low-light conditions in the forest interior of the eastern United States (Barden, 1987; Horton and Neufeld, 1998). Moreover, *M. vimineum* is frequently found in highly productive alluvial forests in the southeastern states, where other shade-tolerant species might be expected to out-compete this C_4 species. Horton and Neufeld (1998) suggest that the plant has a competitive advantage over native C_3 plants in similar environments because *M. vimineum* may better utilize brief periods of sunlight (‘‘sunflecks’’) for carbon gain, resulting in higher growth rates. Barden (1987) found that, particularly following canopy or groundcover disturbance, *M. vimineum* was able to rapidly invade floodplain forests in North Carolina, out-competing even the highly invasive, shade-tolerant *Lonicera japonica* Thunb. Similarly, it has been suggested that *M. vimineum* can also flourish in full light conditions following canopy disturbances or removals (Oswalt et al., 2004), which could potentially disrupt the natural regenerative processes of native hardwood stands.

This paper focuses on one portion of a larger study designed to investigate the use of artificial oak (*Quercus* spp.) reproduction combined with various silvicultural options. The larger study was designed to test the success of outplanted, high-quality oak seedling stock following canopy disturbance treatments on a highly productive minor floodplain in west Tennessee, USA (Oswalt et al., 2006). Field observations of *M. vimineum* in the forest understory pre- and post-canopy disturbance lead us to believe the species might have an impact on post-disturbance regeneration. Specifically, we noticed what appeared to be a dramatic increase in post-disturbance *M. vimineum*, which we hypothesized would compete with native woody species regeneration, negatively impacting species diversity and seedling density. Therefore, our objectives were to (1) compare *M. vimineum* response (using biomass as a measure of response) in units with canopy disturbance against the control unit, (2) quantify the relationship, if any, between *M. vimineum* percent cover and native woody species regeneration density, and (3) to quantify the relationship, if any, between *M. vimineum* percent cover and native woody species regeneration diversity.

2. Study site

We conducted the study on the Ames Plantation in southwest Tennessee, along an intermittent stream in the headwaters region of the North Fork of the Wolf River (NFWR) (35°09′N, 89°13′W). The site encompasses about 80 acres of mixed hardwood forest dominated by various oak species and is part of the Southeastern Mixed Forest Province (Bailey, 1995). Historically, the study site was used for agriculture, grazing, and timber production. Surrounding properties include woodlands interspersed with soybean, cotton, and other agricultural crops common to the southeast.

Two distinct landforms were identified within the immediate study site: an abandoned minor bottom near the confluence of the stream with the NFWR and ancestral terraces of the stream (Hodges, 1997). Changes in local hydrology have precluded these sites from the influence of flooding.

The headwaters region of the NFWR is located within the Mississippi Embayment of the Gulf Coastal Plain. The geology is dominated by the highly erodible Wilcox and Claiborne formations of Tertiary age exposed by the erosion of Quaternary and Tertiary fluvial deposits and the overlying Pleistocene loess deposits common in western Tennessee (Safford, 1869; Fenneman, 1938). The principal soil groups are Grenada-Loring-Memphis on the terraces and Falaya-Waverly-Collins within the minor bottom (USDA, 1964).

3. Methods

3.1. Study design

In fall, 2001, we identified three experimental blocks based on landform and position. Differences in average stand basal area were significant among the blocks (20–36 $m^2 ha^{-1}$, $P = 0.04$), which appeared to be a result of past selective cutting. Twelve 0.8 ha treatment units (about 61 m × 122 m) were designated within the experimental blocks with four units located within the minor bottom (bottom block) and eight units located within the terrace sites upstream from the minor bottom (four each within the East and West blocks). Dominant species composition at the time of establishment consisted of oak on the ancestral terraces and yellow-poplar (*Liriodendron tulipifera* L.) and sweetgum (*Liquidambar styraciflua* L.) in the minor bottom (Oswalt et al., 2006).

Three canopy disturbance treatments (0 $m^2 ha^{-1}$ or 0% residual canopy; 3.2 $m^2 ha^{-1}$ or 10% residual canopy; and 4.6 $m^2 ha^{-1}$ or 20% residual canopy) and an undisturbed control (32.6 $m^2 ha^{-1}$ or 100% residual canopy) were randomly assigned to the four units within each of the three replicate blocks using a randomized complete block design. Canopy disturbance treatments were completed in the winter of 2001–2002 and represent a gradient from the most severe disturbance (complete canopy removal) to least severe or no disturbance (undisturbed control) (Table 1).

3.2. Vegetation sampling

To compare post-treatment *M. vimineum* biomass between treatment units and the control, herbaceous biomass was measured monthly (35–45 days) throughout the first (2002) growing season for three periods (early, mid, and end-of-season). Five randomly placed 0.01 m^2 samples were collected within each block-by-treatment combination, resulting in 60 samples for each of the three measurement periods ($n = 180$). All material was clipped at ground level, categorized, dried (50 °C for 72 h), and weighed *sensu* Mueller-Dombois and Ellenberg (1974). Although *M. vimineum* was not expressly quantified prior to canopy disturbance, the species was positively identified within all units before treatment, and no qualitative differences were noted. Therefore, the control unit was assumed to be representative of pre-disturbance conditions.

Table 1
Description and residual basal area for each canopy disturbance treatment

Treatment	Description	Residual basal area ($m^2\ ha^{-1}$)
Complete (100%) canopy removal (commercial clearcut)	Removal of all stems >15 cm dbh	0
90% canopy removal (two age)	Residual stand basal area of 1.8–2.5 $m^2\ ha^{-1}$ was targeted. Residual stems were chosen based on spacing criteria and the desire to leave stems of desirable species with an opportunity to increase in value. Desirable species included oaks, hickories (*Carya* spp.) and yellow-poplar	3.2
80% canopy removal	Removal of all stems >35.5 cm dbh	4.6
Undisturbed control	Designed to act as the study control. No removals.	32.6

To evaluate the impacts of *M. vimineum* on woody regeneration density and species diversity, percent cover estimates for *M. vimineum* were recorded in late summer 2003 from 60 systematically located 1 m^2 plots in each unit for a total of 720 plots. Concomitantly, cover estimates were recorded for the only other significant non-native invasive, *Lonicera japonica* (Thunb.), within the same plots. Native woody species regeneration in four height classes (<0.61 m, 0.61–1.22 m, 1.22–1.83 m, and >1.83 m) was quantified using a 0.0004 ha (1/1000 acre) plot nested within a 0.004 ha (1/100 acre) plot. Six plots were recorded for each unit for a total of 72 plots. Each regeneration plot was classified into 1 of 4 broad *M. vimineum* cover classes (<25%, 25–50%, 51–75% and >75%) through spatial association with the *M. vimineum* plots.

3.3. Statistical analysis

Mixed-model analysis of variance and least square means were used to discern differences in end-of-season biomass response, native woody species (NWS) density (stems ha^{-1}) and NWS diversity among canopy disturbance levels (SAS Institute Inc., 1989). We compared total native woody species (NWS) density (stems ha^{-1}) among canopy disturbances, and across four height classes to ensure that the populations of comparison were similar. We then used polynomial regression to identify possible relationships and trends between total square-root transformed NWS stems ha^{-1} and mean *M. vimineum* cover and an aggregated variable, referred to as non-native invasive species, of *M. vimineum* and *L. japonica*. In addition, we were interested in whether stem height would influence relationships between NWS density and vegetation percent cover, so we repeated the polynomial regression using stems ha^{-1} by height class as separate dependent variables, and mean *M. vimineum* cover as independent variables.

Shannon's and Simpson's diversity indices, along with species richness, were used to quantify NWS diversity. To ensure that treatment was not a covariant factor in NWS diversity regression models, we compared species richness among three canopy treatments (no control) using ANOVA. We then used simple linear regression to identify possible trends and relationships between diversity and mean *M. vimineum* cover across two diversity indices (Shannon's H and Simpson's D). Simple linear regression was also used to investigate possible relationships between diversity and mean non-native invasive cover across both diversity indices. In addition, protected one-way analysis of variance using Tukey's studentized range test to control for Type I experiment-wise error was used to detect differences in both NWS density and diversity (Shannon's and Simpson's indices and species richness) among broad *M. vimineum* cover classes.

4. Results

4.1. Response to canopy disturbance

End-of-season *M. vimineum* biomass did not differ among the three canopy disturbance treatments ($P = 0.282$), but did differ between treatments and the control ($P = 0.009$). Additionally, *M. vimineum* biomass increased between early- and end-of-season measurements in all treatments with the exception of the uncut control units (Fig. 1). Although large standard errors reflect a large degree of variation around the mean, *M vimineum* biomass was 2–10 times greater than all other vegetation categories in all levels of canopy disturbance, with the exception of the forb category which contained more than 18 species (Table 2).

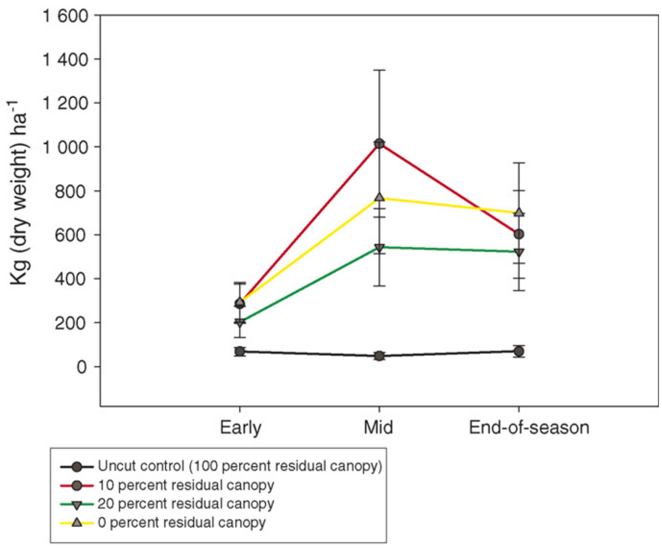

Fig. 1. Mean dry weight of *Microstegium vimineum* biomass among three canopy disturbance treatments and an uncut control across three measurement periods on The Ames Plantation, TN.

Table 2
Most common identified plants for each vegetation category

Species[a]	Common name
(1) Poison Ivy	Poison ivy
Toxicodendron radicans (L.) Kuntze	
(2) Japanese Honeysuckle	
Lonicera japonica Thunb.	Japanese honeysuckle
(3) Forbs	
Acalypha gracilens Gray	Slender three-seeded mercury
Asteraceae L.	Aster family
Boehmeria cylindrica (L.) Sw.	Smallspike false nettle
Centrosema virginianum (L.) Benth.	Spurred butterfly pea
Commelina sp. L.	Dayflower
Desmodium sp. Desv.	Ticktrefoil
Erechtites hieraciifolia (L.) *Raf. ex DC.*	American burnweed
Erigeron sp. L.	Fleabane
Gamochaeta purpurea (L.) Cabrera	Spoonleaf purple everlasting
Impatiens capensis Meerb.	Jewelweed
Phytolacca americana L.	American pokeweed
Plantago sp. L.	Plantain
Solidago sp. L.	Goldenrod
Trifolium sp. L.	Clover
Verbascum sp. L.	Mullein
Viola sp. L.	Violet
(4) Smartweeds	
Polygonum hydropiperoides Michx.	Swamp smartweed
(5) Semi-woody plants	
Rubus argutus Link.	Sawtooth blackberry
(6) Ferns and fern allies	
Phegopteris hexagonoptera (Michx.) Fée	Broad beechfern
Polystichum acrostichoides (Michx.) Schott	Christmas fern
Onoclea sensibilis L.	Sensitive fern
(7) Sedges	
Carex sp. L.	Sedge
Cyperus croceus Vahl	Baldwin's flatsedge
(8) Microstegium	
Microstegium vimineum (Trin.) A. Camus	Japanese stilt grass
(9) Vines	
Campsis radicans (L.) Seem. ex Bureau	Trumpet creeper
Parthenocissus quinquefolia (L.) Planch.	Virginia-creeper
Smilax sp. L.	Smilax
Vitis aestivalis Michx.	Summer grape
Vitis sp. L.	Grape
(10) Grasses	
Dichanthelium commutatum (J.A. Schultes) Gould	Variable panicgrass
Panicum sp. L.	Panicgrass
(11) Rushes	
Juncus sp. L.	Rush
(12) Unknown	

[a] Binomial nomenclature and authority follows USDA, NRCS (2006).

This observation suggests that *M. vimineum* experienced a greater overall response to canopy disturbance than other native and non-native species and validates our observations of dramatic *M. vimineum* response to canopy disturbance (Table 3).

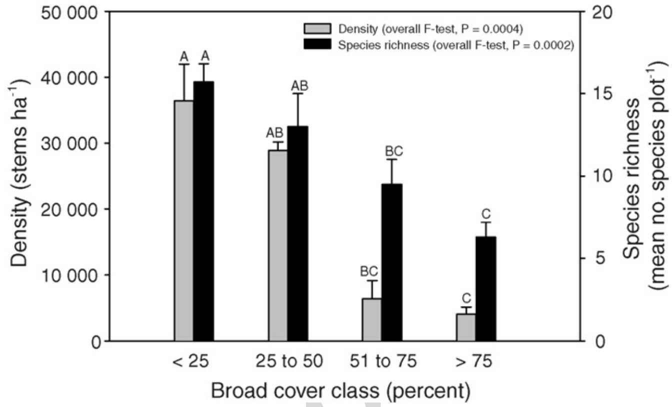

Fig. 2. Mean stem density and species richness of native hardwood seedlings across four broad cover classes of *M. vimineum* on The Ames Plantation, TN.

4.2. Impacts on native woody species stem density

Native woody species density (stems ha^{-1}) did not differ among the three canopy treatments ($P = 0.4104$) or across four height classes ($P = 0.3702$, 0.2560, 0.1959, 0.3410 for height classes 1–4, respectively), supporting our assumption that the samples among the disturbance treatments were similar, and could be pooled for regression analysis. Subsequent polynomial regression indicated a negative relationship between mean non-native invasive species percent cover and total NWS stems ha^{-1} ($r^2 = 0.81$, slope = −1.4, $P < 0.001$). More notably, regression models using only *M. vimineum* percent cover as the independent variable also indicated a strong negative relationship with total NWS stems ha^{-1} ($r^2 = 0.80$, slope = −1.1, $P < 0.001$), suggesting that *M. vimineum* may be driving the relationship. Interestingly, similar polynomial regression models indicated that *M. vimineum* may have had a greater influence on the smaller height classes. The coefficient of determination was larger and associated *P*-value smaller for height class 1 ($r^2 = 0.82$, $P < 0.0001$). Progressing through larger height classes resulted in decreasing R^2 values and increasing *P*-values until significant relationships no longer existed for the largest seedling height class ($r^2 = 0.70$, $P < 0.0001$, $r^2 = 0.50$, $P = 0.002$, $r^2 = 0.16$, $P < 0.11$ for HC2, HC3 and HC4, respectively).

Native woody species density (total stems ha^{-1}) differed among the four broad *M. vimineum* cover classes ($P = 0.0004$) (Fig. 2). The >75% cover class resulted in significantly fewer stems ha^{-1} than both the <25% and 25–50% cover classes.

4.3. Impacts on native woody species diversity

Native woody species richness did not differ among the three canopy treatments (control excluded) ($P = 0.782$), supporting our assumption that treatment populations were similar and could be pooled for analysis. Simple linear regression using Shannon's H diversity index as the dependent variable and total mean percent cover of all non-native invasive species as the independent variable indicated a moderately negative relationship ($r^2 = 0.42$, slope = −0.008, $P = 0.005$). Rerunning the regression model using Simpson's D diversity index confirmed

Table 3
Mean end-of-season herbaceous biomass (dry weight) estimates for each of the twelve vegetation categories across four levels of canopy disturbance

Herbaceous category	Percent residual canopy			
	0	10	20	30
Biomass in kg ha^{-1} (S.E.)				
Ferns	0 (0)	0 (0)	0 (0)	74 (44)
Forbs	1864 (849)	2797 (600)	1612 (888)	0 (0)
Grasses	102 (51)	238 (157)	327 (239)	0 (0)
Japanese honeysuckle	287 (188)	45 (24)	371 (261)	22 (8)
M. vimineum	2194 (1665)	3513 (1605)	800 (800)	116 (81)
Poison ivy	110 (110)	11 (11)	57 (57)	18 (11)
Rushes	53 (49)	38 (25)	23 (12)	33 (33)
Sedges	115 (81)	169 (106)	130 (73)	2 (2)
Semi-woody	14 (9)	6 (6)	9 (9)	25 (16)
Smartweeds	267 (241)	36 (3)	238 (213)	8 (8)
Vines	125 (94)	99 (76)	221 (113)	1 (1)
Unknown	19 (19)	16 (16)	0 (0)	0 (0)

a weak negative relationship between diversity and percent cover of non-native species ($r^2 = 0.28$, slope = −0.028, $P = 0.03$).

Finally, running the regression model using Shannon's H as the dependent variable and *M. vimineum* alone as the independent variable produced results similar to the first model, with an r^2 value of 0.47, and a slope of −0.007 ($P = 0.002$). Rerunning this model using Simpson's D diversity index again showed a weak negative relationship ($r^2 = 0.31$, slope = −0.02, $P = 0.02$).

Both species richness and Shannon's H diversity index differed among the broad *M. vimineum* cover classes ($P = 0.0002$ and $P = 0.01$, respectively) (Figs. 2 and 3, respectively). Similar to the regression analysis, ANOVA results indicate that species richness consistently declined with progressively increasing *M. vimineum* percent cover. Differences are particularly noticeable between the <25 and >75% cover classes. Differences in Shannon's H among the broad cover classes include only a difference between the <25 and >75% classes (Fig. 3).

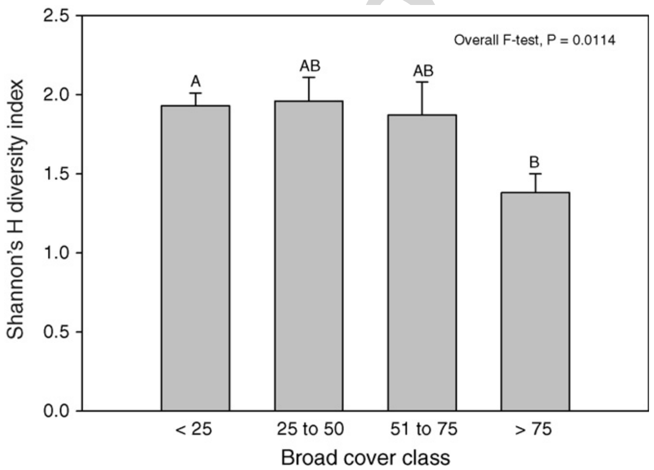

Fig. 3. Calculated Shannon's diversity index of native hardwood seedlings across four broad cover classes of *M. vimineum* on The Ames Plantation, TN.

5. Discussion and conclusion

Our findings suggest that *M. vimineum* responds to canopy disturbance with a sudden increase in biomass, subsequently impeding regeneration of native woody species and lowering overall species diversity and stem densities. Rapid, explosive increases in growth led to the development of *M. vimineum* "mats" on the forest floor (Fig. 4), a phenomenon that may impede native woody species regeneration in multiple ways: directly, through competition for sunlight, nutrients, and water and indirectly, by reducing the likelihood of successful seed to soil contact for germination. Our findings support those of Barden (1987) who also found that, following canopy disturbance, *M. vimineum* was able to rapidly invade forests, out-competing other species.

Results from our regression analyses support our hypothesis that *M. vimineum* growth following canopy disturbance impedes regeneration. Our results suggest that as levels of non-native invasive species cover increase, the ability of woody stems to successfully compete decreases. The trend remains strong when understory vegetation categories other than *M.*

Fig. 4.

vimineum are removed from the model, suggesting that *M. vimineum* is driving the relationship. Our results also suggest that, in addition to reducing the density of woody stems ha^{-1}, *M. vimineum* may also negatively impact the woody species richness of disturbed sites. Other authors have documented similar decreases in species diversity following invasion by non-native species (Gordon, 1998).

The results from this study suggest that *M. vimineum* may be a threat to woody species regeneration following canopy disturbance. As a result, this easily overlooked understory grass warrants further attention by researchers and land managers. Our findings represent one growing season, therefore, we may find that trends stabilize or reverse over time. Additionally, we suspect that the dense mats of dead material formed by the plant during the winter may act as mulch for planted seedlings or trees that are able to successfully establish and push up through the grass layer.

Further studies may reveal that the formation of a new canopy layer over time, decreasing the amount of light, moisture, and nutrients available to herbaceous plants, may result in a steady decline in *M. vimineum* cover. Such a decline may result in the system ''resetting'' itself until another canopy disturbance occurs, though effects on the herbaceous plant composition may persist.

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