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ScienceDirect
Forest Ecology and Management 249 (2007) 199–203
Forest Ecology and Management
www.elsevier.com/locate/foreco

Winter litter disturbance facilitates the spread of the nonnative invasive grass *Microstegium vimineum* (Trin.) A. Camus

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Received 19 January 2007; received in revised form 27 April 2007; accepted 7 May 2007

Abstract

We investigated the impacts of winter litter disturbance on the spread of the nonnative invasive plant *Microstegium vimineum* (Trin.) A. Camus through experimental removals. We hypothesized that light penetration through the litter layer facilitates the spread of *M. vimineum* in forested systems. Our objective, therefore, was to quantify *M. vimineum* spread following litter removal. Linear spread and cover expansion from established *M. vimineum* patches was documented for one growing season under intact, undisturbed hardwood canopies within plots receiving one of two treatments. Treatments included litter removal (hereafter "removal") and no litter removal (hereafter "undisturbed"). After one growing season, plots receiving the removal treatment experienced a spread of *M. vimineum* 4.5 times greater than plots receiving the undisturbed treatment ($P < 0.0001$; 1.66, and 0.37 m expansion, respectively). Cover expansion (measured as percent cover in 0.5 m^2 blocks at 0.5, 1, 1.5, and 2 m from established *M. vimineum*) averaged 16, 4, 0, and 0%, respectively, for the undisturbed treatment and 87, 64, 31, and 9%, respectively, for the removal treatment. Differences existed in cover expansion between treatments at the 0.5, 1, and 1.5 m distances ($P < 0.0001$, $P < 0.001$, and $P = 0.01$, respectively). Our results suggest that winter litter removal as a result of harvest activities, floodwater scour, or animal activities can drastically increase *M. vimineum* spread and may enhance potential ecological impacts of invasions by increasing *M. vimineum* percent cover. Previous studies have shown that *M. vimineum* responds to canopy removal with dramatic increases in biomass. This study suggests one mechanism facilitating rapid expansion of *M. vimineum* following site disturbance, and indicates that *M. vimineum* can experience rapid growth in response to site disturbance even in the absence of canopy removal.
Published by Elsevier B.V.

Keywords: Dispersal; Disturbance; Invasive species; Japangrass; *Microstegium vimineum*; Litter layer; Nepalese browntop; Regeneration; Seed ecology

1. Introduction

Nonnative invasive plant species threaten native biodiversity (Mooney and Cleland, 2001) and alter the structure of forest stands and function of ecosystems (Gordon, 1998; Mack et al., 2000; Oswalt et al., 2007). Consequently, efforts to identify both natural and anthropogenic factors that influence the establishment and spread of nonnative invasive species have become a focus of both basic and applied ecological research. While the factors that determine whether a plant species will successfully establish and spread have been extensively investigated from a basic research perspective (e.g. investigations of resource availability, propagule supply, and ecological resistance) (Lodge, 1993; Davis et al., 2000; Levine et al., 2004; Sutherland, 2004; Lockwood et al., 2005), explanations are not complete (Gordon, 1998). Moreover, the impacts of human activities, such as silvicultural operations, on the spread of many nonnative invasive plants remain unclear.

M. vimineum is a shade-tolerant C_4 grass originating from Asia. Unlike most C_4 plants, *M. vimineum* successfully invades and persists under low-light conditions in the forest interior of the Eastern United States. In the Southeastern States, *M. vimineum* is frequently found in highly productive alluvial forests where native shade-tolerant species might be expected to outcompete 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 floodplain scour, *M. vimineum* was able to rapidly invade floodplain forests in North Carolina, outcompeting even the highly invasive, shade-tolerant *Lonicera japonica*.

M. vimineum is spreading throughout the eastern deciduous landscape (US Department of Agriculture, 2006) and researchers

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0378-1127/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.foreco.2007.05.007

have hypothesized the mechanisms involved in its establishment and spread (Barden, 1987; Oswalt et al., 2004; Cole and Weltzin, 2004), and its impacts on native flora and fauna (Oswalt et al., 2004, 2007). Posited and assumed mechanisms contributing to the transport of *M. vimineum* include prolific seed production, "hitchhiking" on fauna, and transport via floodwaters (Barden, 1987; Miller, 2003). Hypothesized mechanisms of establishment and persistence include disturbances to existing groundcover vegetation and increases in light availability through canopy disturbance (Barden, 1987; Oswalt et al., 2004; Cole and Weltzin, 2005; Buckley and Marshall, 2005).

Many aspects of *M. vimineum* invasions remain unclear. *M. vimineum* is a plastic species with wide ecological amplitude. Multiple interacting mechanisms combined with the ability of *M. vimineum* to compensate for inadequate resources like light and/or moisture hamper the ability to narrowly define the driver(s) of *M. vimineum* distribution. *M. vimineum* can persist year after year as a small, inconspicuous plant in low-light conditions (Horton and Neufeld, 1998) while producing copious seed that may have the ability to persist for up to 3 years, and to vigorously respond to increased light (Barden, 1987; Miller, 2003; Oswalt et al., 2004, 2007). This is supported by evidence presented by Cole and Weltzin (2005). However, those authors suggest *M. vimineum* seed does not remain viable for long periods of time, while other authors have suggested it does (Barden, 1987; Miller, 2003).

Multiple researchers anecdotally mention bare soil or disturbance of organic matter and leaf litter when describing optimal conditions for the establishment and spread of *M. vimineum* (e.g. Barden, 1987; Gibson et al., 2002; Cole and Weltzin, 2004). However, beyond anecdotal site descriptions, light availability due to litter disturbance tends to be ignored as a potentially important mechanism facilitating expansion. Instead, general theories regarding establishment and expansion tend to focus on light availability via canopy disturbance. Additionally, some researchers mention that *M. vimineum* tends to be common on moist soils adjacent to riverbanks but are then surprised to find that soil moisture itself does not appear to be a correlate in the persistence or spread of the species, all the while overlooking the tendency for scouring and subsequent removal of leaf litter and exposure of mineral soil along creek banks and floodplains. For example, Cole and Weltzin (2004) investigated multiple environmental correlates to the presence and abundance of *M. vimineum* on a study site in Oak Ridge, TN. Throughout the study, the authors suggest conditions where leaf litter is absent or reduced (e.g. floodplains and riparian zones, steep or nearly vertical sinkholes, roadsides and trails, clearcut or otherwise manipulated sites), and their correlative study reveals negative correlations between *M. vimineum* biomass and litter mass in all but one site (a clearcut) (Cole and Weltzin, 2004). Additionally, their linear regression indicate that at one site, litter mass explained over 50% of the variation in *M. vimineum* biomass and shoot length. However, the relationship between *M. vimineum* biomass and litter mass, while discussed further, was beyond the scope of the experiment and was not fully explored, while *M. vimineum* biomass development and presence/absence were largely attributed to soil pH and light availability associated with canopy density.

In a later study, Cole and Weltzin (2005) note that *M. vimineum* is often absent beneath mid-story trees, and test various hypotheses to help explain that phenomenon. In their 2005 study, the researchers conducted both *in situ* and greenhouse experiments. In the *in situ* experiments, the researchers removed all litter and existing vegetation prior to sampling, confounding the ability to judge whether canopy openness or light penetration through the litter layer facilitate the spread of the species (Cole and Weltzin, 2005). While there is no doubt that light availability associated with canopy density impacts *M. vimineum* growth and expansion, the overall plasticity of the species and its wide ecological amplitude suggest that a variety of environmental factors facilitate spread and growth. Buckley and Marshall (2005) likewise suggest that it is unlikely that a "single overriding factor" can be used to predict *M. vimineum* performance.

We posit that, in addition to the degree of canopy openness, light availability due to litter disturbance or removal is also an important factor in *M. vimineum* establishment and expansion. Multiple factors influence seed germination. Light cues can either promote or inhibit germination in herbaceous plants (Galagher and Cardina, 1997; Malik and Vanden Born, 1987). Soil moisture, oxygen exchange, and osmotic potential also partially control germination (Drew, 1992; Gutterman et al., 1992). The proximity of a seed to the soil surface impacts the level of moisture available to a developing seed and may promote germination (Wuest et al., 1999). Boyd and Van Acker (2004) tested the germination success of several annual and perennial weed species under varying light conditions, oxygen levels, and osmotic conditions. They concluded that the effects of light penetration to the soil surface, soil oxygen concentrations, and soil osmotic potential on germination varied by individual species, and that *in situ* tests were necessary to evaluate "real-life" effects of the environment on weed germination (Boyd and Van Acker, 2004).

Here, we used a simple manipulative experimental design to investigate the possibility that winter litter disturbance facilitates the expansion of *M. vimineum* within an undisturbed forested hardwood system in the southeast. Our objective was to quantify the extent of *M. vimineum* spread from previously established patches following winter litter removal under an intact hardwood canopy. Specifically, we hypothesized that winter litter disturbance, through complete litter removal, would facilitate both the linear spread and increased cover of *M. vimineum*.

2. Methods

We conducted the study on the Ames Plantation in southwest Tennessee in the headwaters region of the North Fork of the Wolf River (NFWR) (35°09′N, 89°13′W). The site consists primarily of mixed hardwood forest dominated by various oak species (*Quercus* sp.) and yellow poplar (*Liriodendron tulipifera*), 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.

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). Principal soil groups include Grenada–Loring–Memphis and Falaya–Waverly–Collins (US Department of Agriculture, 1964). Mean annual precipitation is approximately 142 cm, mean maximum and minimum temperatures are 70.8 and 47.5 °F, respectively and mean annual growing season length is approximately 225 days.

In the late summer of 2004, established *M. vimineum* patches were identified and marked for relocation and future plot/treatment installation. In December 2004 a total of 40 plots (2 m × 0.5 m) were established within 10 blocks of two replicates each (two plots per replicate, two replicates per block, Fig. 1). Each block consisted of one established *M. vimineum* patch located beneath an undisturbed, closed hardwood canopy and controlled for slope and aspect. In addition, plots were controlled for large differences in initial leaf litter thickness. Plot installation resulted in each plot radiating 2 m out from the established *M. vimineum* patch with the 0.5 m face adjacent to the patch. One of two treatments was randomly assigned to each plot within a block. Treatments included a disturbed (litter removed) and undisturbed (no litter removed) litter layer. For the disturbed treatment all leaf litter was removed from the plot and special care was taken to leave the A horizon intact. Plots were visually marked in such a way as to minimize the chance of further anthropogenic disturbance.

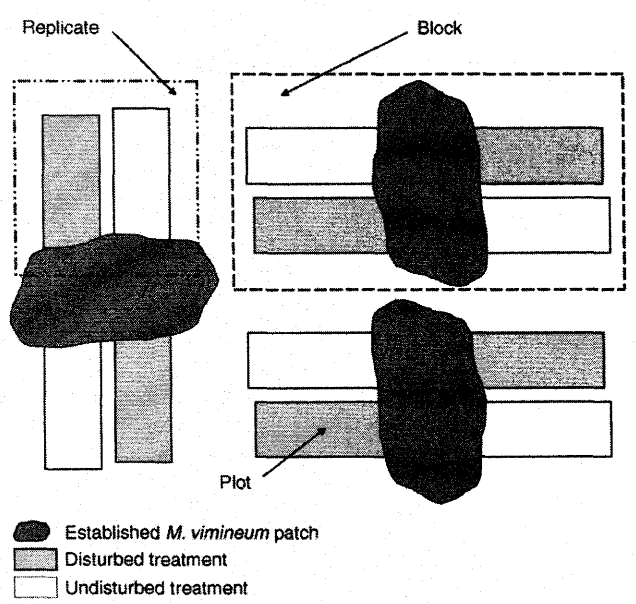

Fig. 1. Experimental design showing plots within replicates and replicates within blocks.

Linear spread and cover expansion from established *M. vimineum* patches were documented following one complete growing season in the fall of 2005 for each plot. Linear spread was quantified by measuring the linear distance (meters) from the previously delineated boundary between the plot and established *M. vimineum* patch to the furthermost stem of *M. vimineum*. Cover expansion was quantified by estimating percent *M. vimineum* cover for each of four 0.5 m^2 subsections of the plot (Fig. 1), defined as 0–0.5, 0.5–1.0, 1.0–1.5, and 1.5–2.0 m in progressive 0.5 m divisions from the established *M. vimineum* patch. Simple analysis of variance (ANOVA) was used to test for significant differences between treatments for linear spread and cover expansion with α of less than 0.05 used to indicate differences. Fishers Least Significant Difference (LSD) tests were used for post-ANOVA mean separation (SAS Institute Inc., 1999). A simple one-sample *t*-test was used to test if the linear spread of the undisturbed plots was different from zero.

3. Results

After one growing season, plots receiving the disturbed treatment experienced *M. vimineum* spread 4.5 times greater than plots receiving the undisturbed treatment (Fig. 2, $P < 0.0001$). Linear spread averaged 1.66 and 0.37 m for the disturbed and undisturbed treatments, respectively. The least amount of linear spread was 1.2 m, while the largest linear spread distance was 2.2 m (0.2 m beyond the disturbed plot). The large difference between the mean linear spread for the two treatments (1.29 m) validates the hypothesis that winter litter disturbance would facilitate the extension of established *M. vimineum* invasions.

Commensurate with the linear spread analysis, cover expansion from established *M. vimineum* was greatest for the disturbed plots (Fig. 3). While mean *M. vimineum* cover decreased significantly as subsection distance from the established plot increased for both the undisturbed and disturbed plots, *M. vimineum* cover was significantly greater for each subsection within the disturbed plots ($P < 0.001$). *M.*

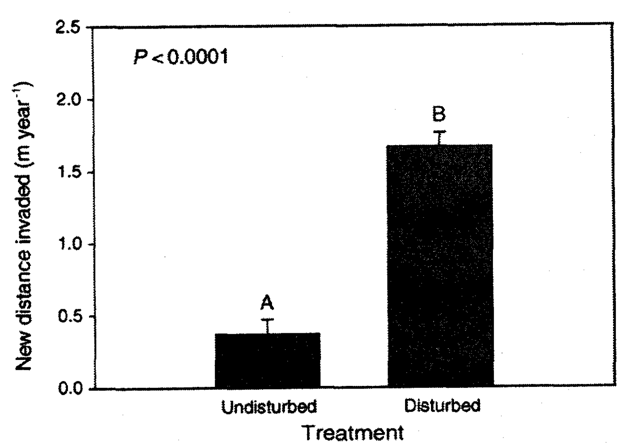

Fig. 2. Mean linear distance invade by *Microstegium vimineum* for the disturbed and undisturbed treatments.

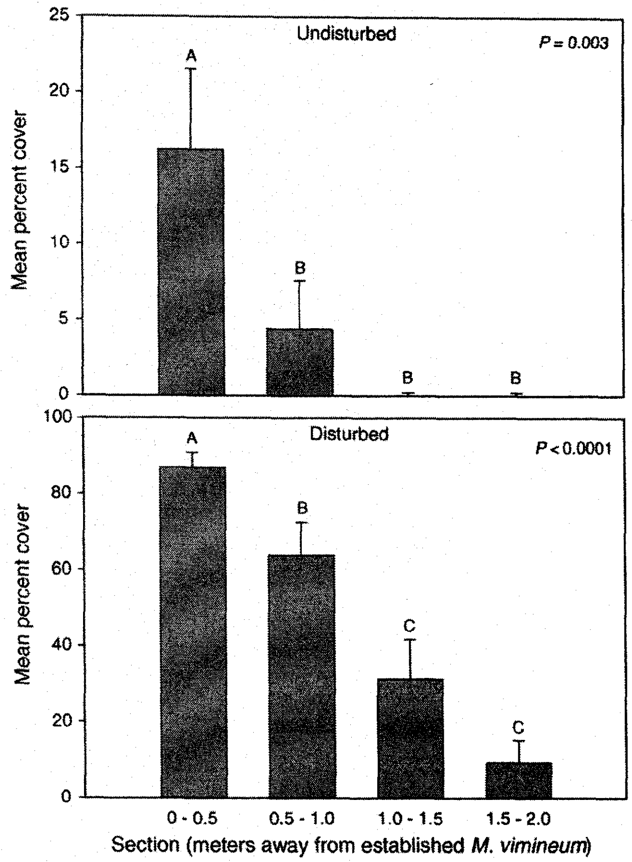

Fig. 3. Mean percent cover of *M. vimineum* in each of four measured plot sections for the disturbed and undisturbed treatments.

vimineum cover averaged 16, 4, 0, and 0% for the undisturbed treatment and 87, 64, 31, and 9% for the disturbed treatment in the 0–0.5, 0.5–1.0, 1.0–1.5, and 1.5–2.0 m subsections, respectively. Differences in cover expansion existed between treatments at the 0.5, 1, and 1.5 m distances ($P < 0.0001$, $P < 0.001$, and $P = 0.01$, respectively).

4. Discussion and management implications

It is well known that silvicultural operations, such as harvesting activity, can significantly disturb the leaf litter layer in hardwood stands. Specifically, the movement of mechanical machinery within a stand will often cause relocation of litter causing some areas, particularly skid trails and paths, to be devoid of an appreciable leaf litter layer. Accordingly, the results of this study suggest that harvesting activities are likely to increase the extent of an *M. vimineum* invasion when the plant is present prior to site manipulation. Of course, leaf litter disturbance as a result of harvesting will be dependent upon the intensity of the harvesting operation and the site conditions of the harvest. Likewise, native faunal trails established in the late fall and winter, if adjacent to established *M. vimineum* patches, may also act as a conduit to spread the nonnative grass or increase the severity of a small invasion.

Methods in this study were designed to avoid disturbances to mineral soil layers. Therefore, it is unclear at this point if more severe disturbances that perturb multiple soil horizons would result in different levels of spread. However, preliminary results from ongoing investigations by Buckley and Marshall (2005) indicate that such disturbance severity can still result in significant increased *M. vimineum* presence. In addition, Buckley and Marshall (2005) are investigating multiple mechanisms and interactions among those mechanisms that influence *M. vimineum* establishment and growth at multiple scales.

Interestingly, *M. vimineum* linear spread was significant for even the undisturbed treatment ($P = 0.004$). In this study, *M. vimineum* was able to spread from established patches an average of 0.37 m (1.2 ft) over one growing season below closed canopy forests even when the litter layer was undisturbed. Although this trend was somewhat expected, it is an alarming example of the ability of *M. vimineum* to persist and spread under a variety of conditions, and yet another indication that multiple environmental factors contribute to the establishment and growth of the species.

Resource managers often associate the spread of invasive plant species with changes in forest canopy cover and, therefore, light availability to the forest floor. This study shows, however, that canopy disturbance is not always necessary to facilitate invasive species spread. In fact, adaptable species like *M. vimineum* may respond vigorously to many types of disturbance. Furthermore, when complete or partial canopy removal is coupled with the disturbance of the leaf litter layer, the potential for *M. vimineum* establishment and spread appears to be particularly high. Forest harvesting practices often result in significant disturbances to forested systems. Harvesting activities commonly result in perturbation of the leaf litter layer. The results of this study illustrate how late fall and/or winter harvesting, or similar natural disturbances, can facilitate the spread and increase of the nonnative invasive grass *M. vimineum*. Combined with the results from previous studies (Oswalt et al., 2004, 2007; Cole and Weltzin, 2004, 2005; Buckley and Marshall, 2005) our results suggest that these type of disturbances not only facilitate *M. vimineum* spread, but can also influence the future developmental pathway of the regenerating stand. Oswalt et al. (2004) reported that invading *M. vimineum* can negatively impact the growth of planted hardwood seedlings. Furthermore, a study by Oswalt et al. (2007) illustrated the reduction in hardwood regeneration density and diversity attributed to *M. vimineum*. These studies suggest that *M. vimineum* has the potential to influence both the future species composition and future stand structure, drastically altering the developmental trajectory of the stand and significantly influencing its economic and ecological value.

Acknowledgements

Funding for this research was provided by The University of Tennessee Department of Forestry, Wildlife and Fisheries and the U.S. Forest Service, Southern Research Station Center for Bottomland Hardwood Research. The authors gratefully acknowledge the assistance of Dr. Allan Houston and the Hobart Ames Foundation for in-kind support. In addition, the authors thank Dr. Wayne Clatterbuck and Dr. Thomas Brandeis for their reviews and suggestions that resulted in an improved manuscript.

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