Using GIS to Integrate FIA and Remotely Sensed Data to Estimate the Invasibility of Major Forest Types by Non-Native Invasive Plants in the Upper Midwest, USA

Zhaofei Fan
Forest and Wildlife Research Center
Mississippi State University
Box 9681
Mississippi State, MS 39762-9681
zfan@cfr.msstate.edu

W. Keith Moser
Northern Research Station
U.S. Forest Service
1992 Folwell Ave.
St. Paul, MN 55108
wkmoser@fs.fed.us

Michael K. Crosby
Forest and Wildlife Research Center
Mississippi State University
Box 9681
Mississippi State, MS 39762-9681
mkc34@msstate.edu

Weiming Yu
Forest and Wildlife Research Center
Mississippi State University
Box 9681
Mississippi State, MS 39762-9681
wyu@cfr.mssstate.edu

Abstract

Non-native invasive plants (NNIP) are rapidly spreading into natural ecosystems such as forests in the Upper Midwest. Using the strategic inventory data from the 2005-2006 U.S. Department of Agriculture, Forest Service's Forest Inventory and Analysis (FIA) program and forest land cover data, we estimated the regional-invasibility patterns of NNIPs for major forest types by using Geographic Information Systems (GIS) and geostatistical tools. We define the regional invasibility of a forest ecosystem as its susceptibility to the colonization and establishment of NNIPs, measured by a function of NNIP presence and cover percent. The invasibilityof four major forest types to multiflora rose (*Rosa multiflora Thunb.*) and garlic mustard (*Alliaria*

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petiolata (M. Bieb.) Cavara & Grande) have been estimated and mapped and potential management applications discussed.

Keywords: multiflora rose, presence probability, invisibility, invasion stage, CART

Introduction

For natural resource managers, the occurrence of non-native invasive plants (NNIPs) has become a significant concern. NNIPs threaten ecosystems through a reduction in biodiversity by displacing plants from their native ranges (Moser et al. 2009). A NNIP invasion of an area typically occurs in four stages: introduction, colonization, establishment, and spread (Theoharides and Dukes 2007). The introduction of NNIPs to an area can occur as a result of travel and commerce. The surviving NNIPs are then able to colonize in the area before reaching the establishment stage. At this point, NNIPs become more widespread and self sustaining before reaching the spread stage, when they become widespread throughout a region over a longer period of time.

Figure 1. Seven state study area in Upper Midwest of the United States.

In forested ecosystems, NNIPs can pose a major threat to understory diversity and development and be extremely difficult and costly to combat (Hobbs and Humphries 1995). After they become established, management efforts shift their focus to controlling the species' continued spread (Webster et al. 2006). In order to prevent the establishment of NNIPs in an ecosystem, early detection through strategic regional inventory is essential. This study will seek to determine the threat of two selected NNIPs: multiflora rose (*Rosa multiflora* Thunb.) and garlic mustard (*Alliaria petiolata* (M. Bieb.) Cavara & Grande) through the following objectives: (1) delineate their invasion stages based on the presence and cover percentage data collected across the Upper Midwest and (2) quantify the invasibility of four major forest types in the Upper Midwest to these two species.

Methodology

Our study area encompasses seven states in the Midwestern United States – Illinois, Indiana, Iowa, Michigan, Missouri, Minnesota, and Wisconsin (Figure 1). This area is a mix of forested/agricultural lands and prairies, with the primary forest types being made up of the oak/hickory (*Quercus* spp., *Carya* spp.), maple/beech/birch (*Acer* spp. / *Fagus grandifolia* / *Betula* spp.), elm/ash/cottonwood (*Ulmus* spp. / *Fraxinus* spp. / *Populus* spp.)and oak-hardwood groups (Potts et al., 2004). The data for this study was provided by the U.S. Forest Service, Northern Research Station, Forest Inventory and Analysis (FIA) program for the years 2005-2006. This dataset is comprised of 8863 Phase 2 plots with 25 NNIPs including multiflora rose and garlic mustard being sampled (Moser et al. 2009).

To determine the invasion stage of the two selected species across the Midwest counties, principal component analysis (PCA) and Classification and Regression Tree (CART) models were employed. To identify the presence probability of multiflora rose and garlic mustard for each county, it is important to account for the bias due to the varying sample sizes across the Midwest. To accomplish this, we calculate presence probability as:

$$p_i = \frac{\sum_{j \in \eta_i} s_j}{\sum_{j \in \eta_i} n_j} \tag{1}$$

where: s_j is the number of the NNIP-presence plots in the county j, n_j is the total plots in the county j, η_i is the set of neighbors for the county i, including the county i. Then a PCA was conducted to determine the principle component from the presence probability and cover percent. CART allows for the determination of the levels of the first principal component generated by PCA by using the presence probability as the splitting variable and the delineation of invasion stages. To assess the invasibility of a forest community, we calculated the means of presence probability and cover percent by invasion stage. A simple linear regression was used to analyze the relationship between cover percent (response variable) and presence probability (independent variable). The slope (increase of cover percent per unit of change of presence probability) of the regression was used to measure the "relative invasibility" of a forest community.

Results and Discussion

The PCA and CART results allow a more detailed analysis of the spread of NNIPs throughout the region. The results of the invasion stages of two NNIPs (multiflora rose and garlic mustard) are presented. The fourth stage of invasion (spread) can be seen across areas of Indiana, Illinois, Missouri, Iowa, and Wisconsin (Figure 2). Much of the rest of the area was found to be in the establishment stage. Based on the FIA data, garlic mustard has much less coverage as compared to multiflora rose, with relatively few counties showing signs of establishment and most of them concentrated in northern Illinois and central and southern Wisconsin (Figure 3) although anecdotal evidence suggests a much wider distribution, from at least Kaudiyohi County in west-central Minesota to Door County, Wisconsin Green Bay (pers. Comm. Lee Frelich, University of Minnesota, 24 February 2012).

The combination of competitive ability and human interference might offer an explanation of this pattern. *Alliaria petiolata* is phenotypically plastic and can adapt to environments far different from the mesic shady forest floors in its native Europe (Grime et al., 1988). The species can produce hundreds of seeds per plant that can be spread by animals, water, and human activity; with the seeds remaining viable for up to 7 years (Czarapata, 2005). *Rosa multiflora* is also a prolific seed producer (500,000 per plant per year). These seeds remain viable up to 20 years (Czarapata, 2005). Yet, two factors distinguish the establishment patterns and prominence of the respective species. The first is that multiflora rose was promoted by government agencies at various times as soil erosion treatment, a living fence in agroecological systems and a wildlife food (Amrine, 2002; Czarapata, 2005). Because of these reasons the species was often established in open or semi-open areas that either became wooded or spread into neighboring forested areas. The other ecological advantage of multiflora rose is derived from its woody growth habit. While garlic mustard is a prolific seed producer, the plant is a biennial, producing seeds only in its second year. Multiflora rose, however, reproduces not only by seeding, but also vegetatively via stolons or stem tips becoming rooted (Czarapata, 2005). The ability to retain prior years' woody structure and root system gives further advantage to *R. multiflora*. Also, forests in Wisconsin are more mesic, lacking wildfire (Rooney and Rogers, 2011) that have originated since European settlement. Rooney and Rogers point out that the lack of fire creates a positive feedback loop where mesic, shade-tolerant invaders reinforce an environment favorable to their growth. Lacking the governmental promotion that favored multiflora rose, perhaps garlic mustard needs more time to attain the dominance enjoyed by the woody invasive.

To illustrate the invasibility of major forest types by multiflora rose and garlic mustard, the regression lines were plotted (Figures 4 and 5). For both species, mixed-upland-hardwood has the highest level of invasibility as indicated by the steepest slope of the regression line. The relative invasibility of four major forest types takes the order (from high to low) of Upland-Mixed-Hardwood > Oak-Hickory > Elm-Ash-Cottonwood > Maple-Beech-Birch for multiflora rose and Upland-Mixed-Hardwood > Elm-Ash-Cottonwood > Oak-Hickory > Maple-Beech-Birch for garlic mustard, respectively.

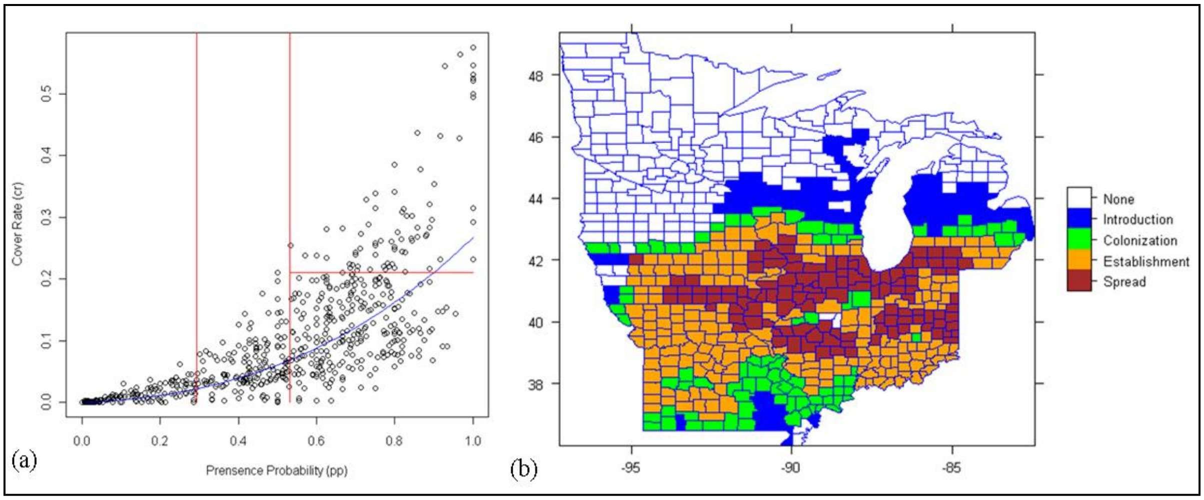

Figure 2. Invasion stages of multiflora rose.

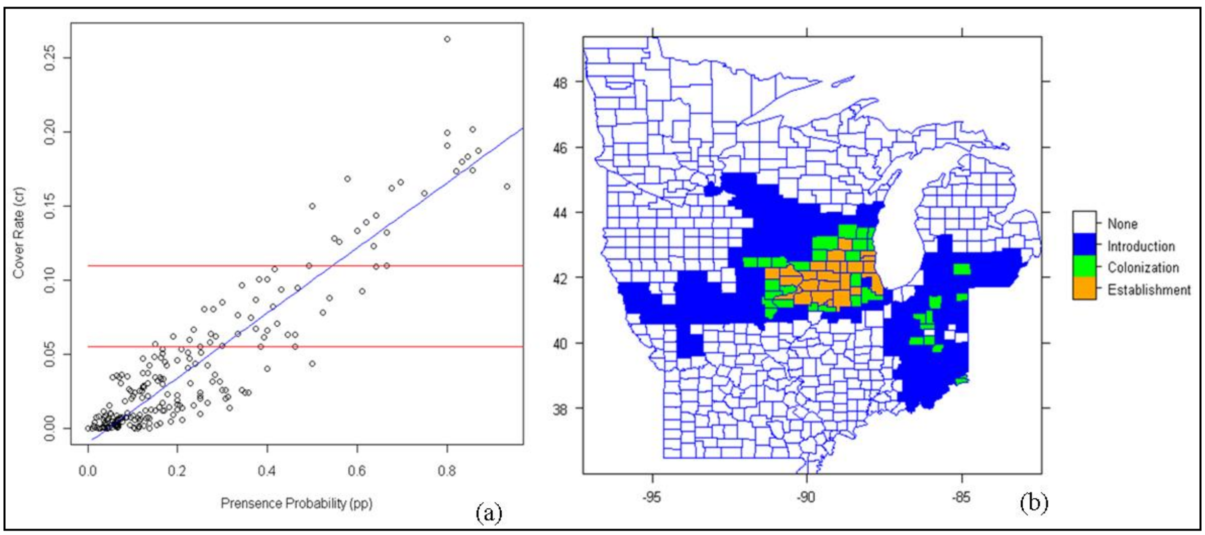

Figure 3. Invasion stages of garlic mustard.

As a forest progresses from an early-successional stage to a late-successional stage, unoccupied growing space progressively decreases as more niches are captured by particular species. Accordingly, more invasive plants would be expected in the early-successional stage. Disturbance, either natural or anthropogenic, can disrupt this progression (Oliver and Larson 1996), particularly if the disturbance is severe (Frelich and Reich 1995). By upsetting the dominance hierarchy of a forested ecosystem, disturbance can free up growing space and allow invasive plants the opportunity to gain a foothold on a site and, should the disturbance continue, expand from there. There appears to be a progression of decreasing invasibility as the forest types move toward more shade-tolerant or late successional species. The upland mixed hardwood forest type is a catch-all forest type in the eastern deciduous forest region that contains a mixture of hardwood species. In the Midwest, this type can include several species which are shade-intolerant or mid-tolerant (e.g., aspen *(Populus tremuloides),* birch, oaks (Dieser and Ek

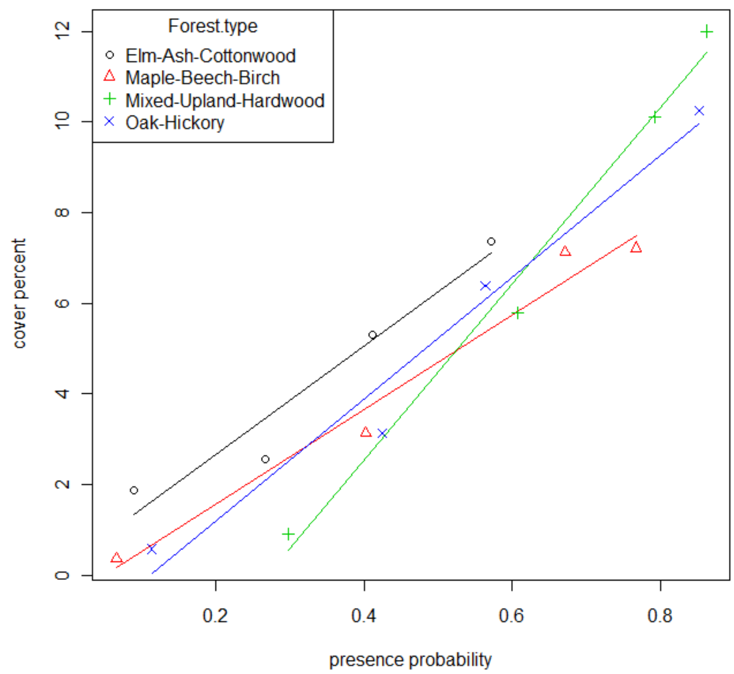

Figure 4. Invasibility of major forest types by multiflora rose.

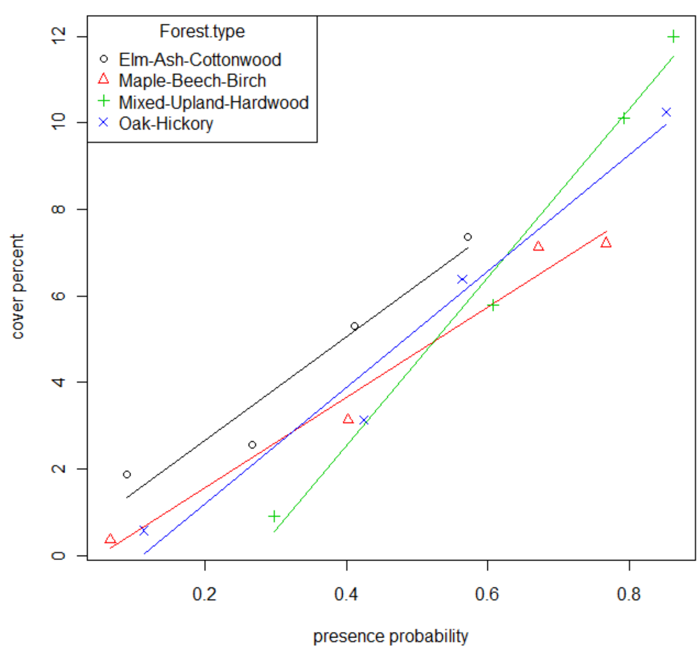

Figure 5. Invasibility of major forest types by garlic mustard.

2011)). While this type may have its ecological genesis in presettlement times due to widespread fires over a landscape dissected by streams and topography (e.g., southern Minnesota), the current character of this type is in large part due to frequent human disturbance, resulting in highly-fragmented second-growth forests**.** Oak-hickory forests are considered mid-successional and in such a forest, growing space is available at times; growing space that can be captured by invasives. By the nature of some of the component species, elm-ash-cottonwood can also be considered an early- to mid-successional forest type. Cottonwood is an extreme shade-intolerant species which usually regenerates on highly disturbed landscapes, such as newly-formed sandbars in riparian areas (Van Haverbeke 1990). Such sites are also conducive to colonizing by invasive plant species. Maple-beech-birch forests are generally considered late-successional (Delcourt and Delcourt 2000), containing predominantly shade-tolerant species such as sugar maple (*Acer saccharum*), basswood (*Tilia Americana*), and beech. With a higher leaf area index and lower light availability under intact canopies, such sites do not provide as much opportunity for colonization and establishment by these invasive plants.

Conclusions

The invasion stage for a variety of NNIPs as well as the relative invasibility of major forest types has been proposed using data from the FIA plots in the Upper Midwest, USA.. Shrubs were the most extensive group of NNIPs in the area, largely due to the extent of multiflora rose, as it was introduced as ground cover and for erosion control (Doll, 2006). If left unchecked, this species and others (e.g., garlic mustard) will continue to establish and spread throughout the area. Future research may consider seeding habits and vectors of the major species in the Upper Midwest. Resource managers in these areas should continually monitor forested areas, particularly those with the forest types at highest risk (e.g., mixed upland hardwood), for the presence of NNIPs. If detected early, it may be possible to eradicate a NNIP species before it can establish and spread throughout an area.

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