
3 Relationship of Invasive Groundcover Plant Presence to Evidence of Disturbance in the Forests of the Upper Midwest of the United States

*W. Keith Moser, Mark H. Hansen,
Mark D. Nelson, and William H. McWilliams*

CONTENTS

3.1	Introduction	30
3.1.1	Definition of NNIPs	31
3.1.2	Study Region	31
3.1.3	Factors Influencing Invasive Establishment	31
3.1.4	Site	32
3.1.5	Disturbance	32
3.1.6	Competition	33
3.1.7	Spread	33
3.1.8	Adaptation	33
3.2	Study Objectives	34
3.3	Methodology	34
3.3.1	Measurement of Distance from Plots to Roads	36
3.3.2	Fragmentation Data	36
3.3.3	Variable Reduction	37
3.4	Results	37
3.4.1	Presence and Location	37
3.4.2	Relationship between NNIP and Overstory Forest Type	38

3.4.3	Woody Species.....	39
3.4.3.1	Multiflora Rose.....	40
3.4.3.2	Nonnative Bush Honeysuckles.....	42
3.4.3.3	Common Buckthorn.....	43
3.4.4	Herbaceous Species.....	44
3.4.5	Vines.....	45
3.4.6	Grasses.....	47
3.4.7	Regional and Climatic Limitations.....	48
3.4.8	Stand, Site, and Disturbance Factors.....	51
3.5	Discussion and Conclusions.....	53
	Acknowledgments.....	55
	References.....	55

3.1 INTRODUCTION

Nonnative invasive plants (NNIPs) have been introduced to North America by humans since European settlement. Much like other exotic-invasive organisms, NNIPs typically have some advantage over native plants, such as prolific seed production and dispersal. Native forest ecosystems that developed over centuries are limited in their ability to compete against these invaders. Some species, such as kudzu, were deliberately introduced (Mitich 2000), while others were introduced inadvertently, such as in contaminated crop seed. Introduction, however, does not necessarily mean establishment. Although a particular NNIP may have a competitive advantage over native species, timing of emergence and seed dispersal, site quality, and other factors determine whether an NNIP will take hold in an ecosystem. Once established, NNIP threatens the sustainability of native forest composition, structure, function, and resource productivity (Webster et al. 2006).

NNIPs occur in all the major life forms found in forest ecosystems: trees, shrubs, vines, forbs/grasses, and other herbs. Although there is scant knowledge of other life forms, such as lichens and mosses, they are likely to be impacted as well. Examples of invasive trees include Norway maple (*Acer platanoides*) and tree-of-heaven (*Ailanthus altissima*). Many shrub species currently influence North American forests. Some very important examples that have spread nationwide include multiflora rose, bush honeysuckles, Russian/autumn olive, and privet.* Examples of invasive vines include kudzu, Japanese honeysuckle, oriental bittersweet, and mile-a-minute vine. Forbs/grasses and other herbs include a host of species, such as garlic mustard, Japanese and giant knotweed, and Japanese stiltgrass.

NNIPs pose significant challenges for decision makers attempting to develop policies for control and amelioration. There is an underlying need for improvement of inventory and monitoring efforts nationwide. New methods of control and restoration of impacted systems are also needed, and these will require novel approaches because of a dearth of relevant literature. Information on the invasion process indicates that efforts to control invasive plants should focus on the establishment phase (Webster et al. 2006). This introduces further difficulties for monitoring and planning efforts

* Scientific names of the species in this study are listed in Table 3.1.

because populations are sparse in the establishment phase and the subsequent expansion and saturation phases occur rapidly. Once saturation has occurred, the challenges of control and restoration become immense. The high cost of managing impacted forest ecosystems is prohibitive, especially when costly mechanical and chemical activities are required. In some cases, there are no known biological controls for invasive plants. More research on the impacts of invasives and related science is sorely needed.

This issue has become a hot topic not only in local communities, but also in Washington, DC. Dale Bosworth, former Chief of the U.S. Department of Agriculture Forest Service, has listed the threat from invasives among the top four threats facing our forests today:

Another threat is from the spread of invasive species. These are species that evolved in one place and wound up in another, where the ecological controls they evolved with are missing. They take advantage of their new surroundings to crowd out or kill off native species, destroying habitat for native wildlife. ...—at a cost that is in the billions [of dollars]

**Four Threats to the Nation's Forests and Grasslands,
U.S. Forest Service Chief Dale Bosworth at the Idaho Environmental Forum,
Boise, Idaho—January 16, 2004. <http://fsweb.wo.fs.fed.us/pao/four-threats/>.**

3.1.1 DEFINITION OF NNIPs

We define NNIPs as those plants that (1) are not indigenous to the ecosystem and (2) have a competitive advantage that causes deleterious impacts on structure, composition, and growth in forested ecosystems.

3.1.2 STUDY REGION

The Upper Midwest region of the United States is at the nexus of several ecoregions. Historically, the Upper Midwest region encompassed many different forest compositions and structures, ranging from closed-canopy forest in the Lake States and the Ozarks to woodland ecosystems in southern Wisconsin to savannas and prairies in Iowa, Illinois, and Indiana. The fertile soils of this region were ideal for farming, and settlers proceeded to clear the land for agriculture. In the heavily timbered areas of northern Minnesota, Wisconsin, and Michigan and in southern Missouri, large-scale commercial harvesting exploited the magnificent stands of eastern white pine, short-leaf pine, and other species. Subsequent fires and lack of scientific management resulted in a radically altered forested landscape. The combination of settlement or clearing and timber harvesting created a highly fragmented landscape, offering many opportunities for NNIPs to establish in its forests.

3.1.3 FACTORS INFLUENCING INVASIVE ESTABLISHMENT

Studies have identified elements of four factors that influence invasion success: disturbance, competitive release, resource availability, and propagule pressure (Richardson and Pyšek 2006). To gauge if a plant community or habitat is more invasible, investigators must ask not only if there are more potential invaders present

but also whether the habitat is more susceptible to invasions (Lonsdale 1999; Richardson and Pyšek 2006). We will examine how these factors might influence invasibility in the Midwest United States.

3.1.4 SITE

Site quality is an important factor influencing invasion success. Gelbard and Belnap (2003) found that plant communities with high resource availability (i.e., deep, silty, or otherwise fertile soils) were particularly susceptible to disturbance and invasion. They add that disturbance, when combined with high site conditions, maximized a plant community's vulnerability to invasives. Richardson and Pyšek (2006) postulated that resource availability was a facilitator of invasiveness at larger spatial scales. Much has been made of the role of diversity in defending against nonnative invasives (Elton 1958). Yet, Huston and DeAngelis (1994) pointed out that species-rich communities occur in habitats with high levels of heterogeneity in terms of climate, soil, and topography and that alien species are more likely to gain a toehold in such sites than in those habitats that are less heterogeneous. Climate also plays a role. NNIPs often successfully establish in habitats with climate similar to that of their native ecosystems (Richardson and Pyšek 2006). According to Sax (2001), Rapoport's rule states that the number of naturalized species is negatively correlated, and geographic range size is positively correlated, with latitude. We will see evidence of this characteristic later in this chapter.

3.1.5 DISTURBANCE

Disturbance increases the resource availability for plants, including invasive species. Disturbance can upset the competitive balance and site occupancy of prior plant communities, making abiotic factors more important as determinants of invasion success than biotic factors (Richardson and Bond 1991; Hood and Naiman 2000). The larger the difference between gross resource supply and resource uptake, the more vulnerable a plant community becomes to invasive species. Even intermittent or short fluctuations in resource availability have long-term impacts on the outcome of an invasion, particularly if these fluctuations coincide with the availability and arrival of suitable propagules (Richardson and Pyšek 2006).

One prominent indicator of disturbance and a correlate of other measures of disturbance is the density of roads. A study in Utah found that the activities of expanding roads in interior forest areas (road construction, maintenance, and vehicle traffic) "corresponded with greater cover and richness of exotic species and lower richness of native species" (Gelbard and Belnap 2003). An inverse relationship exists between distance to road and prevalence of exotic species (e.g., Watkins et al. 2003), although the influence is most pronounced within 15–30 m of a road. Forman and Alexander (1998) could not document many cases where species spread more than 1 km from a road. For these reasons, this study assumed that distance to the nearest road is a surrogate for human activity, rather than a direct conduit for invasive exotics.*

* In examining the relationship between density of roads and the presence and coverage of invasive species, the assumption was that road density was correlated with any point's distance to the nearest road.

3.1.6 COMPETITION

As we stated earlier, Elton (1958) suggested that there is a negative relationship between native species diversity and community invasibility. He apparently based his hypothesis on the idea that, with less diverse assemblages of species, interspecific competition is less robust because there are empty niches available. Richardson and Pyšek (2006) found numerous studies that supported Elton's hypothesis, but also reported that others found that areas with a high species diversity harbored more alien species. They noted Levine and D'Antonio's (1999) conclusion that species richness may be too broad a factor to explain observed differences in community invasibility, given that other factors (disturbance, nutrient availability, climate, and propagule pressure) are frequently covariates with species richness.

3.1.7 SPREAD

We can sometimes determine the date an invasive plant is introduced into the country or region. The likelihood of invasion increases with the time since the original introduction. "Minimum residence time" (MRT) is often used when the initial introduction of an inoculum is unknown. MRT integrates the time of potential establishment opportunity, the size of the propagule bank (seeds and shoots), and (with expanding populations) the area from which the propagules originate (Richardson and Pyšek 2006). Such knowledge does not always help us to determine the rate of spread. Plant invasions do not move across the landscape in a continuous wave or front; both local and long-distance transport will determine the spatial pattern (Pyšek and Hulme 2005). These authors summarized data about 100 taxa worldwide and found an average local spread rate <400 m per year, but a long-distance dispersal rate that was 2–3 orders of magnitude greater. For this reason, Richardson and Pyšek (2006) concluded that invasions are often faster than most natural migrations. Given the serendipitous nature of inadvertent human transport, the most significant driver of postinvasion spread (Hodkinson and Thompson 1997), it is hard to predict the source and final destination of many invasive species. Those species that are widespread (1) have shown that they are adapted to a wide range of conditions and (2) have a greater source of propagules to continue the spread (Booth et al. 2003).

3.1.8 ADAPTATION

There are several interesting precepts of NNIPs that this study had hoped to examine. Daehler (2001) postulated that exotic species in an area with native species of the same genus have a better chance of naturalizing because they share a certain amount of preadaptation to the conditions of the region. Yet Daehler (2003) also concluded that invasive species have greater phenotypic plasticity than co-occurring native species, suggesting that the shared features are less important than the individually unique ones. Some invaders benefit from release of fitness constraints present in their original habitat while others evolve after arriving in this country (Ellstrand and Schierenbeck 2000). Crawley et al. (1999) speculated that NNIPs may occupy vacant niches at either end of the plant performance spectrum perhaps by growing either very small or very big in size, by flowering very early in the season or very late, or by

foregoing dormancy, or by exhibiting a very long dormant period. However, the interaction of ecological and evolutionary forces is context-dependent (Daehler 2003) and unique to each invasive episode (Richardson and Pyšek 2006).

3.2 STUDY OBJECTIVES

Drake et al. (1989) summarized the then-current knowledge around three fundamental topics: which species invade, which habitats are invaded, and how these invaded ecosystems can be managed. Research to understand the factors influencing the invasibility of a site focuses on the availability of resources, disturbance effects, competition, and the availability of invasive material (“propagule pressure”) (Richardson and Pyšek 2006). We examined characteristics such as overstory basal area, basal area of oak species, stand age, and stand density for clues of their influence over invasive species’ presence and coverage. Variations in overstory diversity, whether compositional (species) or structural (height or diameter), influence available growing space and present opportunities for ground flora. We examined characteristics such as overstory species (compositional) diversity and diameter and height (structural) diversity. Finally, we examined the impact of human influences, such as forest fragmentation and roads.

3.3 METHODOLOGY

Meaningful NNIP inventory requires a large network of sample plots measured consistently over time. Over the past decade, the U.S. Forest Service, Northern Research Station, Forest Inventory and Analysis (NRS-FIA) unit has implemented a new inventory system that embodies the challenges of developing national and international consistency. Complete documentation of the plot design and all measurements can be found at <http://socrates.lv-hrc.nevada.edu/fia/dab/databandindex.html> and North Central Research Station, Forest Inventory and Analysis (NCRS-FIA 2005).

The FIA program utilizes three phases of inventory designed to produce estimates of forest extent, composition, structure, health, and sustainability. Phase 1 uses remote sensing (currently Landsat TM imagery) to identify accessible forestland and to develop stratification layers for improving precision of postsampling stratified estimates. Phase 2 consists of a systematic grid of ground samples where detailed measurements of tree and forest attributes are taken on a 5 year remeasurement cycle with one-fifth of the grid measured every year. Each Phase 2 sample consists of 4–7.3 m (24 ft) radius subplots at an intensity of 1 per 2400 ha (5960 acres) (McRoberts 1999). We included data from the 2005 and 2006 inventory of forest resources on Phase 2 plots in Indiana, Illinois, Iowa, Missouri, Michigan, Wisconsin, and Minnesota. Phase 3 ground samples include more detailed forest health protocols, including a complete ground vegetation sample, that are measured during the summer growing season months on a subset of the Phase 2 samples. Each Phase 3 sample represents about 39,000 ha (96,000 acres). In lieu of national protocols for monitoring all vegetation on Phase 2 samples, some regional FIA programs, including the NRS, have implemented exotic-invasive plant surveys to address the burgeoning need for this information (Rudis et al. 2006).

TABLE 3.1
NNIPs Surveyed on FIA Plots in the Upper Midwest
of the United States in 2005–2006

Common Name	Scientific Name
Woody species	
Multiflora rose	<i>Rosa multiflora</i>
Japanese barberry	<i>Berberis thunbergii</i>
Common buckthorn	<i>Rhamnus cathartica</i>
Glossy buckthorn	<i>Frangula alnus</i>
Autumn olive	<i>Elaeagnus umbellata</i>
Nonnative bush honeysuckles	<i>Lonicera</i> spp.
European privet	<i>Ligustrum vulgare</i>
Vines	
Kudzu	<i>Pueraria montana</i>
Porcelain berry	<i>Ampelopsis brevipedunculata</i>
Asian bittersweet	<i>Celastrus orbiculatus</i>
Japanese honeysuckle	<i>Lonicera japonica</i>
Chinese yam	<i>Dioscorea oppositifolia</i>
Black swallowwort	<i>Cynanchum louiseae</i>
Wintercreeper	<i>Euonymus fortunei</i>
Grasses	
Reed canary grass	<i>Phalaris arundinacea</i>
Phragmites, Common reed	<i>Phragmites australis</i>
Nepalese browntop, Japanese stiltgrass	<i>Microstegium vimineum</i>
Herbaceous	
Garlic mustard	<i>Alliaria petiolata</i>
Leafy spurge	<i>Euphorbia esula</i>
Spotted knapweed	<i>Centaurea biebersteinii</i>
Dame's rocket	<i>Hesperis matronalis</i>
Mile-a-minute weed, Asiatic tearthumb	<i>Polygonum perfoliatum</i>
Common burdock	<i>Arctium minus</i>
Japanese knotweed	<i>P. cuspidatum</i>
Marsh thistle	<i>Cirsium palustre</i>

During 2005–2006, 8663 Phase 2 forested plots were surveyed for presence and cover of any of 25 noninvasive plant species (Table 3.1) (Olson and Cholewa 2005; NCRS-FIA 2005). If one or more of these species was observed, the percent cover was estimated on each subplot and placed into one of seven ordinal categories (Table 3.2). Where an NNIP was found on a plot but had not been previously documented to exist in that state, a specimen was collected and sent to NRS-FIA staff in St. Paul, MN, for positive identification. In winter, the crews treated the plants as if they were in a leaf-on condition for purposes of cover calculation.

Measures of individual trees resulted in summaries of species, diameters, and heights and estimates of density using overstory basal area and the stand density index (SDI) (Reineke 1933; Woodall and Miles 2006) and diversity, using the

TABLE 3.2
Cover Codes and Ranges of Percent
Cover of NNIPs Used in Recording
Invasive Species' Presence, FIA
Plots in 2005–2006

Cover Code	Range of Percent Cover
1	<1%, trace
2	1%–5%
3	6%–10%
4	11%–25%
5	26%–50%
6	51%–75%
7	76%–100%

Shannon index (H') (Shannon 1948; Magurran 1988) for species, heights, and diameters. To convert continuous variables like height or diameter into categorical ones, we assigned heights to 0.9 m (3 ft) classes and diameters to 5 cm (2 in.) classes.

3.3.1 MEASUREMENT OF DISTANCE FROM PLOTS TO ROADS

Distances (km) from NRS-FIA plots to roads were calculated with a geographic information system (GIS), for each of five categories of roads within the ESRI StreetMaps dataset, version 2005, with 2006 updates. Distances were calculated simultaneously from all plots across the seven states to National Freeway, State Freeway, and Major Highway features. Because a large number of local roads within Minor Highway and Local Street features resulted in unwieldy processing, these features were subset and analyzed on a state-by-state basis, including a 20 km buffer around each state to allow for more representative calculations for plots near state boundaries. In addition, the “NEAR” command was constrained to search for the nearest Minor Highway and Local Street within a 10–25 km buffer radius of each plot, with buffer radius varying by state.

3.3.2 FRAGMENTATION DATA

To evaluate fragmentation, we divided total forestland area by total land area in each county. This metric is useful for establishing the relative amount of forested growing space and, by inference, the amount of edge-to-area ratio that would provide the entry for forest invasives. On a smaller scale, we looked at the percent of each plot that was forested. While most of the plots were 100% forested, some of the plots intersected a forest–nonforest edge, giving us a sample of local fragmentation to compare with the county-level measures.

One measure of the effects of disturbance on forests is “forest intactness,” a composite of several metrics of class- and landscape-level fragmentation. We used a sum of ordinal measures prepared by Heilman et al. (2001) in their analysis of fragmentation in 39 forested ecoregions in the lower 48 states. Using

TABLE 3.3
List of Candidate Stand, Site, and Disturbance Variables
for Our Models of NNIP Invasiveness

Stand Variables	Site Variables
Total basal area	Site index
Oak basal area	Aspect (cosine)
Stand age	Physiographic class code
SDI—All	
SDI—5" plus	
H' species	Disturbance Variables
H' diameter	County percent forest
H' height	Plot percent forest
	Minimum distance to the nearest road
	Index of forest intactness (sum of all expanded ordinal scores)

FRAGSTATS 2.0, they combined ordinal scores of road density, class area (the amount of the landscape comprised of a particular patch type), core area (the area within a patch beyond a specified buffer), percentage of landscape (the percentage of the total landscape occupied by a particular class), and nearest neighbor (the edge-to-edge distance to the nearest patch of the same type) (McGarigal and Marks 1995). This summary index combines most measures of fragmentation and provides a representative measure of the entry and establishment opportunities of NNIPs. Because of the way Heilman et al. (2001) defined forests, this index did not apply to all of our plots, omitting many plots in the central part of our region.

3.3.3 VARIABLE REDUCTION

On the basis of the considerations outlined earlier, we started out with 15 candidate variables (Table 3.3). We then employed bidirectional stepwise regression of a linear model of these variables. The stepwise regression was checked by manually removing variables that would reduce the AIC level (Akaike Information Criterion; Akaike 1974) the most. The model with the reduced dataset was rerun to obtain the coefficient and Pr(t) values, which were used to determine the level of significance.

3.4 RESULTS

3.4.1 PRESENCE AND LOCATION

Present-day forested areas are concentrated in the northern and southern edges of the region and include a mix of private and public forest (Figure 3.1). NNIPs are present on many FIA plots throughout the Upper Midwest. Figure 3.2 displays those plots with at least one NNIP present. When comparing this figure to Figure 3.1, we found that invasive species are highly associated with fragmented forests. The juxtaposition of developed areas, agricultural land, and forest has created a vehicle for the establishment and spread of NNIPs in forested landscapes.

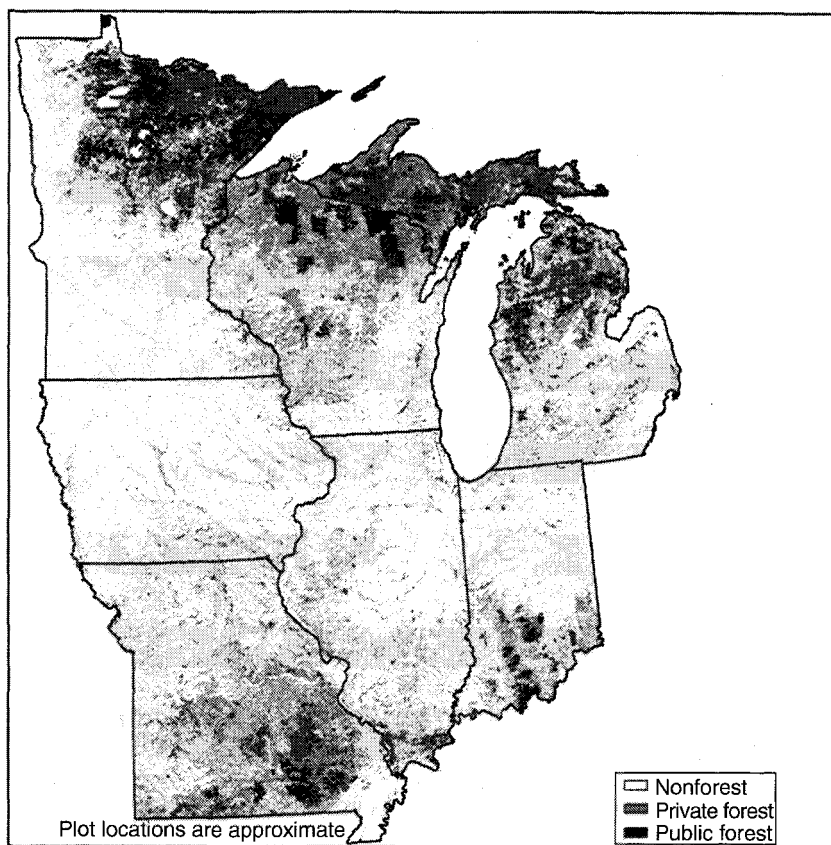


FIGURE 3.1 Distribution of forestland by owner group, Upper Midwest, United States. (From States—ESRI Data & Maps, 2002 ESRI 2002; Ownership—Protected Areas Database, Della Salla et al. 2001.)

Approximately 25% of the forested plots visited in 2005 and 2006 had at least one occurrence of an NNIP (Table 3.4). The top five occurrences included three woody species (multiflora rose, nonnative bush honeysuckles, and common buckthorn), one herbaceous species (garlic mustard), and one vine (Japanese honeysuckle). The second five included common burdock, autumn olive, Japanese barberry, reed canary grass, and marsh thistle.

Figure 3.3 displays the dramatic differences in proportion of plots that have at least one invasive species. In Iowa, Indiana, and Illinois, over 70% of the plots had at least one NNIP on them, while in Minnesota less than 10% of the plots had at least one NNIP.

3.4.2 RELATIONSHIP BETWEEN NNIP AND OVERSTORY FOREST TYPE

Of the 61 total forest types within the Upper Midwest region, 21 were present on the bulk of the plots and three types—aspens, white oak-red oak-hickory, and sugar

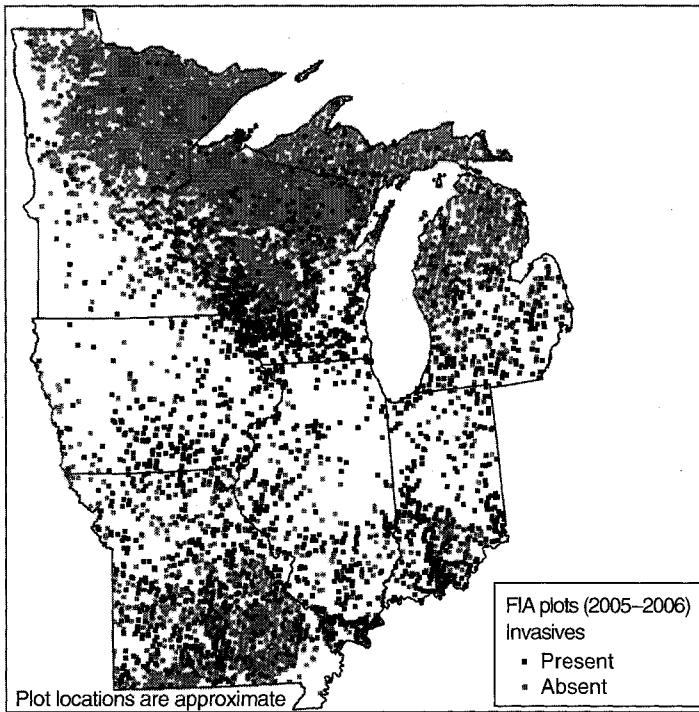


FIGURE 3.2 Distribution of plots with and without invasives of any type, Upper Midwest, 2005–2006.

maple-beech-yellow birch—comprised almost half of the plots (Figure 3.4). Several forest types, including white oak-red oak-hickory, mixed upland hardwoods, and sugarberry-hackberry-elm-green ash had proportions of plots with NNIPs near 50% or greater. To provide an indication of overstory tree density relative to NNIP presence, our NNIP distribution maps overlay the volume per acre of the top 12 species (by volume) in the Upper Midwest.

3.4.3 WOODY SPECIES

Woody NNIPs were the predominant life forms among the invasive plants sampled in this study of the Midwest’s forests (Figure 3.5). Because of their perennial nature, woody NNIPs often were planted for aesthetic and wildlife purposes. Examination of the distribution of woody NNIPs by percent cover reveals strong geographical trends (Figure 3.6). Multiflora rose and nonnative bush honeysuckles were the most prominent species in the region, particularly in Illinois, Indiana, Iowa, and Missouri. Common buckthorn was prominent in most states, particularly Minnesota and Wisconsin, while Japanese barberry was evident in Illinois and Michigan.

TABLE 3.4
Number of Occurrences (Plots) for Each of the 25 Nonnative Invasive Plant Species Sampled during the 2005 and 2006 Panels, Ranked by Number of Occurrences

Seven States Total	Cover Class							
	0	1	2	3	4	5	6	7
Invasive species	0	1	2	3	4	5	6	7
Multiflora rose	7343	351	473	208	136	106	31	15
Nonnative bush honeysuckles	7875	169	231	143	99	75	45	26
Common buckthorn	8248	120	108	56	60	27	28	16
Garlic mustard	8397	57	57	51	36	33	21	11
Japanese honeysuckle	8441	46	54	32	33	31	18	8
Common burdock	8465	93	62	27	9	5	2	0
Autumn olive	8491	39	61	21	21	18	11	1
Japanese barberry	8549	41	49	9	10	3	1	1
Reed canary grass	8574	13	21	10	7	11	12	15
Marsh thistle	8628	18	13	2	0	2	0	0
Spotted knapweed	8634	9	9	3	1	3	4	0
Glossy buckthorn	8637	5	5	3	9	3	1	0
Nepalese browntop	8651	3	3	3	0	1	2	0
Wintercreeper	8652	5	1	1	2	0	1	1
Asian bittersweet	8654	3	4	1	0	1	0	0
Chinese yam	8657	4	1	1	0	0	0	0
European privet	8658	1	0	1	2	1	0	0
Dames rocket	8658	0	1	1	1	1	0	1
Phragmites	8658	1	0	1	1	0	2	0
Japanese knotweed	8660	2	1	0	0	0	0	0
Kudzu	8660	1	1	1	0	0	0	0
Leafy spurge	8662	1	0	0	0	0	0	0
Black swallowwort	8662	1	0	0	0	0	0	0
Mile-a-minute weed	8663	0	0	0	0	0	0	0
Porcelain berry	8663	0	0	0	0	0	0	0

Note: Cover class categories are as follows: 0, none found; 1, <1%, trace; 2, 1%–5%; 3, 6%–10%; 4, 11%–25%; 5, 26%–50%; 6, 51%–75%; 7, 76%–100%.

3.4.3.1 Multiflora Rose

Multiflora rose is a widespread shrub introduced as rootstock for ornamental roses in 1866 (Plant Conservation Alliance 2006). The species was distributed and planted widely for erosion control, “living fences” for livestock, and cover for wildlife. Multiflora rose spreads quickly and establishes dense cover that shades out other plants. Its seeds are dispersed by birds and remain viable in soils for many years. It is currently found across the United States and is classified as “noxious” in several states. Control methods include mechanical and chemical methods that require repeated application for success, making control very expensive (Evans 1983).

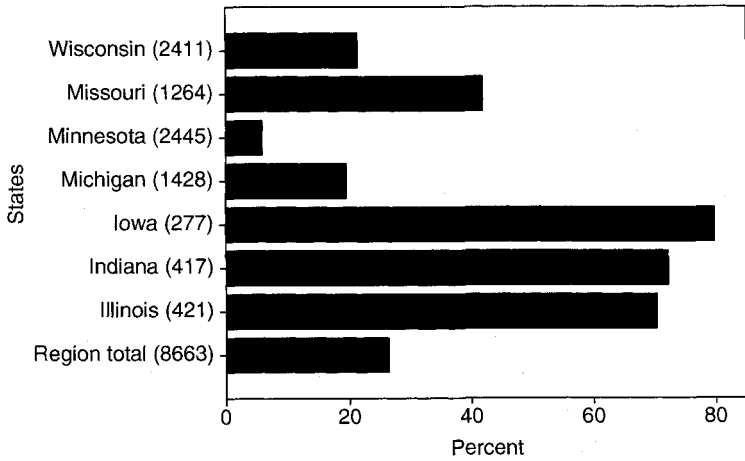


FIGURE 3.3 Percent of all plots sampled that have at least one NNIP present, by state and region total, 2005 and 2006 panels. Numbers next to state names are the number of forested plots in the state.

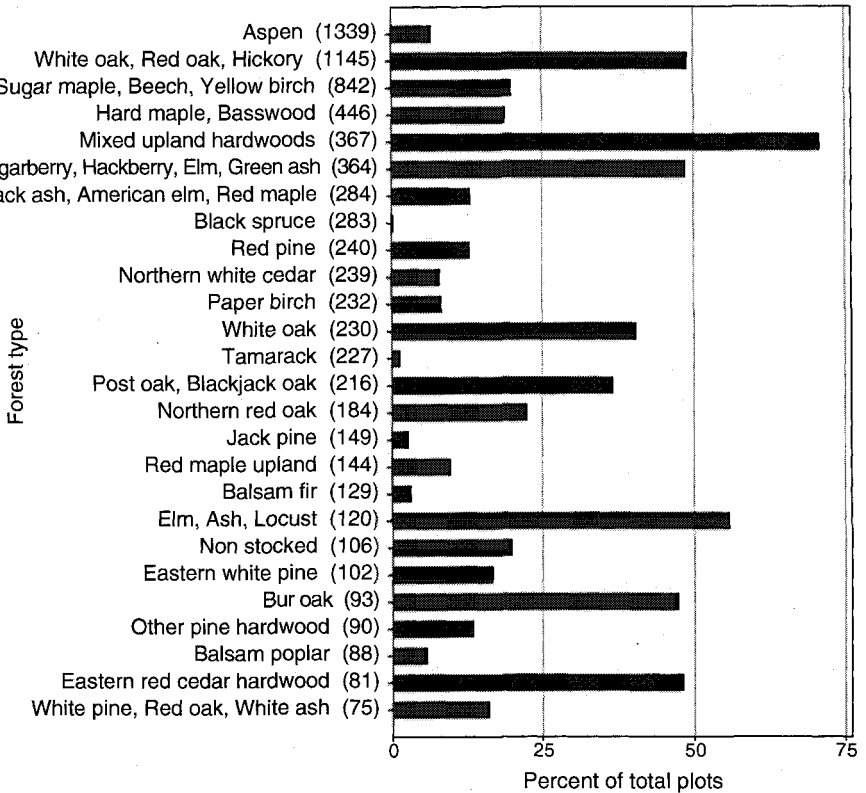


FIGURE 3.4 Percentage of plots in each forest type with 75 or more plots with at least one NNIP, 2005–2006.

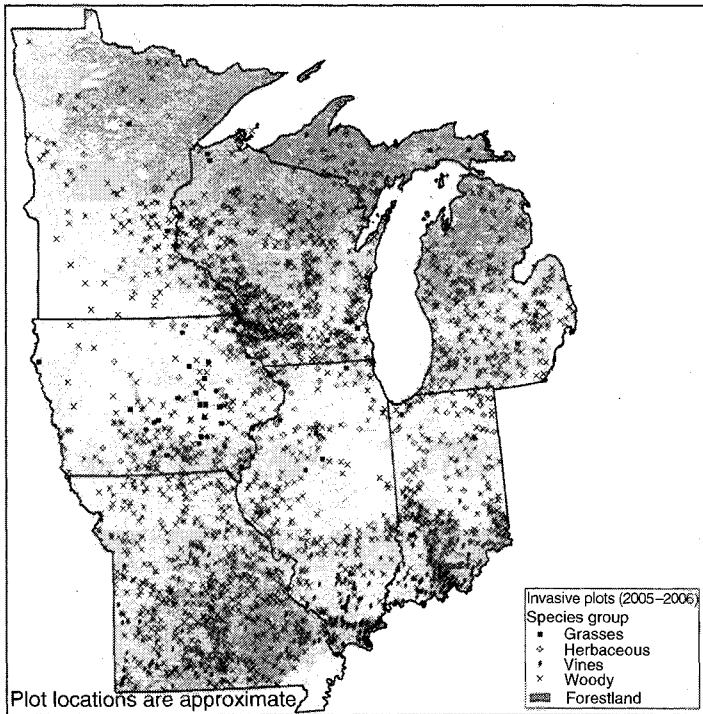


FIGURE 3.5 Distribution of plots with invasives in the Upper Midwest, by life form in 2005–2006.

In this study, multiflora rose was the most frequently found NNIP in the Upper Midwest (Table 3.4). It was detected on over 14% of all plots, with cover classes greater than 10% occurring on over 3% of all plots in the seven-state region (Figure 3.7).

3.4.3.2 Nonnative Bush Honeysuckles

Nonnative bush honeysuckles were recorded on 9% of plots sampled in 2005 and 2006 and were distributed over most of the forested areas in the region except for the extreme north (Figure 3.8).

These honeysuckles are natives of eastern Asia and were imported to the United States for use as ornamentals and for wildlife habitat. Fragmented forest remnants are vulnerable to honeysuckle invasion and establishment, particularly sites with limestone geology, which is prominent in the southern part of our region. Bush honeysuckles frequently become well established on the forest edge (Luken and Goessling 1995). They not only outcompete native shrubs, but also reduce understory diversity by shading the forest floor. The bush honeysuckles produce small juicy berries that are eaten and distributed by many species of small mammals

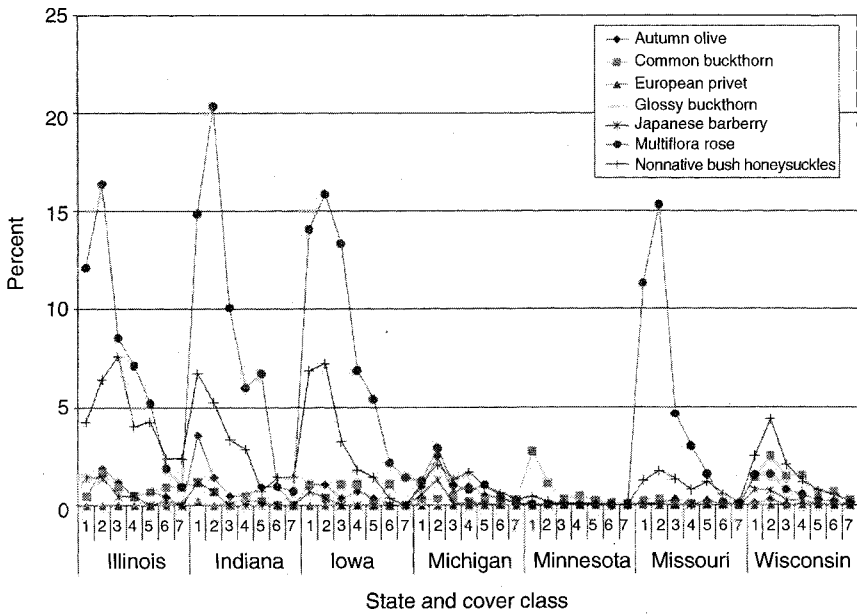


FIGURE 3.6 Presence of nonnative woody species in the seven states of the Upper Midwest, as measured by percent of all forested inventory plots sampled in 2005 and 2006, by state and cover class category. Cover class categories: 1 = <1%, trace; 2 = 1%–5%; 3 = 6%–10%; 4 = 11%–25%; 5 = 26%–50%; 6 = 51%–75%; and 7 = 76%–100%. Cover class 0—no invasives found—is not shown so as to preserve graphic scale.

and birds. Honeysuckles are generally believed to have a minimal interval between dispersal and germination and a short-lived seed bank. The species relies on the heavy seed output and sprouting from buds at the base of the stems on large plants (Luken 1988).

3.4.3.3 Common Buckthorn

Both of the major species of buckthorns found in eastern United States (glossy and common buckthorn) were introduced from Europe. Now common to the Midwest and New England, the species have been utilized as ornamental plantings and for wildlife habitat (Webster et al. 2006). Both of the buckthorns exhibit classic hyper-competitor behavior: they leaf out earlier than their native competitors, resprout vigorously, and produce large amounts of seeds that are spread by birds (Harrington et al. 1989). Buckthorns can suppress seedling height and diameter growth, both by shading as well as belowground competition from their extensive root systems. In one study, tree seedling survival was found to be about half that of open-grown seedlings (Fagan and Peart 2004). Common buckthorn observations were most frequent along the prairie forest “tension zone”—a diagonal line extending from

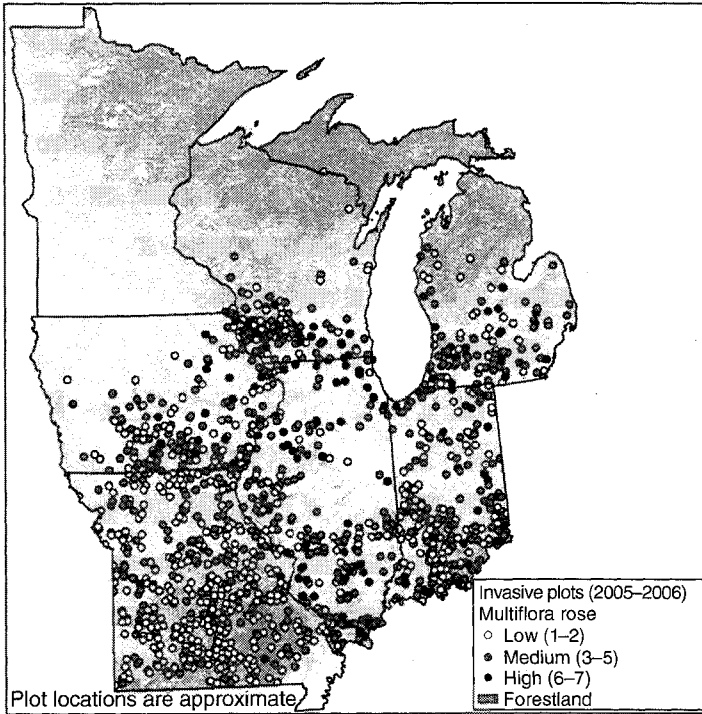


FIGURE 3.7 Distribution of plots with multiflora rose, Upper Midwest, 2005–2006.

central Minnesota through southeastern Wisconsin. Other states contained scattered observations (Figure 3.9).

In contrast with other NNIP species that have the highest frequency of observations in the 1%–5% cover class, buckthorn observations were most numerous in the cover category of <1% (trace) (Table 3.4).

3.4.4 HERBACEOUS SPECIES

Garlic mustard and common burdock were the most prominent herbaceous NNIPs in the Upper Midwest (Figure 3.10). Garlic mustard had a greater extent in Illinois and Indiana, whereas the two species were similar in extent in Iowa and Wisconsin. Minnesota had the lowest overall percentage of plots with NNIP herbaceous species present.

Garlic mustard is an herb from Europe that was originally introduced to the United States in the mid-1800s (Meekins and McCarthy 1999), but is now present throughout the eastern United States (Nuzzo 1993). The species is very common in disturbed forests, which occur primarily in the central portion of our study region (Figure 3.11).

It has the capability, considered unusual for an invasive plant species, to invade mature second-growth forests (McCarthy 1997). The species reproduces

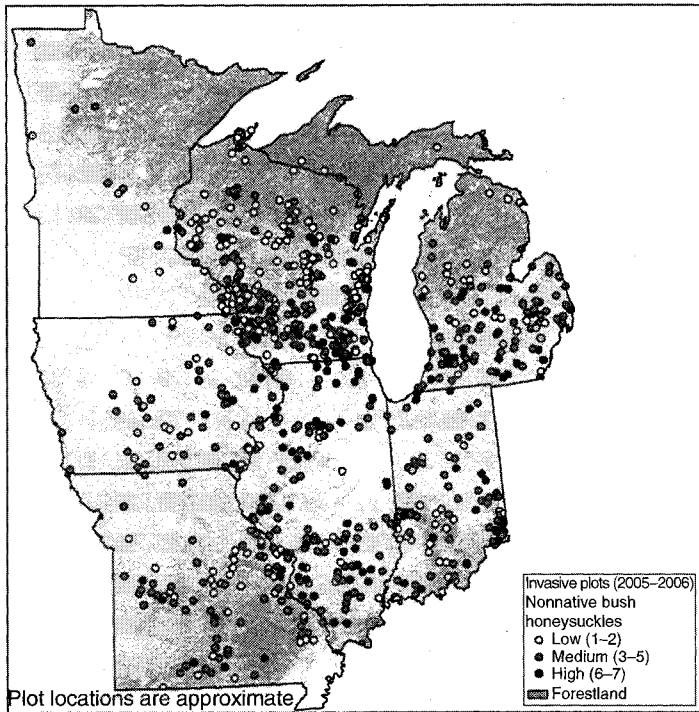


FIGURE 3.8 Distribution of plots with nonnative bush honeysuckles, Upper Midwest, 2005–2006.

sexually, after which the plants die (Nuzzo 1999). By its presence and superior competitive ability, species richness and growth of the ground-level flora and tree regeneration are suppressed. Some forest types, such as upland oak types with species such as *Quercus prinus* (chestnut oak), are particularly susceptible to being invaded and the tree regeneration outcompeted by garlic mustard (Meekins and McCarthy 1999). Garlic mustard was the most prominent herbaceous NNIP found in the Upper Midwest, occurring on 3% of the plots inventoried in 2005–2006 (Table 3.4).

3.4.5 VINES

Invasive vines were concentrated in the southern part of the region, particularly along the Ohio River watershed in Illinois and Indiana (Figure 3.5). Japanese honeysuckle was the most prominent species in this category (Figure 3.12).

Japanese honeysuckle is a persistent vine introduced as an ornamental and for erosion control and wildlife habitat in the mid-1800s (Plant Conservation Alliance 2006). The species thrives in a wide variety of habitats and quickly becomes established on disturbed sites (Rhoads and Block 2000). It is currently distributed in most states including Hawaii, but is limited by cold temperatures and low

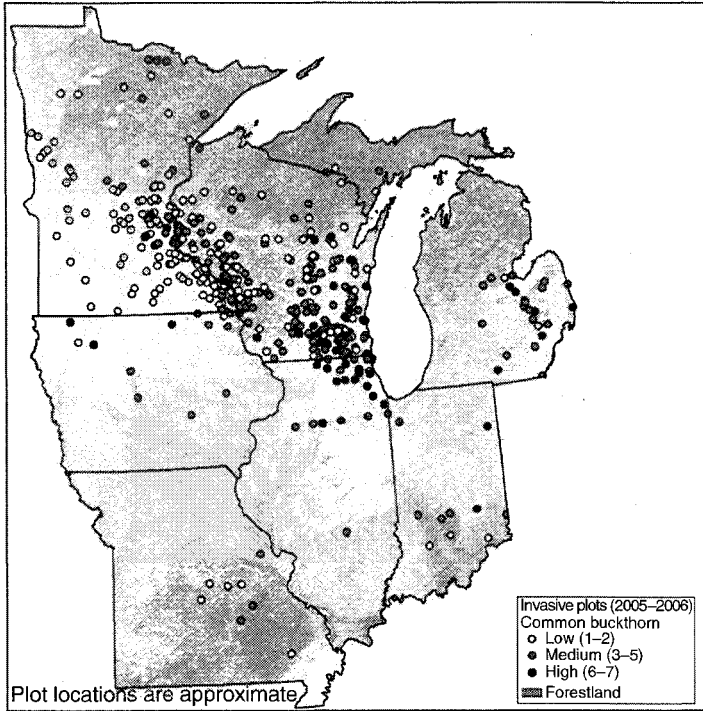


FIGURE 3.9 Distribution of plots with common buckthorn in the Upper Midwest, 2005–2006.

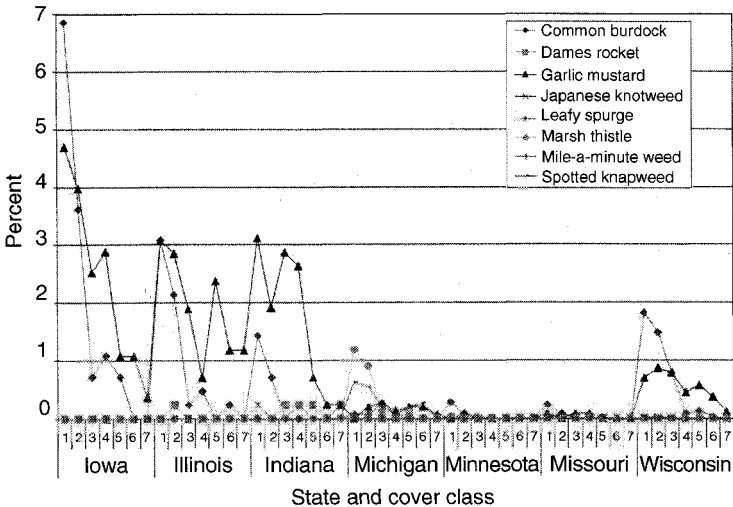


FIGURE 3.10 Presence of nonnative invasive herbaceous species in the seven states of the Upper Midwest, as measured by percent of all forested inventory plots sampled in 2005–2006, by state and cover class category. Cover class categories: 1 = <1%, trace; 2 = 1%–5%; 3 = 6%–10%; 4 = 11%–25%; 5 = 26%–50%; 6 = 51%–75%; and 7 = 76%–100%. Cover class 0—no invasives found—is not shown so as to preserve graphic scale.

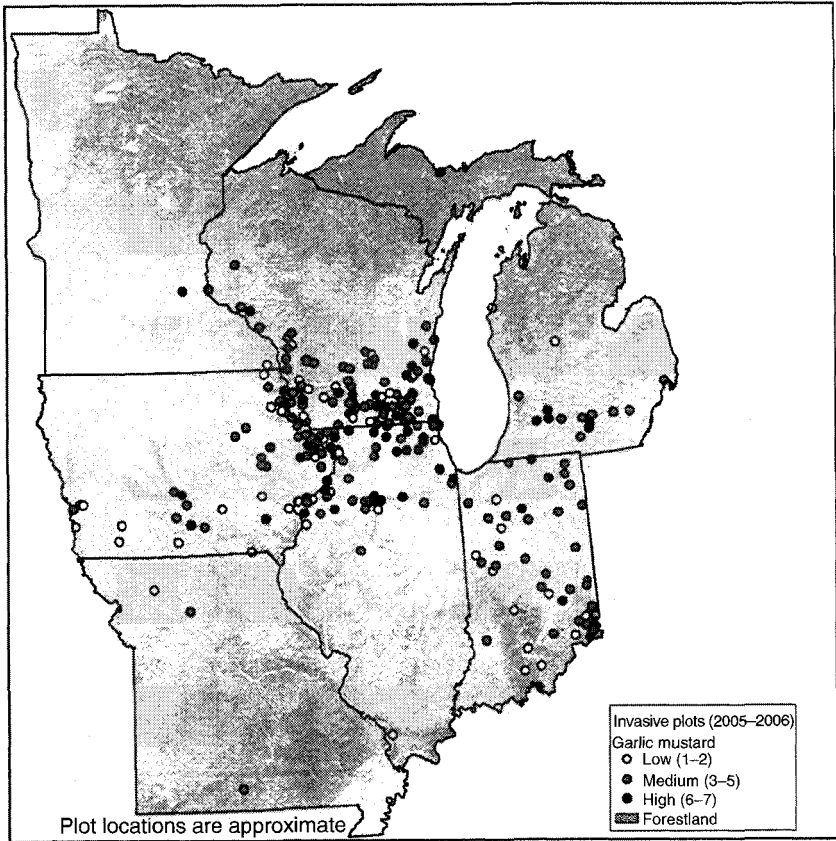


FIGURE 3.11 Distribution of plots with garlic mustard, Upper Midwest, 2005–2006.

precipitation (U.S. Department of Agriculture, NRCS 2007; Plant Conservation Alliance 2006). Japanese honeysuckle spreads by vegetative runners, underground rhizomes, and seed dispersal, particularly by birds. It quickly becomes established and crowds out native plants (Missouri Department of Conservation 1997). Among vines in this study, Japanese honeysuckle was the most prevalent and was found in 2.5% of all plots inventoried in 2005–2006 (Table 3.4). Plots with high cover classes (4–7) were more common for this species than for other NNIPs (Table 3.4). This NNIP species occurs primarily along the Ohio and Mississippi River basins in Indiana, Illinois, and Missouri (Figure 3.13).

3.4.6 GRASSES

Invasive grasses were observed largely in forests near extensive agricultural land—eastern Iowa and northern Illinois—rather than areas with extensive closed-canopy forests like northern Minnesota or southern Missouri. Reed canary grass was the

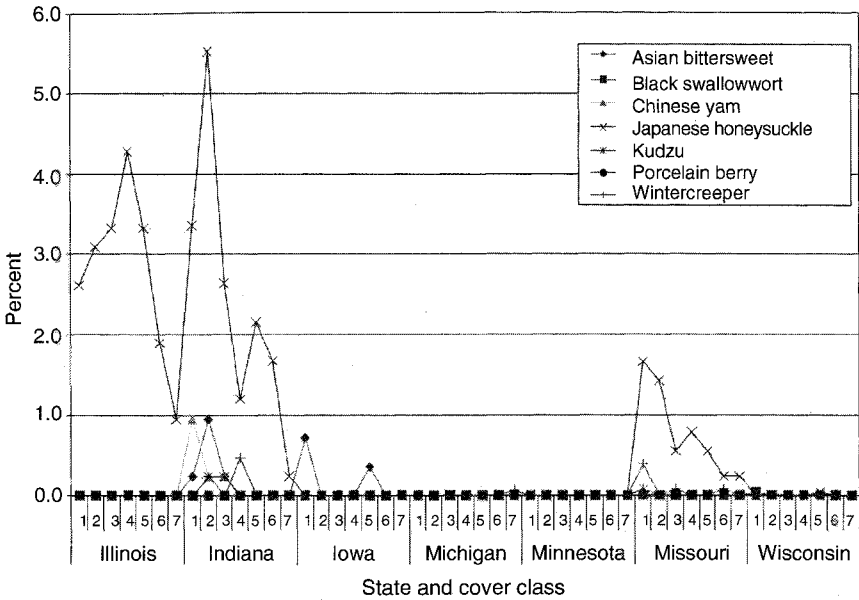


FIGURE 3.12 Presence of nonnative invasive vines in the seven states of the Upper Midwest, as measured by percent of all forested inventory plots sampled in 2005–2006, by state and cover class category. Cover class categories: 1 = <1%, trace; 2 = 1%–5%; 3 = 6%–10%; 4 = 11%–25%; 5 = 26%–50%; 6 = 51%–75%; and 7 = 76%–100%. Cover class 0—no invasives found—is not shown so as to preserve graphic scale.

most prominent NNIP grass on forested plots in the Upper Midwest, particularly Iowa (Figure 3.14).

Among the NNIP grasses, reed canary grass was the most prominent at 1% of forested plots inventoried in 2005–2006. It was the only NNIP where plots with cover classes greater than 10% exceeded the number of plots with cover classes 10% or less (Table 3.4). Although it is widespread in nonforested areas, the principal indication of reed canary grass presence on forested lands was in Iowa (Figure 3.15).

3.4.7 REGIONAL AND CLIMATIC LIMITATIONS

In preparation for analysis of site factors that might relate to invasive presence, we examined regional limits of each species as an indicator of climatic influence. Initial attempts at variable reduction always found that latitude and longitude were the major influences on NNIP presence. Some of this distribution might be due to historical factors, such as the preference for a species by a state agency, and some of the cause may be due to climatic limitations, such as a species’ intolerance of extreme cold. We used these apparent limits as sideboards to closely examine the influence of site- and stand-specific variables. We visually estimated the latitudinal and longitudinal ranges that contained ~90%–95% of the plots with each species,

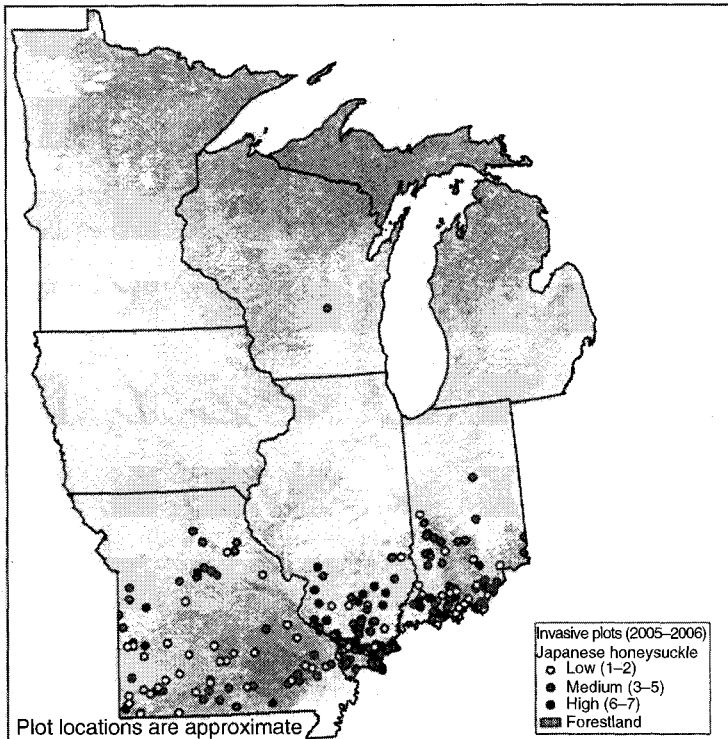


FIGURE 3.13 Distribution of plots with Japanese honeysuckle, Upper Midwest, 2005–2006.

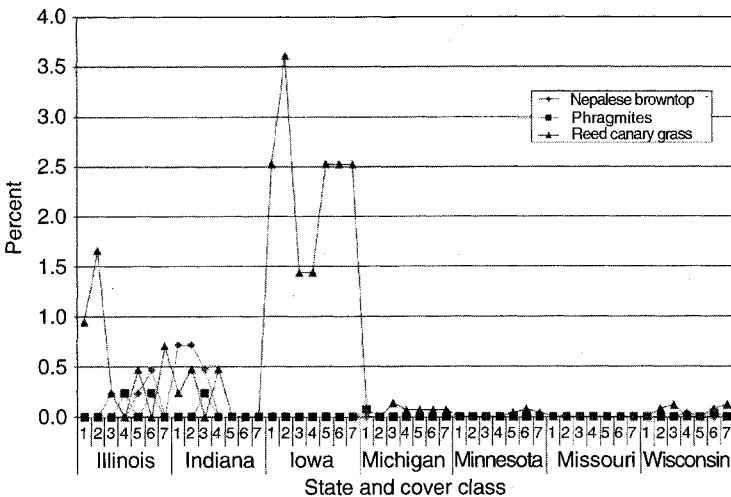


FIGURE 3.14 Presence of nonnative invasive grasses in the seven states of the Upper Midwest, as measured by percent of all forested inventory plots sampled in 2005–2006, by state and cover class category. Cover class categories: 1 = <1%, trace; 2 = 1%–5%; 3 = 6%–10%; 4 = 11%–25%; 5 = 26%–50%; 6 = 51%–75%; and 7 = 76%–100%. Cover class 0—no invasives found—is not shown so as to preserve graphic scale.

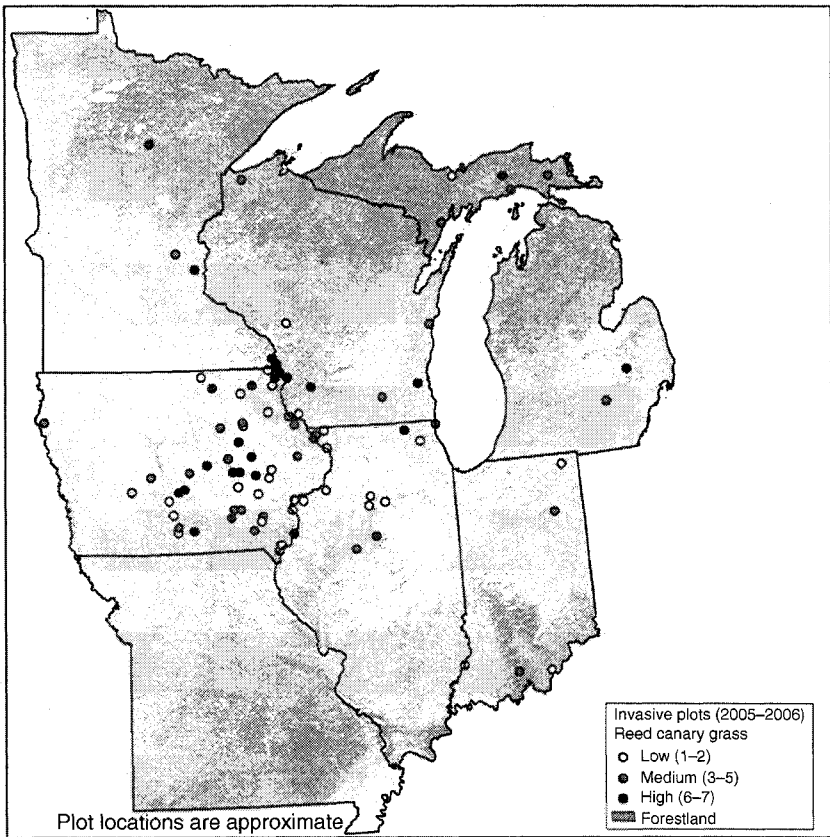


FIGURE 3.15 Distribution of plots with reed canary grass, Upper Midwest, 2005–2006.

then subset the dataset for each species, and examined site and disturbance relationships within this subset.

There were some pronounced regional influences on NNIP presence (Figure 3.16). Regarding multiflora rose, there was no noticeable longitudinal influence while there was a noticeable latitudinal cutoff north of 44° N (Figure 3.7). Other investigators have suggested that the species is not tolerant of cold weather (Amrine 2002; Munger 2002). Nonnative bush honeysuckles, on the other hand, were distributed widely throughout the region (Figure 3.8). Situated across the Midwest and along all but the northernmost latitudes, these species were present in most of the Midwest's major forest types. Common buckthorn was present in the longitudinal range centering on Wisconsin and Minnesota (Figure 3.9). Although there are occurrences farther south, buckthorn presence generally decreased south of 42° N latitude. Garlic mustard was widespread longitudinally, but exhibited a sharp decline above 44° N latitude (Figure 3.11). Research suggests that Japanese honeysuckle prefers warmer climates (Leatherman 1955). Our data support this contention;

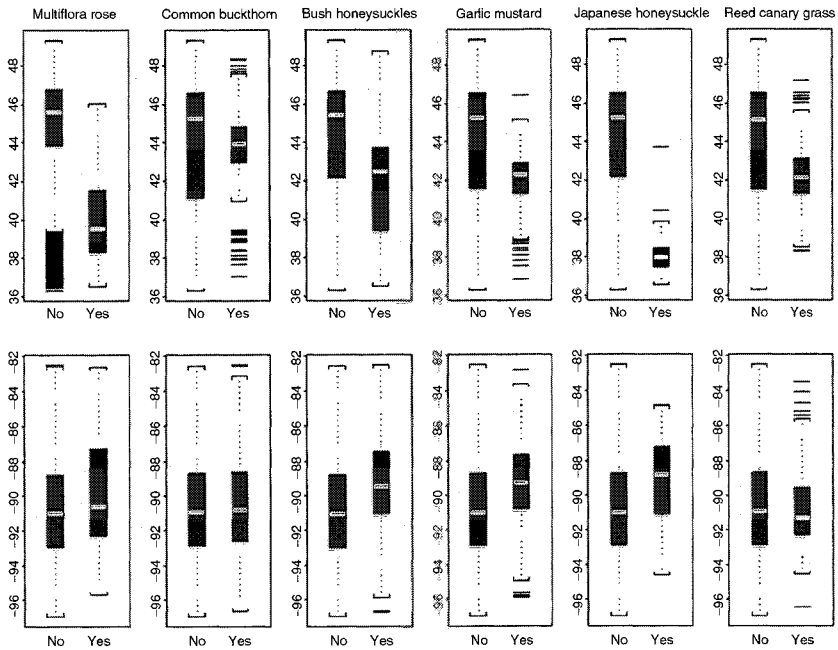


FIGURE 3.16 Latitudinal and longitudinal distribution of the six NNIPs of interest. Presence (“Yes”) is on the right side of each plot; absence (“No”) is on the left side. Latitudinal range is 36°–48° N; longitudinal range is 82°–96° W.

observations of the species centered on southern Illinois and southern Missouri (Figure 3.13). Reed canary grass was primarily found in the middle latitudes and longitudes of the region, with the North–South observations particularly clustered (Figure 3.15).

3.4.8 STAND, SITE, AND DISTURBANCE FACTORS

We used a bidirectional stepwise regression to reduce the candidate variables to a subset considered to have a significant relationship with NNIP abundance. Table 3.5 displays the complete list of variables with a value and level of significance for those variables remaining in each model. Measurements of disturbance and fragmentation had a significant relationship with NNIP presence and cover across the board (Table 3.5). County percent forest had a highly significant relationship with almost every invasive species and 4 of the 6 individual species we tracked. This variable also displayed a significant relationship with Japanese honeysuckle. The three woody species and reed canary grass had a significant negative relationship with forest intactness. Common buckthorn and nonnative bush honeysuckles displayed a significant negative relationship with increasing distance from the road while, conversely, reed canary grass had a positive relationship.

TABLE 3.5
Site and Disturbance Variables Significantly Related to the Presence and Abundance of NNIPs in the Upper Midwest, United States in 2005–2006

Variable	Any Invasive Species	Multiflora Rose	Common Buckthorn	Nonnative Bush Honeysuckles	Garlic Mustard	Japanese Honeysuckle	Reed Canary Grass
Stand variables							
Total basal area							
Oak basal area	-0.08102***	-0.02725**					-0.2557***
Stand age	-0.0798**			-0.03482***		-0.0343**	-0.09407***
SDI—All	-0.04684**	-0.008662		-0.01202*			-0.04406
SDI—5' plus	0.06826**			0.01189		0.01637*	-0.106**
H' species				0.7033			
H' diameter				-0.9138	3.338*		
H' height	2.211**				-3.009*		-3.559**
Site variables							
Site index		0.05335**	-0.0326*			-0.701	
Aspect (cosine)			Mesic: 1.386, Xeric: -0.2375				
Physiographic class code							
Disturbance variables							
County percent forest	-17.58***	-5.139***	-6.264***	-4.748***	-10.28***	-5.113*	
Plot percent forest		2.360					
Minimum distance to the nearest road			-0.001135	-0.001175*			0.009***
Index of forest intactness (sum of all expanded ordinal scores)		-3.448 × 10 ⁻⁵ *	-5.542 × 10 ⁻⁵ ***	-1.898 × 10 ⁻⁵	4.873 × 10 ⁻⁴ *	3.929 × 10 ⁻⁵	-6.186 × 10 ⁻⁵ *
R ²	0.0595	0.0577	0.0562	0.0423	0.0249	0.0724	0.133

Note: The values in each cell represent the parameter estimates in the final linear model.

* Indicates a positive (negative) relationship at the 0.05 level.

** Indicates a positive (negative) relationship at the 0.01 level.

*** Indicates a positive (negative) relationship at the 0.001 level; blank predictor variables were dropped during stepwise regression.

The correlation with site index was less conclusive. Site index was positively significant for multiflora rose coverage and was negatively related to nonnative bush honeysuckles coverage. We found little correlation between aspect and NNIP coverage. Stand variables, surprisingly, did not display a consistent relationship with NNIP abundance. Oak basal area, stand age, and all-tree stand density indices were negatively significantly related to any NNIP abundance, but relationships with individual species were more variable. Stand age had a significant negative relationship with multiflora rose and nonnative bush honeysuckles, consistent with expectations of high basal area and time since the last disturbance, yet total basal area was not significant for these species.

Our results could have emanated from alternate yet co-occurring influences. For example, the negative relationship of oak basal area and NNIPs could be the result of *Quercus* species' frequent presence on drier sites, a difficult habitat for moisture-loving Japanese honeysuckle and reed canary grass. The apparent contradiction between SDI of all trees' (usually negative) relationship and SDI of trees 12 cm and greater (often positive) relationship points to the impact of low shade, more frequently found in stands with diameters ranging from 2.4 cm to sawtimber size (30 cm), than in stands where the bulk of the trees is much larger.

3.5 DISCUSSION AND CONCLUSIONS

This study examined patterns of distribution and relationships with selected forest and site characteristics for 25 exotic plant species/species groups of interest in the Upper Midwest of the United States. NRS-FIA recorded one or more of these 25 species on one-quarter of the forested plots inventoried in 2005 and 2006. In some portions of the region, plots had even higher rates of NNIP presence. Iowa, Indiana, and Illinois had the highest overall proportion of plots with invasives, while Minnesota had the lowest. Our data revealed a strong latitudinal separation, particularly for woody invasives. Common buckthorn was prominent in Wisconsin and Minnesota, while multiflora rose was more prevalent in Missouri, Illinois, and Indiana.

Most subboreal forest types had lower percentages of NNIP presence. Accordingly, we also saw lower occurrences in the Lake States of Minnesota, Wisconsin, and Michigan than those in the southern-tier states. Early successional forest types in the center of the region appear to have a higher percentage of plots with NNIPs, but it was difficult to separate any relationship from the sampling effect, as these early successional forest types were often the most predominant on the landscape. Grasses were particularly prominent in fragmented forestland in the center of our study area. Our results support Richardson and Pyšek's (2006) contention that agricultural or urban sites are the most invadable biomes. The nature of our sample set meant that we were only examining successful invaders on forested plots, not those species that failed to establish in the region. This likely skewed our examination of particular plant characteristics or affinities for a site or disturbance pattern. Although we could not conclusively tie the presence of NNIPs to particular forest types, disturbance likely played a role in the life history strategy of both overstory tree species and understory invasive plants. The predominant forest types in the southern two-thirds

of the region—oaks—are mid-shade tolerants and rely upon disturbance to maintain their position in most parts of the genus' range (Johnson et al. 2002).*

We did not assess time between the start of an invasion and the typical phase of exponential increase. Our inability to determine the contribution of site and stand factors to invasiveness is likely because the NNIP patterns we observe today are largely the net result of introductions and prevailing conditions and processes from 50 to 100 years ago or more. This conclusion suggests a kind of built-in inertia, where the number of naturalized and invasive species will increase in the future even if no additional introductions occur (Kowarik 1995; Richardson and Pyšek 2006).

Metrics of disturbance and fragmentation, such as distance to road, county percent forest or the forest intactness index, were significantly related to NNIP presence and coverage. NRS-FIA treatment or disturbance codes and other measures such as the ratio of tree removals to current volume revealed no significant connection with NNIP presence. Disturbances that initiated an invasive plant's presence likely occurred several decades ago (Hulme 2003; Richardson and Pyšek 2006), which is why patterns of fragmentation and landscape-level forest proportions are better measures of disturbance history.

While some of our results may be extrapolated to other species or regions, we should remember Pyšek's (2001) words that "in predicting the success of potential invaders, it is easier to predict invaders than non-invaders among exotic species." A posteriori analysis of invasive species at one point in time is usually not sufficient to evaluate trends in regeneration, expansion, or growth (Rejmánek 1989). The NRS-FIA database tracks disturbance and silvicultural treatments, but only in the interval since the previous inventory. The anthropogenic activities that resulted in the establishment of these nonnative invasive species likely occurred many years ago. Repeated measures on a wide scale will be necessary to verify any trends.

Given the history of natural and human-caused disturbance and forest types whose shade tolerance results in understory growing space that is not completely occupied, we expected to find multiple relationships between NNIP and forest and site characteristics. When looking at disturbance, we observed that multiflora rose, Japanese honeysuckle, and reed canary grass significantly benefited from lower overstory basal areas, but this relationship did not apply to other species. Another measure of disturbance, distance to nearest road, had a significant negative relationship with the presence of nonnative bush honeysuckles and reed canary grass.

The percent of total land area in a county that is forest provided a striking indicator of historic disturbance. This metric displayed an almost universally significant negative relationship with NNIP abundance. These results are not surprising; invasive species are known to thrive on sites with more available resources (Richardson and Pyšek 2006). The challenge is separating the human influence from the ecological. One could easily argue that our results reflect the heavily disturbed nature of the Midwest's second- and third-generation forests, which either reestablished following the abandonment of farmland or pasture or were influenced by heavily disturbed adjacent land. The characteristics of the landscape that influenced invasive species

* In fact, the lack of disturbance is resulting in a shift in species composition of regeneration in oak forests throughout the genus' range (Moser et al. 2006).

presence may also be a significant relationship with homestead choice by settlers. Even our disturbance measures, lower basal area, and high road density could reflect the lingering influence of historic human disturbance as the microsite attributes that allowed them to thrive.

Disturbance events, coupled with anthropogenic establishment of individual species, displayed lingering effects on the Midwest forest ecosystem long after they occurred. Site conditions and stand structures cannot be relied upon to reverse these trends. As with most situations where ecological restoration is the goal, elimination of NNIPs in the Upper Midwest will demand both aggressive action to stop the spread of the species and significant investment in efforts to restore invaded ecosystems to their pre-NNIP state.

ACKNOWLEDGMENTS

The authors thank Barry T. Wilson for developing the map template used as the background for the NNIP distribution maps and Sonja Oswalt and Andy Gray for their reviews of earlier versions of this manuscript.

REFERENCES

- Akaike, H., A new look at the statistical model identification, *IEEE Trans. Automat. Contr.*, 19, 6, 716, 1974.
- Amrine, J.W., Multiflora rose, in *Biological Control of Invasive Plants in the Eastern United States*, Van Driesche, R., Blossey, B., Hoddle, M., Lyon, S., and Reardon, R., Eds., USDA Forest Service Publication FHTET-2002-04, Washington, DC, 265, 2002.
- Booth, B.D., Murphy, S.D., and Swanton, C.J., *Weed Ecology in Natural and Agricultural Systems*, CABI, Wallingford, 2003.
- Crawley, M.J., Brown, S.L., Heard, M.S., and Edwards, G.G., Invasion-resistance in experimental grassland communities: Species richness or species identity? *Ecol. Lett.*, 2, 140, 1999.
- Daehler, C.C., Darwin's naturalization hypothesis revisited, *Am. Nat.*, 158, 324, 2001.
- Daehler, C.C., Performance's comparisons of co-occurring native and alien invasive plants: Implications for conservation and restoration, *Annu. Rev. Ecol. Syst.*, 34, 183, 2003.
- Della Sala, D.A., Stans, N.L., Strithott, J.R., Hackman, A., and Lacobelli, A. An updated protected areas database for the United States and Canada, *Nat. Areas J.*, 21, 124, 2001.
- Drake, J.A., Mooney, H.A., Di Castri, F., Groves, R.H., Kruger, F.J., Rejmánek, M., and Williamson, M., *Biological Invasions: A Global Perspective*, Wiley, Chichester, UK (published on behalf of the Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions, Series SCOPE report, no. 37), 1989.
- Ellstrand, N.C. and Schierenbeck, K.A., Hybridization as a stimulus for the evolution of invasiveness in plants? *Proc. Natl. Acad. Sci. USA*, 97, 7043, 2000.
- Elton, C.S., *The Ecology of Invasions by Animals and Plants*, University of Chicago Press, Chicago, IL, 1958.
- ESRI Data & Maps, 2002. CD-Rom, Environment Systems Research Institute, Inc. 2002.
- Evans, J.E., A literature review of management practices for multiflora rose (*Rosa multiflora*), *Nat. Areas J.*, 3, 1, 6, 1983.
- Fagan, M.E. and Peart, D.R., Impact of the invasive shrub glossy buckthorn (*Rhamnus frangula* L.) on juvenile recruitment by canopy trees, *For. Ecol. Manage.*, 194, 1-2, 95, 2004.

- Forman, R.T.T. and Alexander, L.E., Roads and their major ecological effects, *Ann. Rev. Ecol. Syst.*, 29, 207, 1998.
- Gelbard, J.L. and Belnap, J., Roads as conduits for exotic plant invasions in a semiarid landscape, *Conserv. Biol.*, 17, 2, 420, 2003.
- Harrington, R.A., Brown, B.J., Reich, P.B., and Fownes, J.H., Ecophysiology of exotic and native shrubs in Southern Wisconsin. II. Annual growth and carbon gain, *Oecologia*, 80, 368, 1989.
- Heilman, G.E., Slosser, N.C., and Strittholt, J.R., *Forest intactness of the coterminous United States* (CD-ROM database prepared for the World Wildlife Fund and the World Resources Institute's Global Forest Watch), Conservation Biology Institute, Corvallis, OR, 2001.
- Hodkinson, D.J. and Thompson, K., Plant dispersal: The role of man, *J. Appl. Ecol.*, 34, 1484, 1997.
- Hood, W.G. and Naiman, R.J., Vulnerability of riparian zones to invasion by exotic plants, *Plant Ecol.*, 148, 105, 2000.
- Hulme, P.E., Biological invasions: Winning the science battles but losing the conservation war? *Oryx*, 37, 178, 2003.
- Huston, M.A. and DeAngelis, D.L., Competition and coexistence—The effects of resource transport and supply rates, *Am. Nat.*, 144, 954, 1994.
- Johnson, P.S., Shifley, S.R., and Rogers, R., *The Ecology and Silviculture of Oaks*, CABI Publishing, New York, 501, 2002.
- Kowarik, I., Time lags in biological invasions with regard to the success and failure of alien species, in *Plant Invasions: General Aspects and Special Problems*, Pyšek, P., Prach, K., Rejmanek, M., and Wade, M., Eds., SPB Academic, Amsterdam, 15, 1995.
- Leatherman, A.D., Ecological life-history of *Lonicera japonica* Thunb., University of Tennessee, Knoxville, TN, 97, 1955 (unpublished dissertation).
- Levine, J.M. and D'Antonio, C.M., Elton revisited: A review of evidence linking diversity and invasibility, *Oikos*, 87, 1, 15, 1999.
- Lonsdale, W.M., Global patterns of plant invasions and the concept of invasibility, *Ecology*, 80, 1522, 1999.
- Luken, J.O., Population structure and biomass allocation of the naturalized shrub *Lonicera maackii* (Rupr.) Maxim. in forest and open habitats, *Am. Midl. Nat.*, 119, 2, 258, 1988.
- Luken, J.O. and Goessling, N., Seedling distribution and potential persistence of the exotic shrub *Lonicera maackii* in fragmented forests, *Am. Midl. Nat.*, 133, 1, 124, 1995.
- Magurran, A.E., Ecological diversity and its measurement. Princeton University Press, Princeton, New Jersey, 192, 35, 1988.
- McCarthy, B., Response of a forest understory community to experimental removal of an invasive nonindigenous plant (*Alliaria petiolata*, Brassicaceae), in *Assessment and Management of Plant Invasions*, Luken, J.O. and Thieret, J.W., Eds., Springer-Verlag, New York, 117, 1997.
- McGarigal, K. and Marks, B.J., FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure, USDA, Forest Service Pacific Northwest Research Station, Gen. Tech. Rep. 351, Portland, OR, 122, 1995.
- McRoberts, R.E., Joint annual forest inventory and monitoring symposium: The North Central perspective, *J. For.*, 97, 12, 27, 1999.
- Meekins, J.F. and McCarthy, B.C., Competitive ability of *Alliaria petiolata* (garlic mustard, Brassicaceae), an invasive, nonindigenous forest herb, *Int. J. Plant Sci.*, 160, 4, 743, 1999.
- Missouri Department of Conservation, Missouri vegetation management manual, Jefferson City, MO, 161, 1997.
- Mitich, L.W., Intriguing world of weeds: Kudzu (*Pueraria lobata* (Willd.) Ohwi), *Weed Technol.*, 14, 231, 2000.

- Moser, W.K., Hansen, M.H., McWilliams, W., and Sheffield, R., Oak composition and structure in the Eastern United States, in *Fire in Eastern Oak Forests: Delivering Science to Land Managers* (Proceedings of a conference, November 15–17, 2005, Columbus, OH), Dickinson, M.B., Ed., Gen. Tech. Rep. NRS-P-1, U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA, 49, 2006.
- Munger, G.T., *Rosa multiflora*, in Fire effects information system [Online], U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer), Missoula, MT, 2002. Available at <http://www.fs.fed.us/database/feis/>, accessed November 15, 2007.
- North Central Research Station, Forest Inventory and Analysis (NCRS-FIA), *Forest Inventory and Analysis National Core Field Guide, Volume 1: Field Data Collection Procedures for Phase 2 Plots, Ver. 2.0.*, USDA, Forest Service North Central Research Station, St. Paul, MN, 290, 2005.
- Nuzzo, V.A., Distribution and spread of the invasive biennial *Alliaria petiolata* [(Bieb.) Cavara & Grande] in North America, in *Biological Pollution: Control and Impact of Invasive Exotic Species*, McKnight, B.L., Ed., Indiana Academy of Sciences, Indianapolis, IN, 115, 1993.
- Nuzzo, V.A., Invasion pattern of the herb garlic mustard (*Alliaria petiolata*) in high quality forests, *Biol. Invasions*, 1, 1, 169, 1999.
- Olson, C.L. and Cholewa, A.F., Nonnative invasive plant species of the North Central region. A guide for FIA field crews, USDA, Forest Service, St. Paul, MN, 120, 2005 (unpublished field guide).
- Plant Conservation Alliance, Various species' websites, U.S. Department of the Interior, Bureau of Land Management, Plant Conservation Alliance, Alien Plant Working group, Washington, DC. Available at <http://www.nps.gov/plants/alien/fact.htm>, accessed September 24, 2007, 2006.
- Pyšek, P., Past and future of predictions in plant invasions: A field test by time, *Divers. Distrib.*, 7, 145, 2001.
- Pyšek, P. and Hulme, P.E., Spatio-temporal dynamics of plant invasions: Linking pattern to process, *Ecoscience*, 12, 345, 2005.
- Reineke, L.H., Perfecting a stand-density index for even-aged stands, *J. Agric. Res.*, 46, 627, 1933.
- Rejmánek, M., Invasibility of plant communities, in *Biological Invasions: A Global Perspective*, Drake, J.A., Mooney, H.A., di Castri, F., Groves, R.H., Kruger, F.J., Rejmanek, M., and Williamson, M., Eds., Wiley, Chichester, UK, 369, 1989.
- Rhoads, A.F. and Block, T.H., *The Plants of Pennsylvania, An Illustrated Manual*, Morris Arboretum of the University of Pennsylvania, University of Pennsylvania Press, Philadelphia, PA, 1060, 2000.
- Richardson, D.M. and Bond, W.J., Determinants of plant-distribution—Evidence from pine invasions, *Am. Nat.*, 137, 639, 1991.
- Richardson, D.M. and Pyšek, P., Plant invasions: Merging the concepts of species invasiveness and community invasibility, *Prog. Phys. Geogr.*, 30, 3, 409, 2006.
- Rudis, V.A., Gray, A., McWilliams, W., O'Brien, R., Olson, C., Oswald, S., and Schulz, B., Regional monitoring of nonnative plant invasions with the Forest Inventory and Analysis program, in *Proceedings of the Sixth Annual FIA Symposium* (September 21–24, 2004, Denver, CO), McRoberts, R.E., Reams, G.A., Van Deusen, P.C., and McWilliams, W.H., Eds., Gen. Tech. Rep. WO-70, U.S. Department of Agriculture, Forest Service, Washington, DC, 49, 2006.
- Sax, D.F., Latitudinal gradients and geographic ranges of exotic species: Implications for biogeography, *J. Biogeogr.*, 28, 139, 2001.
- Shannon, C.E., A mathematical theory of communication, *Bell System Tech. J.*, 27, 379, 1948.

- U.S. Department of Agriculture, The PLANTS database, Natural Resource Conservation Service, National Plant Data Center, Baton Rouge, LA, 2007. Available at <http://plants.usda.gov>, accessed September 24, 2007.
- Watkins, R.Z., Chen, J., Pickens, J., and Brosofske, K.D., Effects of roads on understory plants in a managed hardwood landscape, *Conserv. Biol.*, 17, 2, 411, 2003.
- Webster, C.R., Jenkins, M.A., and Jose, S., Woody invaders and the challenges they pose to forest ecosystems in the eastern United States, *J. For.*, 104, 7, 366, 2006.
- Woodall, C.W. and Miles, P.D., New method for determining the relative stand density of forest inventory plots, in *Proceedings of the Sixth Annual Forest Inventory and Analysis Symposium* (September 21–24, 2004, Denver, CO), McRoberts, R.E., Reams, G.A., Van Deusen, P.C., and McWilliams, W.H., Eds., Gen. Tech. Rep. WO-70, U.S. Department of Agriculture Forest Service, Washington, DC, 105, 2006.