ESTIMATION OF INVASIVE PROBABILITY OF MULTIFLORA ROSA IN THE UPPER MIDWEST

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ABSTRACT

Multiflora rose (*Rosa Multiflora* Thunb.) (MFR) is widely spreading across the United States, with up to 38 states in the contiguous United States reporting the presence of this species. In this study, U.S. Forest Service, Northern Research Station Forest Inventory and Analysis (FIA) data from the Upper Midwest states for the period of 2005-2006 were used to calculate MFR presence probability at the county level. The classification and regression tree technique is used to classify the counties into invasive stages based on the estimated presence probability and a map of invasive stages is obtained, which is helpful for forest managers to optimally allocate resources. A simultaneous autoregressive model (SAR) was used to identify the driving factors of the spread of MFR. The contiguous invasive stages indicated a strong invasive pattern in all directions, particularly southward and eastward. MFR presence shows a positive spatial autocorrelation and is negatively associated with latitude and county forest cover percentage. Our results suggest that the distribution of MFR is likely limited by its intolerance to extreme cold temperatures and anthropogenic disturbance (forest fragmentation and deforestation) plays an important role in the spread of MFR.

INTRODUCTION

Non-native invasive plants (NNIPs) are defined 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 (Moser et al., 2009). Due to their competitive advantages compared with the native plants, some NNIPs can expel the native plants, alter the local ecosystem, threaten native biodiversity, and lower value of local ecosystem (Macdonald 1994). In the USA, the estimated loss due to NNIPs is more than $33 billion per year (Pimentel et al., 2005).

The invasive process is classified into four stages: introduction, colonization, establishment and spread (Theoharides and Dukes 2007). The factors that affect the spread of NNIP include temperature, site quality, stand size, forest fragmentation, distance to road, county percent forest etc (Moser et al 2009). A factor may play a role in one or more stages. The management of NNIPs depends on the stages of invasion since the cost dramatically increases as the population of NNIPs expands (Hobbs and Humphries 1995). It is prohibitively expensive to remove most of the NNIPs from the invaded region after they are well established. Webster et al. (2006) pointed out that the efforts to control invasive plants should focus on the establishment or earlier phases. Thus, the early detection of the NNIPs is very important.

In this study, we focus on multiflora rose (*Rosa multiflora* Thunb.) (MFR), which is widely established across United States. In fact, 38 states in the contiguous United States report the existence of MFR. MFR can exclude native ground flora and suppress tree regeneration and has been designated as a noxious weed in many states (Munger 2002, Denight el al., 2008). MFR was introduced to the North America in 1866 as rootstock for ornamental roses. Later, it was used for erosion control and "living fences" to confine livestock from the 1930s to the 1950s (Doll 2006). MFR is extremely prolific and its seeds are dispersed by birds and may remain viable in the soil for many years.

In this study, based on the estimated presence probability at the county level, we investigated the distribution of MFR, classified each county into four invasive stages using Classification and Regression Tree (CART) technique and identified the driving factors that affect MFR establishment and spread.

DATA AND METHODOLOGY

STUDY AREA

The Upper Midwest study region is comprised of seven states: Indiana, Illinois, Iowa, Missouri, Michigan, Wisconsin, and Minnesota. At the nexus of several ecoregions, this area is characterized by diverse vegetation compositions and structures. Northern Minnesota, and Wisconsin, northern Michigan, and southern Missouri are the most heavily forested areas. The middle of this region, most of it prairie during pre-European settlement times, is currently a mosaic of agricultural lands, with embedded

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urban areas. Extensive human activities and fertile soil in this region can favor the establishment of NNIPs.

DATA

In this study, U.S. Forest Service, Northern Research Station Forest Inventory and Analysis (FIA) data from the Upper Midwest states for the period 2005-2006 were used. Phase 2 (tree inventory) data were collected on the standard FIA plot grid (1 plot per 2400 ha). Each Phase 2 plot consists of 4 subplots with radius 7.3 m. Associated with this overstory inventory data was sampling for 25 invasive plants species of interest. These 25 species were categorized as either grasses, vines, herbaceous, or woody species, such as multiflora rose. In total, 8663 phase 2 forested plots were assessed for MFR, where 1320 plots (15.3 percent), were invaded by MFR. Related factors including county forest percentage, inter-state highway density, forest type, and fragmentation were measured or calculated by using auxiliary GIS layers. The coverage of MFR is classified into 7 categories (Moser et al. 2009) and the midpoint values of each cover class are used.

METHODOLOGY

THE PRESENCE PROBABILITY OF MFR—We are interested in the presence probability of MFR at the county level. Therefore, the plot data were aggregated to the county level in order to obtain the number of the MFR-presence and total plots at each of the 649 counties. Mathematically, the presence probability is estimated by the ratio between the number of the MFR-presence and the total plots in each county. However, this estimation is severely biased due to the sample size of each county. For example, some counties only have a couple of plots and others may have more than 100 plots. In order to correct the bias due to the sample size in each county, we redefined the presence probability:

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

where: s_j is the number of the MFR-presence plots in the county j, n_j is the total plots in the county j, η_i is the set of neighbor for the county i, including the county i.

CLASSIFICATION AND REGRESSION TREE (CART)—Then we used the CART (Breiman et al. 1984) to classify each county, based on the estimated presence probability, into different stages: introduction, colonization, establishment, and spread (Theoharides and Dukes 2007). The rpart package in R are used to implement CART (John, M. and John, B. 2003). Based on the classification of the estimated presence probability, we plot the map of invasive stages for the studied area.

MORAN'S I, AND GEARY'S C (WALLER AND GOTWAY 2004)—To investigate the spatial correlation of the presence probability of MFR, Moran's I and Geary's C were calculated via,

$$Moran's\ I = \frac{N * \sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}(Y_i - \overline{Y})(Y_j - \overline{Y})}{\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij} * \sum_{i=1}^{N}(Y_i - \overline{Y})^2}$$

and

$$Geary's\ C = \frac{(N-1) * \sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}(Y_i - Y_j)^2}{2\sum_{i=1}^{N}(Y_i - \overline{Y})^2 * \sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}}$$

where N is the number of counties; Y is the presence probability at each county; w_{ij} is a matrix of spatial weights.

The range of Moran's I is (-1, 1). The negative (positive) value of Moran's I indicates negative (positive) spatial autocorrelation. The value of Geary's C lies between 0 and 2. If Geary's C is less than 1, then it indicates positive spatial autocorrelation; otherwise, it indicates a negative spatial autocorrelation. Geary's C is inversely related to Moran's I and is more sensitive to local spatial autocorrelation.

SIMULTANEOUS AUTOREGRESSIVE MODEL (SAR) (WALLER AND GOTWAY 2004)—We used the simultaneous antoregressive model (SAR) to identify the driving factors of the spreading of MFR with the estimated presence probability (PP) as the dependent variable. The independent variables are: *Longitude (Lon), Latitude (Lat), forest fragmentation (Frag), ecoregion (Eco), road density (Rdens), and county-level forest cover percentage (CFP)*. Though we had tested other driving factors such as forest type, but they were not significant and were not included in the model.

The SAR model is espressed as:

$$PP = \beta_0 + \beta_1 * Lon + \beta_2 * Lat + \beta_3 * Frag + \beta_4 * Eco + \beta_5 * Rdens + \beta_6 * CFP + \varepsilon$$

$$\varepsilon = \rho W\varepsilon + v$$

where: β_is are the parameters that need to be estimated, ν is the independent error vector, ρ is the simultaneous autoregressive error coefficient, W is the spatial weight matrix.

RESULTS AND DISCUSSION

MFR is established in Missouri, Illinois, Indiana, Iowa, and the south of Wisconsin and Michigan and prevalent in northern Missouri, southeast Iowa, central and northern Illinois and Indiana. The forests ofthe northern of Minnesota, Wisconsin, and Michigan are not severely infected by MFR (Fig. 1). From this central core, MFR is spreading northward into the forested lands in southern Wisconsin and Michigan, and southward into the Ozark Highlands in southeast Missouri (Fig 3). There is a positive spatial autocorrelation among the MFR presence (Moral's I = 0.93, Geary's C = 0.08). The contiguous introduction, establishment and spread stages indicated a strong invasive pattern in all directions, but particularly southward and eastward.

The plot of X relative error vs. the tree size (Figure 2, left) suggests that tree size should be 4. And Figure 2 (right) suggested that each county should be classified into one of the four invasive stages: Introduction, <29.55%; Colonization, 29.55%-51.05%; Establishment, 51.05%-66.65%; and Spread, >66.65%. For each stage, we calculate the proportion of the plots for each cover class for each stage. Then the plot of proportion of plots of each class vs. the midpoint value of cover class (Figure 3, left) shows that this classification is reasonable. Finally, the map of invasive stages (Figure 3, right) is obtained based on the above classification.

SAR (Table 1) shows that county forest cover percentage, latitude and proportion of Lower Mississippi Riverine Forest are significantly negatively associated with the presence probability of MFR, while longitude and proportion of Eastern Broadleaf Forest and Prairie parkland are positively associated with the presence probability of MFR. Forest fragmentation and inter-state road density are not significantly related to the presenece probability of MFR.

Denight el al (2008) observed that the northern distribution of MFR is likely limited by its intolerance to extreme cold temperatures as suggested by the negative association with latitude-a surrogate for the winter temperature gradient. The negative association between county forest cover percentage and MFR presence indicated the significance of human disturbances in the spread of MFR. Actually, MFR was widely planted for erosion control in many less forested counties in northern Illinois, southeastern Iowa and northern Missouri between 1930s and 1960s (Doll 2006). As reported, MFR frequently colonizes roadsides, old fields, pastures, prairies, open woodlands, and forest edges but is not found in standing water or in extremely dry areas (Doll 2006), which conforms to the findings of its distribution in different ecoregions/forest types in our study. The positive relationship with longitude also reflects a strong eastward spreading pattern. Today, the species has become widely distributed in the eastern United States (Doll 2006). The non-significant relationship with forest fragmentation and road density seems to be a "scale" effect, for at the plot level; forest fragmentation and distance to roads have been suggested to be important influences of the establishment and spread of MFR.

SUMMARY

The strong spatial autocorrelation of MFR presence and its aggressive spreading southward and eastward reflects the fact that human disturbances and climatic factors, as well as forest conditions play an important role. Even though MFR's spread to the northern states seems to be curbed currently due to cold temperatures, climate change (warming) and the increasing number of anthropogenically-derived deforestation disturbances such as land clearing and urban development may increase the probability of infestation in the forests of the northern part of our study region. To prevent MFR from spreading into the highly forested areas in the northern states, a practical strategy is to eliminate MFR in the counties in the introduction stage and reduce MFR presence in the counties in the establishment stage. And the map of invasive stages can help forest managers to identify the counties in the introduction or establishment stage. Thus it provides a tool for forest manager to optimally allocate resources.

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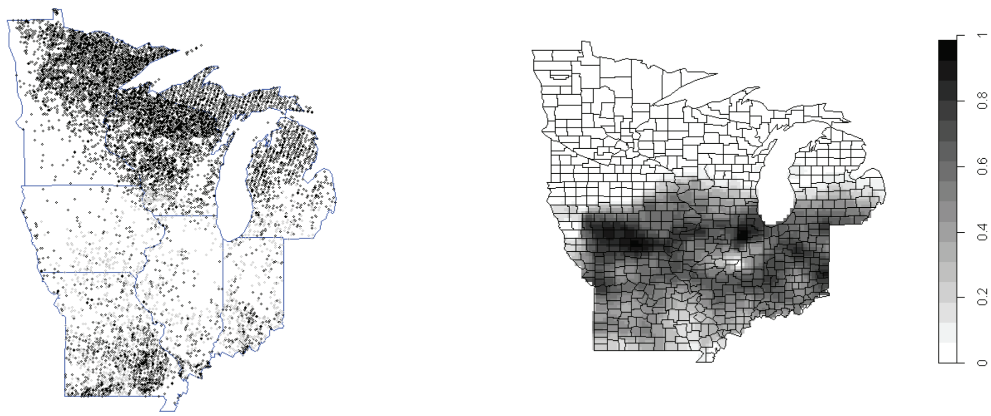

Figure 1—(Left) The distribution of FIA Phase 2 Plots without (black) and with the presence of Multiflora Rose (gray); and (right) the smoothed presence probability of MFR in the Upper Midwest, 2005—2006.

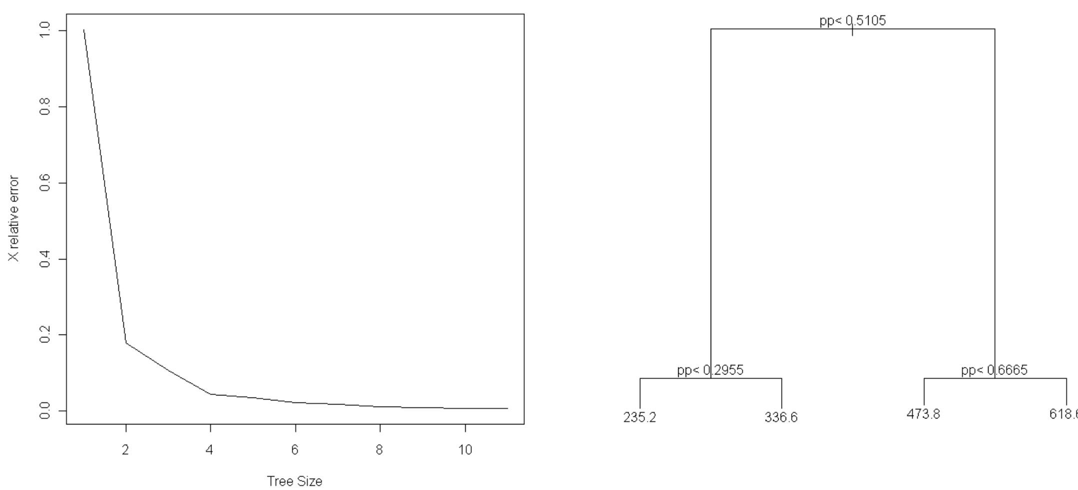

Figure 2—(Left) The plot of X relative error vs. the classification tree size; and (right) the Classification and regression tree partition of the estimated presence probability of MFR in the Upper Midwest, 2005—2006.

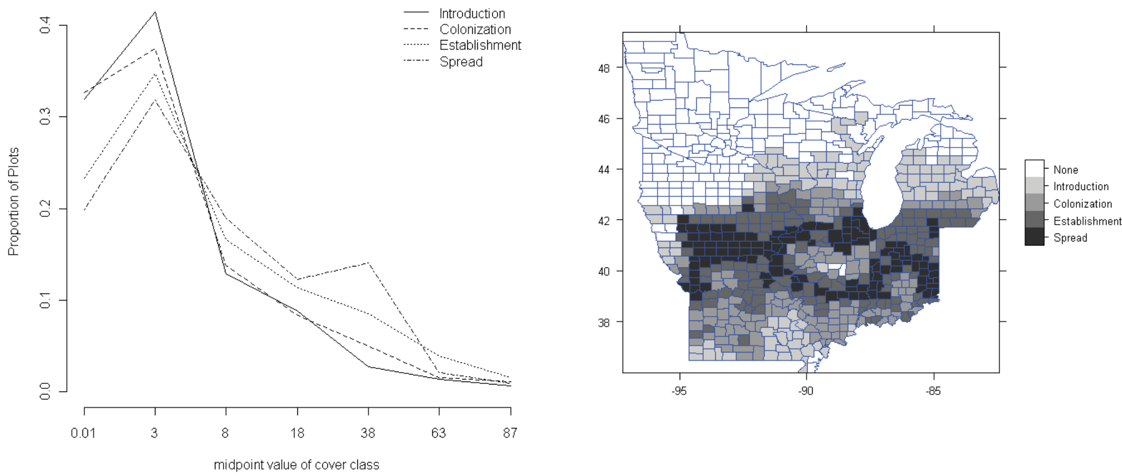

Figure 3—(Left) Proportion of plots vs. the midpoint value of cover class (see Moser and others, 2009 for the cover class categories); and (right) the maps of invasive stages based on the estimated presence probability of MFR in the Upper Midwest, 2005—2006.