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Community-Level Effects of Garlic Mustard Invasion on Wisconsin Forest Communities

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Community-Level Effects of Garlic Mustard Invasion on Wisconsin Forest Communities

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Abstract

Community ecologists frequently assume that impacts of invasive species are negative, but this assertion is poorly supported in the literature. To test this, we surveyed 10 sites invaded with the biennial herb *Alliaria petiolata* (M. Bieb) Cavara and Grande and 3 uninvaded paired sites and tested species diversity between them. We found no significant differences in species diversity between the sites, thereby questioning the hypothesis that invasion causes biodiversity loss. Low biodiversity was instead correlated with human activity, suggesting that niche availability drives invasion in these sites. Nonetheless, invasion "time lag" may be a factor in these sites and long-term, established study is needed to determine effects of the garlic mustard over time.

Introduction

Garlic mustard (*Alliaria petiolata* (M. Bieb) Cavara and Grande) is a nonnative invasive herb implicated in biodiversity loss and community degradation in broadleaf forests across North America (Anderson et. al. 1996, McCarthy 1997, Nuzzo 1993, Welk et. al 2002). However, quantitative data on the effects of garlic mustard on biodiversity in forest communities is lacking, (McCarthy 1997) as is data on community-level effects of invasive species in general (Alvarez and Cushman 2002, Levine 2003 and references cited). Of this, data has often showed some support for invasions causing decline in biodiversity, but results have often been unequivocal (McCarthy 1997) in their correlation between garlic mustard abundance and species diversity, and have suggested that mere presence is enough to cause biodiversity loss. While competition is often used as an explanatory factor for this loss, greenhouse studies have shown the species to have aggressivity equal to native plants (Meekins and McCarthy 1999), further suggesting the unequivocal data surrounding the species. The interrelationship between invasive nonnative species and community diversity has been well established in certain contexts, but less so in this one. Elton's (1958) hypothesis that greater species diversity confers resistance to invasion at the community level has been used as a basis for extensive study (Brown and Peet 2003, Dukes 2002, Kennedy et. al 2002, Knops et. al. 1999, Naeem et. al 2000, Prier-Richard and Lavorel 2000a), for example. However, the correlation that invasion necessarily leads to decreased diversity has not yet equivocally been made. In addition, we wished to explore the link between human presence and activity to invasion and its severity. Garlic mustard is known to actively colonize small disturbances (McCarthy 1997), which anthropogenic activity abundantly provides; human disturbance has been implicated in increasing invasions in existing communities (Vitousek et. al. 1986). The purpose of this study was to explore the relationship between garlic mustard presence, abundance, community diversity, and human impact to determine the correlations between these factors, should any exist.

Data Collection and Experimental Setup

Data for this study was collected as part of an ongoing survey with the Wisconsin Department of Natural Resources intended to gather baseline data before release of biocontrol insects (*Ceutorhynchus* spp.). Data would be collected twice yearly by

Inf. Fig 2. *Map of Experimental Sites.* Experimental sites are represented by black squares. Paired sites are represented by the same square.

volunteers experienced in identifying Wisconsin flora, aided by a botany intern who oversaw all sites. Twelve sites were established in the months of June through August, 2006, throughout the southern half of Wisconsin, mostly on government-owned properties with two private properties included. Study sites were selected based upon continuous, established garlic mustard presence of at least three years and at least 0.5 ha in extent, and commitment from managers to not disturb the site or apply any control measures throughout the duration of the monitoring and insect release study. For the purposes of this study, in 2007 three of these sites were selected to act as baseline areas with identical site setup. Baseline areas were selected to be 500 m or less in proximity with similar soil, topography, and canopy conditions, and no garlic mustard presence. Because of these conditions, only three sites were eligible to contain baseline areas.

Each site contained two 100-meter transects, each containing ten 0.5m (0.5 by 1.0m) quadrats spaced at stratified random intervals, with the first quadrat in each transect at its starting point. If a generated quadrat location did not contain garlic mustard, a new number was generated until the location did. Transects were laid parallel to one another when possible, with 10m separating each transect. In cases where trails, water, or other features intersected transects and prevent them from being laid continuously, transects were moved to the nearest location where they could be established without interruption. To determine presence and abundance of garlic mustard, percent cover estimates were taken at each quadrat of 2^{nd}-year adult plants, 1^{st} year rosettes, total garlic mustard and all other vegetation using 7 cover classes (<1%, 1-5%, 6-25%, 26-50%, 51-75%, 76-95%, >95%). This same scale was also used to record leaf attack in increments of percent removed, with type of damage being noted. All adult plants were measured for height in cm, and number of siliques per plant was recorded. In cases where the density of adults made this unwieldy (>100 adults per quadrat), volunteers measured and recorded height and silique count on the first 30 plants in the

Site Name	County	Forest Type	Soil Type	FQI	Median GM
Devil's Lake	Sauk	Upland Mesic	Silt Loam and Rocky Outcrop	15.58	3
GChris	Buffalo	Upland Mesic	Loam	13	5
Goose Island	La Crosse	Floodplain Mesic	Loamy Sand	10.66	4
Havenwoods	Milwaukee	Lowland Mesic	Silt Loam and Silty Clay Loam	13.86	7
High Cliff*	Calumet	Upland Mesic	Loam	16.44	1
High Cliff (C)*	Calumet	Upland Mesic	Loam	14.33	4
Kettle Moraine* North	Fond du Lac	Upland Mesic	Loam	23.34	1
Kettle Moraine North (C)*	Fond du Lac	Upland Mesic	Loam	25.92	5
Kettle Moraine South*	Jefferson	Upland Mesic	Loam	14.69	1
Kettle Moraine South (C)*	Jefferson	Upland Mesic	Loam	17.67	4
Neosho	Dodge	Upland Mesic	Silt Loam	25.19	3
Storr's Lake	Rock	Lowland Mesic	Silt Loam	15.23	4

Site Fig. 1. *Experimental Site Descriptions.* A designation of "1" of median garlic mustard indicates no garlic mustard (a non-invaded control site). Values beginning with 2 follow the 7 cover classes detailed below in sequential order. An asterisk (*) beside a site indicates that it is paired with another site of the same name, that is, one is a control and one is experimental.

southwest corner of the quadrat. Rosette density was measured using actual counts or, if too numerous, a scale of 7 abundance classes (1-10, 11-25, 26-100, 100-500, 501-1000, 1001-2000, >2001). Percentage of ground cover of soil, wood, leaf, and rock was estimated with the above 7 cover classes or actual measurements totaling 100%, at the volunteer's prerogative. Two measurements of centimeters of leaf litter depth were taken at each quadrat. For the purposes of the biocontrol monitoring, volunteers could choose whether or not to record other plant species, and if they chose to do so could use cover estimates or the cover classes outlined above per quadrat, counts of plants per quadrat, or presence/absence within the quadrat. Ten sites elected to do so and were used in this study. Data used in this study was collected in the months of June, July, and August of 2007 at all twelve garlic mustard sites and in October for the baseline sites. Soil type and soil pH were determined from the USDA Web Soil Survey.

Data Analysis

Species data at all sites was classified to the species level for analysis and exotic species removed from the dataset (presumed to be absent unless "all species" is specified). Because of the method of collection, data was analyzed based on number of quadrats occupied per site, thus the following metrics were calculated as follows: Species richness (S), the Shannon-Weiner diversity index (H) and inverse of the Shannon-Weiner index (H\`). S was defined as S=# quadrats occupied by species. The Shannon-Weiner index (H) is defined as $H=-\sum P \ln P$, where P=# quadrats occupied by species per site/total number of species occurrences. The inverse Shannon-Weiner was defined as H\`=(exp)

H. Sites were classified twice as high or low garlic mustard. The first was a comparative measure of percent cover estimate of garlic mustard versus percent cover estimate of other vegetation. If percent cover of garlic mustard exceeded percent cover of other vegetation at ten or more quadrats, the site was classified as high, if not, as low. The second was a count of number of quadrats containing 26-50% garlic mustard cover. If 10 or more quadrats contained this level of garlic mustard cover, then the site was classified as high, if not, it was classified as low. Human impact was classified as high if it had two of three characteristics: less than 100 meters from a camping area, less than 100 meters from a parking lot or road, less than 100 meters from a frequented trail. FQI (Floristic Quality Index) was calculated for each site as follows: FQI=.mean $C*\sqrt{N}$, where C is the assigned coefficient of conservatism and N is the total number of species occurrences, and mean C=individual C/# species occurring in the site.

To test the differences between the control and invaded sites, we used a one-way analysis of variance (ANOVA) of native species per quadrat in control sites against invaded sites, with no garlic mustard (control sites) as a fixed effect. Species occurrence at uninvaded and invaded sites were also compared using the Kolmogorov-Smirnov (KS) non-parametric test for significant difference. One-way ANOVAs were used to compare number of species per quadrat between uninvaded sites and sites classified as low or high garlic mustard. Student's t-test (two-tailed, paired samples for means) was used to compare native species abundance per site (as opposed to occurrence per site) between the uninvaded sites and their invaded paired sites. Correlation analyses was carried out between the following data and variables: number of native species per quadrat in experimental sites versus quadrat garlic mustard level, overall garlic mustard level, and human impact; and number if native species in all sites versus overall garlic mustard level, human impact, and quadrat garlic mustard level.

We analyzed communities using ordination in PC-Ord 5 (McCune 1999). Invaded and uninvaded sites were analyzed together in two separate analyses. Environmental variables used in both were 1. categorical: invaded or uninvaded, soil type, human impact, and 2. quantitative: pH, FQI, and litter depth. The second analysis included median garlic mustard per site as a categorical variable. Data was analyzed with NMS (Nonmetric Multidimensional Scaling) ordination, a nonparametric method. Data were first analyzed with PO (Polar Ordination or Bray-Curtis ordination) to generate an initial configuration of samples. We used the real data of all species denoted by number of quadrats of occurrence per site. The NMS ordinations were run at 50 iterations. The final axes of the ordination not including garlic mustard were compared using correlation analysis of the final site coordinates against median garlic mustard per site.

Results

One-way ANOVA of species occurrences at all uninvaded and invaded sites did not support the assumption of difference between the sites ($F=0.8122$, $p=0.3684$, $F_{crit}=3.8808$, $\alpha=0.05$). Student's t-test showed no significant differences between plant abundance at the paired sites (t statistic=1.4088, $p=0.1641$, $t_{crit}=2.0000$, $\alpha=0.05$). In addition, the KS test showed no significant difference between species occurrence at invaded and uninvaded sites ($D=0.1333$, $p=0.629$) (Fig 1). Correlation analyses among the raw data showed no significant response of native species to individual quadrat garlic mustard levels or garlic mustard abundance over 25% cover (Table 1). Native species at invaded sites showed medium inverse relationships to relative garlic mustard level and human impact. Quadrat garlic mustard levels at all sites showed no significant response to human impact. Abundance of native species at all sites showed no significant response to relative garlic mustard levels or levels higher than 25% cover and a medium negative response to human impact.

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Correlation Coefficients		
Dependent Variable	*Independent Variable*	*r Statistic*
Invaded Native Species	Quadrat GM Level	-0.05099
Invaded Native Species	Relative Overall GM Level	-0.44036
Invaded Native Species	≥D Overall GM Level	0.07437
Invaded Native Species	Human Impact	-0.49576
Quadrat GM Level	Human Impact	0.01621
All Native Species	Relative Overall GM Level	0.17317
All Native Species	≥D Overall GM Level	0.0846
All Native Species	Human Impact	-0.45107

Table 1. Correlation Responses of Raw Data. Responses of the dependent variables to measures of garlic mustard invasion and human-related disturbance. "Invaded native species" refers to native species occurrences by quadrat at invaded sites only, and "all native species" refers to native species occurrences by quadrat at all sites.

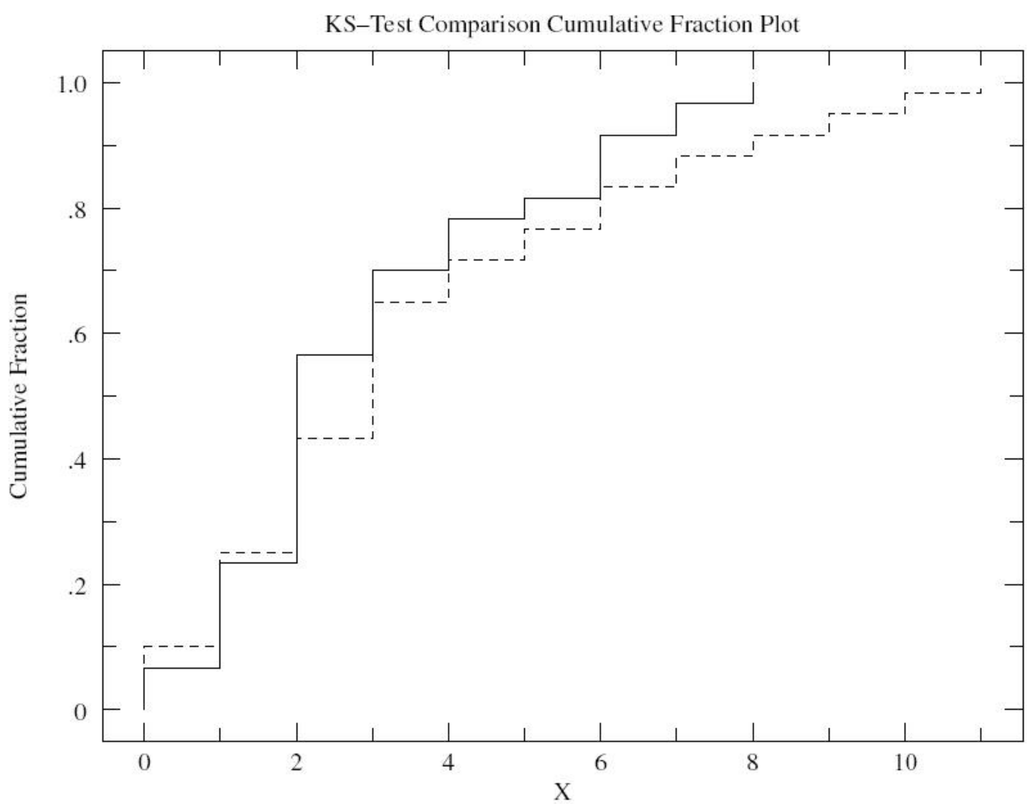

Fig. 1. *Kolmogorov-Smirnov Cumulative Fraction Plot*. Graphical display of data distribution with each "step" displaying percentage of data strictly smaller than X, where X=# of species per quadrat.

Correlation analyses on transformed data (H and H`) showed no significant correlation with median garlic mustard for either index or garlic mustard cover over 25% for H. Garlic mustard cover over 25% showed a small negative correlation to H` and relative garlic mustard level showed a small negative correlation to H and H`.

Correlation Coefficients		
Dependent Variable	*Independent Variable*	*r Statistic*
H	Median Quadrat GM Level	-0.06603
H	Relative Overall GM Level	-.27315
H	≥D Overall GM Level	0.06895
H`	Median Quadrat GM Level	-0.04344
H`	Relative Overall GM Level	-.21932
H`	≥D Overall GM Level	-0.11077

Table 2. *Correlation Responses of Transformed Data-Diversity Indices.*

Ordination results were unable to closely group the sites (Figure 2). Of the axes determined, no one environmental factor was able to describe the first axis, while the second axis was primarily described by leaf litter and the third somewhat described by the FQI (Table 3).

Axis Correlations									
Axis		1			2			3	
	r	r-sq	tau	r	r-sq	tau	r	r-sq	tau
pH	3.17	.100	.337	-.237	.056	-.304	.198	.039	-.048
Litter	.067	.004	.154	-.802	.644	-.585	-.040	.002	.000
FQI	-.116	.013	.182	.135	.018	.152	.547	.299	.364

Table 3. *Environmental Variable Correlations to Non-GM NMS Ordination.*

Axes were also described by the following plant species, with r^2 values accompanying (only species present at 3 or more sites included). Axis 1 was described by *Potentilla simplex* Michx. (.507), *Quercus rubra* L. (.502), *Taraxacum officinale* Weber (.538), and *Viburnum acerifolium* L. (.351). Axis 2 was described by *Parthenocissus quinquefolia*(L.) Planch. (.405). Axis 3 was described by *Circaea lutetiana* L. (.424), *Fraxinus americana* L. (.278), *Geum canadense* Jacq. (.426), and *Rubus idaeus* L. (.304). When tested against these axes, median garlic mustard was found to be significantly correlated to axis 2 (r=.6574), with no significant correlation to any other axis. In the ordination including garlic mustard, axis 1 was largely described by FQI and axis 3

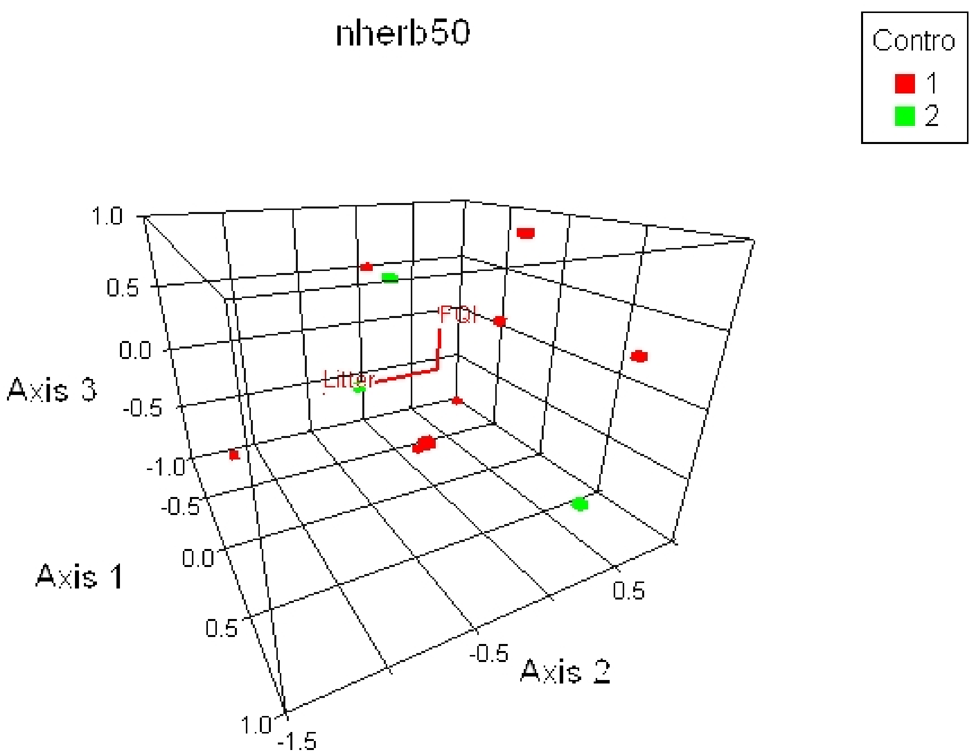

Figure 2. *3-D Ordination Diagram of sites, not including garlic mustard.* Uninvaded sites are represented by green points, while red points represent invaded sites.

largely described by leaf litter. No one environmental factor accounted for axis 2 (Table 4). In this ordination, Axis 1 is described by *Circaea lutetiana* L. (.345), Axis 2 is described by *Potentilla simplex* Michx. (.53), *Taraxacum officinale* Weber (.404) and *Quercus rubra* L. (.387), and Axis 3 is described by *Viola sororia* Willd. (.418). Plants occurring less than 3 times in all sites were also large influences on the axes. Since order of axes is arbitrary in NMS (Gauch 1982), it is unlikely that these two ordinations are significantly different from one another.

Axis		1			2			3	
	r	r-sq	tau	r	r-sq	tau	r	r-sq	tau
pH	-.105	.011	-.112	.247	.061	.176	.347	.121	.048
Litter	-.503	.253	-.215	-.159	.025	.123	.647	.419	.431
FQI	.583	.339	.303	.107	.011	.212	.253	.064	.121

Table 4. *Environmental Correlations to GM NMS Ordination*

Discussion

The results of these studies support previous evidence (Nuzzo 1999, Stinson 2007) that garlic mustard invasion, at least initially, does not lead to a decrease in species richness. Numerous analyses shown above strongly suggest no significant difference between species richness in the uninvaded versus invaded communities. Sites do show a negative correlation to relative garlic mustard cover, but whether garlic mustard has out-competed native species or is taking up space that is otherwise unoccupied is difficult to explicate. Previous evidence has shown that native species, particularly forbs, have the ability to compete equally with garlic mustard (Meekins and McCarthy 1999), and the above evidence shows no correlation to high cover percentage of garlic mustard. Thus, it may be unlikely that it is a competitive effect. Like Stinson et. al (2007), the correlation between garlic mustard and other measures of diversity and equitability (H, H`) are also negative, albeit much less strong. Garlic mustard's effect on diversity in these communities is adverse, but small enough that its significance is questionable. Other factors may contribute more to community decline, such as human impact, which has a medium negative correlation to species abundance at all sites, not simply invaded sites. Garlic mustard invasion was also not correlated with increased human activity, however, this may not necessarily be an explanatory factor in the data. While garlic mustard easily capitalizes on small disturbances (McCarthy 1997), after one such event it is possible that other factors control rate of spread, rather than increased anthropogenic activity. Moreover, we find it more likely that given the possibly limited time scale of this invasion, human activity has had a more profound effect on community degradation than on invasion success, which may change in the future of these communities.

Ordination methods were unhelpful in describing the data as collected. Because of the limited number of sites, small or insignificant factors were able to exhibit a large amount of control over ordination axes (for example, *Toxicodendron radicans,* r^2=0.433 in describing Axis 2 while having only one occurrence in one quadrat in all ten sites, or *Agropyron repens,* r^2=0.446 on Axis 2 while also having only one occurrence in one quadrat at all ten sites). A larger, more comprehensive survey with more species represented more often would be needed to accurately classify these sites to bring to light more explicative data. The ordination did show a negative correlation between Axis 3, which was largely controlled by depth of the litter layer, and garlic mustard abundance at the quadrat level. It is unknown whether this relation could be a consequence of garlic mustard invasion, such as the response seen in other invasive species such as common buckthorn (*Rhamnus cathartica* L., Knight 2007). Garlic mustard's allelopathic activity (Roberts 2001, Vaughn 1999, others) may be responsible for this kind of decline, although this assertion is unsupported and purely hypothetical. Alternatively, garlic mustard may respond positively to forests where litter layers are depauperate where other species do not. As very few species were both numerous and strongly positively correlated with axes controlled by leaf litter, it is difficult to expand this information beyond conjecture.

The results of this study directly contradict the existing paradigmatic idea that garlic mustard, as an invasive, causes biodiversity to decline in invaded communities. This lends indirect support to the idea that garlic mustard is filling empty niches (Mack 1996, Levine and D'Antonio 1999) and that biodiversity decline is not a direct result of invasion. Some simple observations from our study further complicate the issue: for example, the sites at the Northern Kettle Moraine (Site Fig.1, above) show almost twice the floristic quality of the GChris site, despite having equivalent median garlic mustard. Field observations at this site showed plants that were poor quality and often overcome by native species such as *Amphicarpea bracteata* L. Fernald and *Gallium* spp. These observations have the potential for an interesting corollary to Elton's hypothesis, that intact native communities may not simply confer resistance but may have the ability to dampen the effects of an invasion should it occur. However, in this case intact communities were also invaded on equal footing with degraded ones. It is also impossible to discount removal studies which show that diversity resurges after removals (Stinson 2007, McCarthy 1997), suggesting a competitive mechanism. We suggest that it is possible that both mechanisms occur, with primary invasion filling niches and giving the invader a toehold with which to compete. Moreover, the possibility for long-term effects of garlic mustard on community composition at these sites should not be discounted. Invasion at these sites is only confirmed for two years, and the long-term effects of invasion may be far more significant as the "lag time" (Mack 1985, Kowarik 1995) closes. The data show a negative correlation in some diversity metrics (H and H`) before showing any concomitant correlation in richness, suggesting that community evenness may suffer first before invasion causes total eradication of species. The observed decline in these metrics may represent the beginnings of a process which will only reveal itself in subsequent years and timeframes of invasion. Established studies are needed to fully quantify and understand the long-term effects of this invasive on the communities it invades to better inform managers and preserve species diversity should further data support the need to do so.

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