# Naturalized pine (*Pinus nigra*) promotes growth of woody vegetation in native sand prairie: impacts of invasion 130 years after introduction

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## Abstract

The successional dynamics of sand dune systems provide an opportunity to examine how introduced plant species affect plant communities over small spatial scales. We used dendrochronologal analysis to age stands of ***Pinus nigra* (Austrian pine)** at Illinois Beach State Park (IBSP), Zion, IL, USA to reconstruct the invasion process from the original plantings about 130 years ago through the interdunal sand prairie towards the shore of Lake Michigan. The pines form patchy stands and we show how the presence of the stands has changed the composition of the plant community underneath stands of varying age. *P. nigra* is encroaching on the habitat of restored populations of *Cirsium pitcherii* (Pitcher's thistle) among other rare natives of the dune system. We found that *P. nigra* forms single age class stands and that recruitment is **episodic and discrete** in both space and time. *P. nigra* stands are associated with ground cover plant communities with significantly different structures than that of the unaffected sand prairie areas at the site. **Woody species increased dramatically** in areas affected by the pines, and the effect is **progressive,** with woody species increasingly more common as the stands mature. This progressive temporal change in the ground vegetation is accompanied by a significant progressive spatial effect of distance from tree as well, with woody species frequency decreasing, and herbaceous species frequency increasing with distance from a tree. **Overall, bare sand areas decreased dramatically, along with the percentage of graminoid and forb species** in areas affected by *Pinus nigra* stands.

Part of a Mature stand (left) and an Intermediate stand (right) of naturalized *Pinus nigra* (Austrian Pine) in the sand prairie of the dune-and-swale system at IBSP.

Young pines recruit in areas with bare sand. Older pines are associated with a decrease in species such as *Euphorbia corollata* (Flowering Spurge) (above).

## Results

### Dendrochronology and Invasion Reconstruction

The spatial relationships of the stands to each other and to Lake Michigan are illustrated in Figure 1. The cores gave a median age of 113 years for the two Mature stands, of 54 years for the Intermediate stands, and 8 years for the Young stand. These measurements indicate that the trees in the Mature stands began to establish in the year 1894, on average, with the Intermediate stands beginning to establish 59 years later, about 60 m to the east in the year 1953. The Young stand began to recruit 60 m to the east of the Intermediate stand 46 years later, in the year 1999. These dates do not represent the absolute starting points for the stands, but rather represent points in time when a 'critical mass' of trees had successfully established themselves in a circumscribed location. In short, these dates represent a reasonable estimate of when an observer would be able to identify a recognizable "stand" of *P. nigra* developing in the dune system.

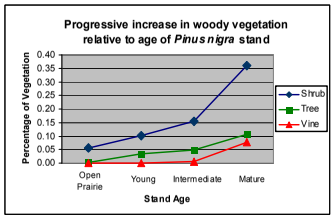
### Effect on Ground Cover

The results of the pairwise comparisons of vegetation type using 5 x 2 contingency chi-squared tests are displayed in Table 2. The vegetation in all of the stands is significantly different ($p < .0001$) in every comparison except for the comparisons of the two Mature stands, and the two Intermediate stands, respectively. These results illustrate the fundamental differences in ground cover composition among stands of *P. nigra* of varying ages. The two non-significant comparisons suggest that the two Mature and the two Intermediate stands are truly replicates of one another.

The results were similar when tested in a slightly different way. When the Shrub and the Vine counts were combined for the analysis of vegetation type with age of tree stand (Mature, Intermediate, Young, Open Prairie [No trees]), the 5 x 4 chi-squared contingency table gave a significant $\chi^2$ value of 313.3, df = 12, $p < 0.0001$.

Particularly remarkable trends illustrated in Figure 2 include the dramatic increase amongst woody species (shrubs, trees, vines) over time, from 6% of the cover in uninvaded sand prairie to 55% of the cover in the Mature stands. Graminoids decrease from 48% to 30% and Forbs decrease from 27% to 12% of the cover in the uninvaded sand prairie and the Mature stands, respectively.

We used 5 x 3 contingency chi-squared analyses to test for an effect of distance from tree (at 1m, 5m, 10m intervals) on vegetation type and found significant differences for Mature stands ($\chi^2 = 16.93$, df = 8, $p = 0.03$) and Intermediate stands ($\chi^2 = 38.5$, df = 8, $p < 0.0001$). Young stands ($\chi^2 = 11.98$, df = 8, $p = 0.15$) did not give a significant effect on vegetation type with distance from tree. It takes a long time (50 years) before a significant effect on the prairie vegetation with distance can be detected, even though the processes that will account for the change (associated with the presence of young pines) are already operating in the young stands.



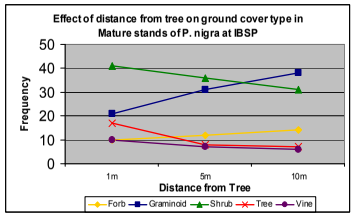




Figure 2: Variation in ground cover composition by functional group among *P. nigra* stands and in the uninvaded sand prairie and at Illinois Beach State Park.

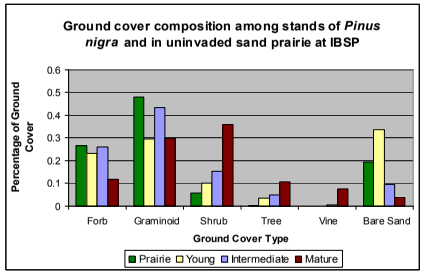



Table 1: Characterization of studied *P. nigra* stands at Illinois Beach State Park

| Stand Name | Number of trees | Birth year of oldest tree in stand | Median Age (yrs) | Birth year of youngest tree in stand | Mean DBH (cm) | Mean distance from lake (m) | Mean nearest neighbor distance (m) |
|---|---|---|---|---|---|---|---|
| Mature 1 | 12 | 1879 | 112 | 1910 | 47.7 | 244 | 6.49 |
| Mature 2 | 13 | 1882 | 114 | 1920 | 49.9 | 248 | 5.74 |
| **Mature** | 25 | 1879 | 113 | 1920 | 48.8 | 246 | 6.10 |
| Intermediate 1 | 11 | 1902 | 54 | 1971 | 37.3 | 191 | 8.80 |
| Intermediate 2 | 15 | 1946 | 53 | 1968 | 38.0 | 185 | 7.24 |
| **Intermediate** | 26 | 1902 | 53.5 | 1971 | 37.7 | 188 | 7.90 |
| **Young** | 27 | 1958 | 8 | 2005 | 11.6 | 130 | 5.10 |

Table 2: Pairwise comparisons of ground cover compositions of stands using 5 x 2 chi-squared contingency tables (Shrub and Vine counts combined) (p, $\chi^2$, significance).

| Stand Name | Mature1 | Mature2 | Intermediate1 | Intermediate2 | Young | Prairie |
|---|---|---|---|---|---|---|
| Mature1 | X | | | | | |
| Mature2 | 0.26, 5.25, NS | X | | | | |
| Intermediate1 | <.0001, 27.0, * | <.0001, 40.4, * | X | | | |
| Intermediate2 | <.0001, 39.4, * | <.0001, 53.0, * | 0.87, 1.24, NS | X | | |
| Young | <.0001, 97.2, * | <.0001, 123.9, * | <.0001, 31.5, * | <.0001, 36.0, * | X | |
| Prairie | <.0001, 128.2, * | <.0001, 156.3, * | <.0001, 29.4, * | <.0001, 29.7, * | <.0001, 37.9, * | X |

## Methods

### Tree Coring, Stand Mapping and Measurement

With the aid of satellite images (Google Earth), we selected a wide swath of land starting at the lakeshore south of the Dead River and continuing westward to an area containing what appeared to be trees of the original introductions. Within this strip of land, we selected all five spatially distinct stands of *P. nigra* trees for dendrochronological analysis. The five stands were grouped into three categories based on presumed age. We took tree cores from every living tree in each stand. The tree rings of each core were counted in the laboratory to determine each tree's age. We measured distances among trees in each stand, and between the boundaries of adjacent stands to create the stand map below.

### Stand Ground Cover and Vegetation Analysis

In order to investigate how pine invasion impacts the presence of other plant species in the ecosystem, we assayed the below-eye-height vegetation in each stand. To speed the analysis, we used **functional plant types** rather than species. There were six categories recorded in the analysis: Tree (woody plant > 1 m), Shrub (woody plant < 1 m), Graminoid, Forb, Vine, and Bare Ground (no plant present at sample point). Each tree was used to generate 12 sample points. We took a sample at 1 m, 5 m, and 10 m in all four cardinal directions around each pine. At each sample point we shined a flashlight beam toward the ground and recorded the functional plant type hit first as the observation at that point.

We used a transect sampling scheme to categorize the vegetation between adjacent stands. We defined ten transects of 25 m in length between each adjacent stand. Thus, 6 sets of 10 transects were sampled (M1-M2, M2-I2, I2-I1, I1-M1, Y1-I1, Y1-I2). Figure 1 shows the relative locations of the stands in the study area. Transects were laid perpendicular to the edge of a stand and adjacent transects were 10 m apart. Five samples were made at points 5 m, 10 m, 15 m, 20 m, and 25 m along each transect, generating 300 sample points in all. Samples were made in identical fashion to the samples taken within stands using the point-intercept method described above.

## Methods

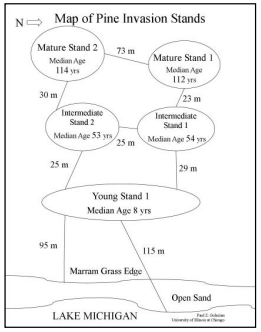
### Data Analysis

### Impact of Trees on Vegetation

The primary means we used to evaluate differences of vegetation among stands was the **contingency chi-squared test** (http://faculty.vassar.edu/lowry/newcs.html). Each of the 5 stands was compared pairwise to each other stand in a **5x2 contingency table**. All the contingency analyses combined shrubs and vines (both are woody and except in the mature stands the counts of vines were very low). We also performed a **5 x 4 chi-squared contingency table test** to look for an effect of all four stand ages (Mature, Intermediate, Young, Open Prairie [no trees]) on associated ground cover vegetation type. The ground cover functional group percentages for each comparison were based on at least 300 ground cover sample points in each case (N=300 for Mature; N=312 for Intermediate; N=324 for Young; N=300 for sand prairie). These analyses quantify a **temporal effect** of the pines on the prairie vegetation. We expect to see **progressive changes** in the vegetation in the order: **prairie-young-intermediate-mature**.

We also used contingency chi-squared analyses to evaluate if distance from the pines had an effect on vegetation. Each of these contingency tests used a **5 x 3 contingency table**, with distance of the sample point from the nearest tree (1 m, 5 m, 10 m) as the 3 columns, and the five vegetation classes (Graminoid, Forb, Shrub, Tree, Open) as the rows. Vine counts were combined with the counts of the Shrub class to assure minimum expected count numbers in the contingency table. These analyses represent our quantification of a **spatial effect** of the pines on the ground cover vegetation. We expect to see **progressive changes** in the vegetation with the counts of a **particular vegetation type at 5m to be intermediate to those at 1m and 10m.**

Figure 1: Schematic map of *P. nigra* stand locations



A Significant Increase in Woody Species

## Conclusions

- ***P. nigra* recruitment is episodic and discrete in both space and time.**
- **Woody species increased significantly in areas affected by the pines, and the effect is progressive, with woody species increasingly more common both closer to a tree, and as the stands mature.**
- **It takes a long time (about 50 years, in Intermediate stands) before a significant effect on the prairie vegetation with distance from a tree can be detected, highlighting the need for long-term ecological studies of the consequences of plant invasions.**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