Weed Technology. 2004. Volume :000–000

Note

?2 # Monitoring Nonnative Plant Invasions Over Fifty Years in Wisconsin Forests[1]

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?1 **Abstract:** Long-term ecological change is often hard to document without reliable baseline data. We obtained baseline data for and resurveyed 80 forest understory communities in Wisconsin first surveyed 50 yr ago. Sixty-two sites were in the forested region of northern Wisconsin, and 18 were in the agricultural region of southern Wisconsin. For 50 yr, the number of sites with nonnative plants increased from 4 to 62. Species richness in 1950 had little influence on nonnative species establishment by 2002, and nonnative species did not seem to influence rates of native species loss over time.
**Additional index words:** Ecologically invasive, forest, monitoring, plant, species loss, Wisconsin.

## INTRODUCTION

How quickly are nonnative plant species invading forests? We lack data in the United States to assess the fraction of our forests that contain nonnative plant species (The Heinz Center 2002), making it impossible to assess changes over time. The absence of long-term monitoring data on the distribution and abundance of nonnative species often prevents us from examining which species are invading most aggressively, whether effects on native species are associated with these invasions, which site-level factors might make communities more resistant to invasion, and how management might alter these patterns.

As part of an effort to quantitatively describe and catalog the plant communities of Wisconsin, Curtis (1959) and his students surveyed more than 1,400 sites in the 1940s and 1950s. They archived the raw data, providing an opportunity for researchers to resurvey sites and examine how species composition changed during the past 50 yr (Leach and Givnish 1996; Rooney et al. 2004). In this study, we use the historic data and our own resurvey data to answer the following questions. (1) How extensive are nonnative plants in native forests, and how has this changed over time? (2) Are ecologically invasive, nonnative plants invading at the same rate as noninvasive, nonnative species? (3) Does high initial species richness influence the likelihood of invasion by nonnative species? (4) Have sites with nonnative species lost more native species than sites without nonnative species?

[1] Received for publication January 12, 2004, and in revised form June 2, 2004. Received for the IPINAMS-EMAPi7 Conference Proceedings.
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## STUDY AREA AND METHODS

The vascular flora of Wisconsin contains 1,889 native species and 683 nonnative species and hybrids (Wetter et al. 2001). Subspecies and varieties are excluded from these figures. Of these 683 nonnative species, nearly 17% or 115 are classified as ecologically invasive (Wetter et al. 2001). The native flora contains boreal, Alleghenian, Ozarkian, prairie, and Atlantic Coastal Plain elements, whereas nonnatives are largely Eurasian in origin (Curtis 1959). (For a description of the physical environment, climate, and vegetation in Wisconsin, see Curtis [1959].) There are two distinct forest regions in the state. The southern part of the state once contained tallgrass prairie, oak savanna, and oak woodland and now has small patches of forest surrounded by agricultural and urban land uses. The northern part of the state was once extensively forested, is still dominated by forest, and has lower human population densities than the south does. Given these differences, we separate invasions in the north and south in our analysis.

In the summers of 2000 to 2002, we relocated 80 stands initially surveyed by Curtis (62 in the north and 18 in the south) that were still forested and at least 3 ha in size. We recorded all vascular plants <2.5 cm DBH in each of one hundred and twenty 1-m$^2$ quadrats, deliberately avoiding wet depressions, logging roads, and trails. Because Curtis (1959) sampled only twenty 1-m$^2$ quadrats per stand, we standardize our 2000 to 2002 data ?4
to a 20-m$^2$ basis. The probability, R, that a species $i$ that occurs $n_i$ times in the 120 quadrats of the 2000 to 2002 sample would occur in a smaller sample of 20 quadrats is $R = 1 - (1 - a_j/A_T)^{n_i}$, where $a_j$ represents the area of the smaller sample (20 quadrats), $A_T$ the area of the

*Table 1.* Changes in nonnative plants, ecologically invasive plants, and native species richness between 1950 and 2000 in northern and southern Wisconsin forests.

| | North ($n$ = 62) | | South ($n$ = 18) | |
|---|---|---|---|---|
| | 1950 | 2000 | 1950 | 2000 |
| Sites with nonnative species | 1 | 45 | 3 | 17 |
| Total no. nonnative species | 1 | 8 | 4 | 25 |
| Total no. ecologically invasive species | 0 | 4 | 3 | 15 |
| Mean no. nonnative species per site | 0.02 | 1.63 | 0.28 | 4.94 |
| Mean no. ecologically invasive species per site | 0 | 0.71 | 0.28 | 3.39 |
| Mean native species richness in 20 $m^2$ per site | 25.1 | 20.4 | 45.3 | 30.1 |

total sample (120 quadrats), and $n_i$ the number of quadrats that species $i$ occurs in of the 120-quadrat sample. We sum these probabilities for all species $i$ to obtain the number of species expected in 20 quadrats (Rooney et al. 2004). Rooney et al. (2004) provided a fuller description of the sites, survey methodology, and rationale. Nomenclature is according to Wetter et al. (2001).

To determine how extensive nonnative species are in forests, we tallied the number of nonnative species present per site in our 2000 to 2002 samples. To determine if nonnative pest species are invading at the same rate as nonpests, we divided nonnative species into two groups: ecologically invasive (according to Wetter et al. 2001) and noninvasive species. We compared differences in the number of all nonnative species and the number of ecologically invasive species per stand in the south and the north using $t$ tests. We also used $t$ tests to examine differences between the north and south in the ratio of nonnative to native species in the stand and the ratio of ecologically invasive to native species.

We used analysis of covariance (ANCOVA) to examine the influence of native species richness in 1950 on nonnative species establishment by 2000 to 2002 (dependent variable). We used region as the treatment variable and species richness (the total number of species present in twenty 1-$m^2$ quadrats) as the covariate. We also checked for interactions between the covariate and the treatment. We repeated this analysis for the subset of ecologically invasive species, using the total number of invasive species present as the dependent variable. We also used ANCOVA to examine the relationship between the rate of change in native species richness (S) during 50 yr (our dependent variable, defined as ln(adjusted $S_{2000}/S_{1950}$)) and the number of nonnative species present in 2000 to 2002, taking region into account. We repeated this analysis using only ecologically invasive species as the covariate and again checked for treatment by covariate interactions.

## RESULTS AND DISCUSSION

In the 1940s and 1950s, most sites lacked nonnative species. By 2002, nonnative species were present at most sites in both regions (Table 1). The number of nonnative species present in stands is three times greater in the south ($t$ = 6.41; df = 78; P < 0.001; Table 1), and the ratio of nonnative to native species is 2.5 times greater (0.20 ± 0.02 vs. 0.08 ± 0.01; $t$ = 3.58; df = 78; P < 0.001). The subset of ecologically invasive, nonnative species follows similar patterns. The mean number of species per stand is almost five times greater in the south than in the north ($t$ = 6.80; df = 78; P < 0.001; Table 1). The ratio of ecologically invasive species to native species is 0.12 ± 0.02SE in the south, three times greater than 0.04 ± 0.01SE in the north ($t$ = 4.79; df = 78; P < 0.001). The ratio of nonnative to native species in forests is smaller in both the south and the north than that for the state flora as a whole (0.361). However, the ratio of ecologically invasive species is greater in southern forests than in the state flora as a whole (0.061) and is slightly smaller in the northern forests.

We find no relationship between initial species richness in 1950 and the number of nonnative species establishing in these stands by 2000 to 2002 (ANCOVA; covariate $F$ = 1.54; P = 0.21), but differences between the north and the south explain 27% of the variation in the number of nonnative species established ($F$ = 29.21; P < 0.001). However, the number of ecologically invasive species establishing by 2000 to 2002 decreases with increasing species richness in 1950, explaining 7.6% of the variation (covariate $F$ = 9.28; P = 0.003), with differences between the north and the south accounting for 20.4% of the variation ($F$ = 24.3; P < 0.001). For ecologically invasive species, we also find a significant interaction between the region and initial richness, accounting for an additional 6.3% of the variation ($F$ = 7.33; P = 0.008), with the stronger ecologically invasive–species richness trend in the south. This finding suggests that more diverse sites are more resistant to ecologically invasive plants at this spatial and temporal scale of analysis, but the trend is weak.

ANCOVA also reveals large differences in the change in native species richness between regions. Native species richness declines 34% per 50 yr in the south and 19% per 50 yr in the north ($F = 9.60$; $P = 0.003$). The rate of native species loss is highest at sites without nonnative species present in 2000 to 2002 ($F = 4.91$; $P = 0.03$). This counterintuitive pattern also holds for ecologically invasive species; the rate of native species loss is lower where there are more ecologically invasive species ($F = 4.54$; $P = 0.04$). We find no significant region by covariate interactions for either analysis. Thus, for nonnative species and ecologically invasive species in aggregate, we find no evidence that they contributed to native species loss during the past 50 yr. This is consistent with the observation that most invasions fail to influence changes in native species richness (Simberloff 1981; Williamson 1996). It should be noted that nonnative and ecologically invasive species are still minor components of most stands sampled. The ratio of nonnative to native species never exceeded 0.52, and the ecologically invasive to native species ratio was always less than 0.41. Although it is possible that these invaders (particularly the ecologically invasive species) will depress native species richness in the future and that sufficient time has not yet elapsed, it is more likely that statistically treating all nonnative species or all ecologically invasive species as equivalent obscures important species-specific influences on communities. Also, because this study was designed to track invasions in forests, our ability to detect effects of ecologically invasive plants is limited.

We continue to add sites and species to this data set, so these results should be considered preliminary. In future analyses, we expect to focus increasingly on landscape-level variables as predictors of invasion. We also are keenly interested in the effects of individual invaders on communities, particularly those classified as ecologically invasive.

## ACKNOWLEDGMENTS

We thank many landowners for letting us sample their lands, including the Dairymens Club, U.S. Forest Service, Wisconsin Department of Natural Resources, Menominee Nation, Lac du Flambeau band of Lake Superior Ojibwe, and many private landowners. We thank H. Iltis, T. Cochrane, E. Judziewicz, and H. Ballard for their help in identifying specimens. Trout Lake Station provided housing during portions of this study. Financial support comes from National Science Foundation DEB 9974041 and 0236333 and NRI-CSREES-USDA 2003-35320-13584.

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