Magnolia grandiflora L. Range Expansion: A Case Study in a North Carolina Piedmont Forest

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Abstract - We analyzed a naturalized population of *Magnolia grandiflora* L. occurring north of its native range in a temperate deciduous forest of the North Carolina piedmont. The population was likely expanding, based on its size-class distribution; however, it had not reached a reproductive size or age. The maximum size of established stems was 9.8 cm dbh and the maximum age, based on a subset of sampled stems, was 26 years. We analyzed the establishment of *M. grandiflora* trees with respect to several environmental variables. Climatic variables included annual minimum winter temperatures, frost-free periods, and precipitation, and topographic variables included elevation, aspect, and slope. We found a strong correlation between establishment and minimum winter temperatures as well as frost-free periods, but not with other environmental variables. *Magnolia grandiflora* has become naturalized north and west of its native range on the southeastern coastal plain; among the possible causes are climate change and the increased use of cold-hardy genotypes.

Introduction

Magnolia grandiflora L. (Southern Magnolia or Bull Bay) is native only to the coastal Southeastern United States (see Fig. 1), but has become naturalized north and west of its native range, into New England, the Midwest, and the Southwest (Basinger 1998, Becker 2004, USDA 2009). Though much research has addressed the local expansion of *M. grandiflora* populations into fire-suppressed pine forests within its native range (Daubenmire 1990, Delcourt and Delcourt 1977, Glitzenstein et al. 1986, Myers and White 1987), no studies have explored the nature of its northward and westward range expansion (Becker 2004). We analyzed a population naturalized in the piedmont region of North Carolina close to the University of North Carolina at Chapel Hill, an area in which *M. grandiflora* has been cultivated for well over 100 years.

We were interested in this invasion in part because broad-leaved evergreens have been used as climate indicators in Europe, due to their sensitivity to low winter temperatures (Berger et al. 2007, Box 1981, Pott 2005, Woodward et al. 2004). European broad-leaved evergreen species are undergoing a climate-induced northward range expansion, potentially due to rising minimum winter temperatures. We therefore compared the time course of *M. grandiflora* establishment with local weather data for this time period.

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The pattern and process of plant invasion is an important topic of current research in ecology and conservation biology (Fridley et al. 2007). Research has found that invasion can be correlated with site environment, primary productivity, disturbance, and community diversity. Of these factors, we examined whether the establishment of *M. grandiflora* was correlated with topography (which is correlated with microclimate and productivity). Although disturbance is potentially significant, this factor is less important for a deeply shade tolerant species like *M. grandiflora*. Hurricane Fran in 1996 and Hurricane Isabel in 2003 caused moderate disturbance in our study area; however, we saw no evidence in the field that *M. grandiflora* establishment was related in any way to treefall gaps, so we did not add this factor to our study.

Our study area is located in Chapel Hill (Orange County, NC), more than 200 km northwest of the nearest native *M. grandiflora* population (Brunswick County, NC). With regards to the established population, we addressed the following questions: 1) what is the extent and size structure of the *M. grandiflora* population in the study area? 2) Has the population produced reproductive individuals?

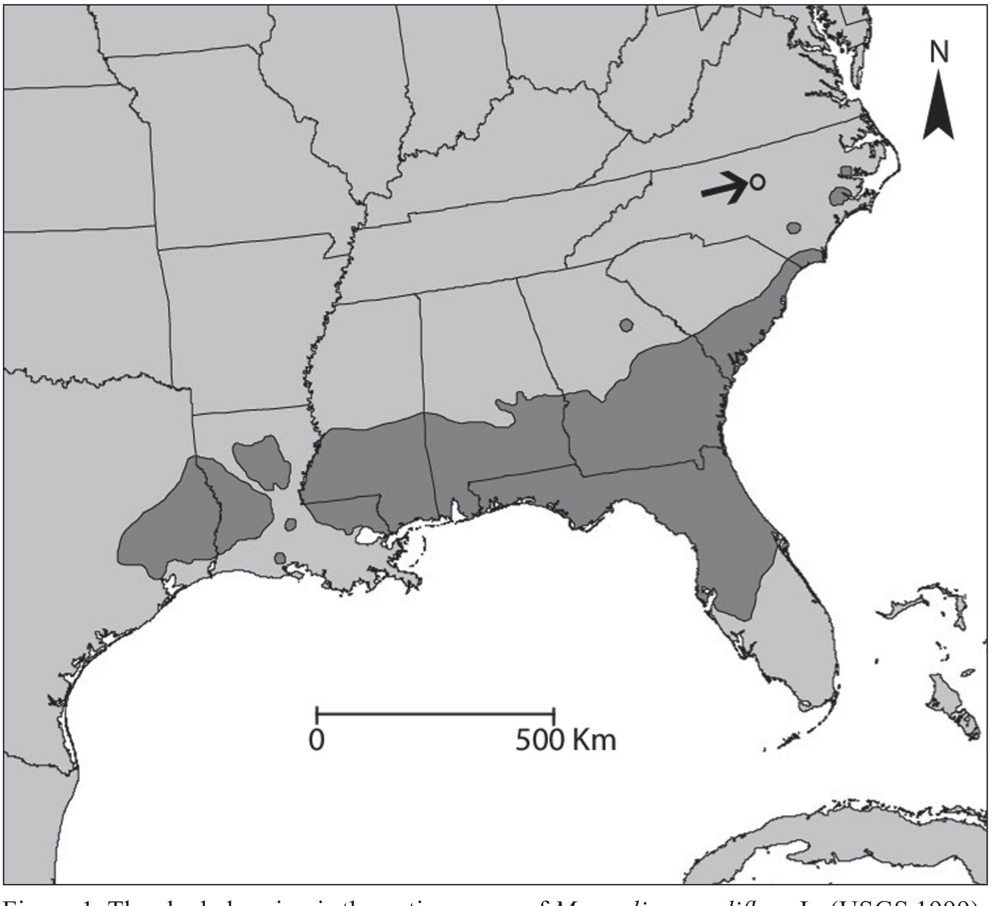


Figure 1. The shaded region is the native range of *Magnolia grandiflora* L. (USGS 1999). The outlying northern locations were likely recorded from cultivation. The arrow points to the location of the study area in Chapel Hill, Orange County, NC.

3) Can we conclude from the answers to questions 1 and 2 that the population is expanding? 4) Do the ages of the *M. grandiflora* stems correlate with a change in yearly minimum winter temperatures, frost free periods, or annual precipitation? and 5) Is the distribution of stems correlated with the elevation, aspect, or slope, environmental variables which may indicate an association with microclimate or site productivity?

Methods

Study area

We studied a 17.5-ha tract in the western part of 37-ha Battle Park (35.914°N, 79.04°W), which is characterized by mature upland deciduous forest dominated by Oak and Hickory (Fig. 2). Battle Park was gifted to the University of North Carolina in 1792 by local citizens (the University was authorized in 1789 and opened in 1793) and became a conservation tract of the North Carolina Botanical Garden in 2004. Though Battle Park was never farmed nor clear cut, and thus has

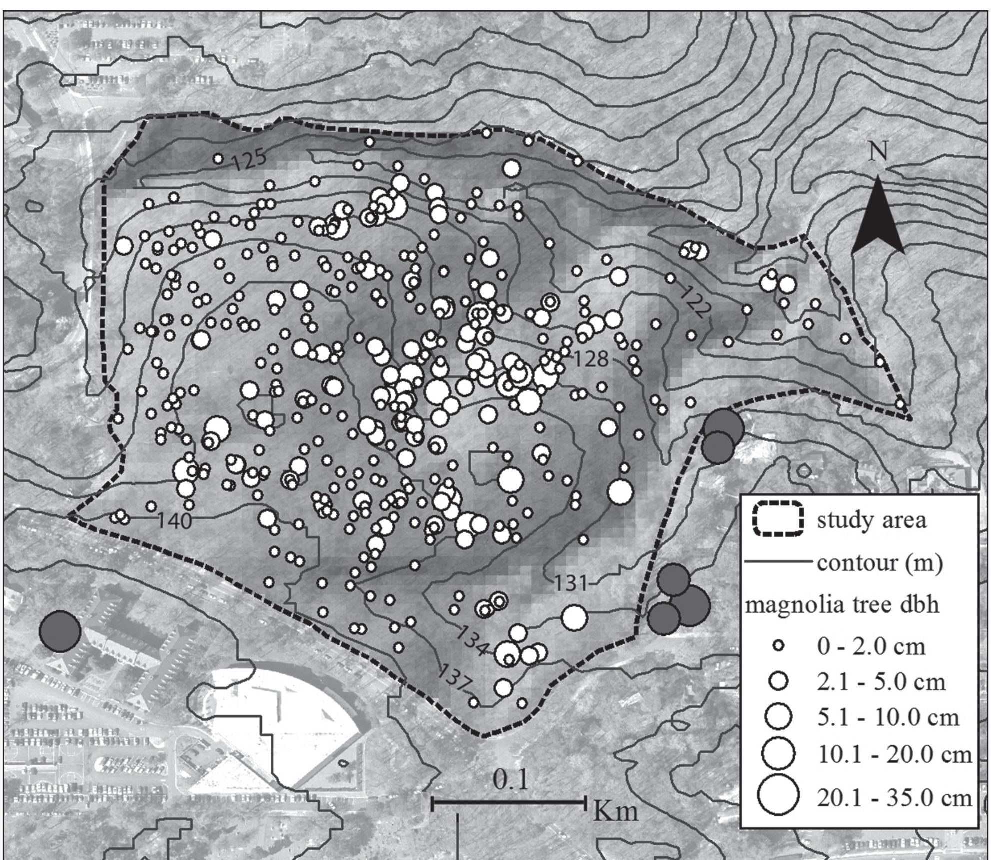


Figure 2. The study area, with transparent hillshade and slope relief. The circles representing the proportional dbh of *M. grandiflora* stems. The shaded circles demark those *M. grandiflora* cultivated outside of the study area; these trees, also represented by proportional dbh, were fertile and potential source trees for the introduced population.

been forest since presettlement times (settlement began in 1742 in Chapel Hill), it did experience selective harvesting for fuel and lumber, as well as understory grazing. These practices ended by the early decades of the twentieth century. Recreational trails have traversed the forest since the late 1800s (Battle et al. 1930) and continue to this day.

The vascular flora of Battle Park includes 642 taxa, 455 of which are native and 187 exotic (Giencke et al. 2007). Dominant trees (from most to least abundant) include *Quercus alba* L. (White Oak), *Liriodendron tulipifera* L. (Yellow Poplar), *Fagus grandifolia* Ehrn. (American Beech), *Acer rubrum* L. (Red Maple), and *Carya alba* (Lam. ex Poir.) Nutt. (Mockernut Hickory). Seventeen of the 187 exotics are escapes from cultivated plants that represent species native to the Southeast (*M. grandiflora* included).

The climate, as recorded by the Chapel Hill 2 W station 3.2 km away from the study area, is characterized by a 30-year (1971–2000) average temperature of 3.5 °C in January and 25.3 °C in July (NOAA 2005). Historical environmental disturbances include two hurricanes (as mentioned, Hurricane Fran in 1996 and Isabel in 2003), both of which caused moderate tree damage within the Park.

Study species

The native range of *M. grandiflora* stretches from the southern-most county of North Carolina to eastern Texas (Fig. 1) (Little 1971, USGS 1999). Across this region, populations of *M. grandiflora* occur in mesic to hydric areas where fires are absent, infrequent, or of low intensity. Additionally, *M. grandiflora* occurs as a late successional species on fire-suppressed sites (Delcourt and Delcourt 1977). The species may spread by dispersal via birds, small rodents, or other mammals, or even vegetatively through underground root shoots and trailing branches (Gardiner 2000).

M. grandiflora has a long history of cultivation in the United States and in several countries worlwide (Missouri Botanical Garden 2011) because of its dark evergreen leaves, large fragrant flowers, symmetrical form, and adaptability to soil and climate in temperate as well as tropical regions. It is often cited as the most popular cultivated broad-leaved evergreen tree (Gardiner 2000, Treseder 1978). However, minimum winter temperatures restrict its cultivation success in the northern United States and British Isles. Seedlings and saplings, in particular, are susceptible to defoliation by frost damage and dehydration by winter winds when temperatures are below -14 °C. Additionally, when subjected to a shorter reproductive season and sooner onset of winter temperatures, older trees will not produce fruits or flowers.

Within its native geographic range, *M. grandiflora* withstands minimum winter temperatures between 6 and -12 °C. In cultivation, its has endured temperatures as low as -18 °C. Its inability to flower when exposed to cold winter temperatures has stimulated selection for cold hardiness by the horticulture industry and hybridization with *Magnolia virginiana* L., to produce cold-hardy genotypes (Gardiner 2000, Treseder 1978).

Within the southeastern United States, *M. grandiflora* cultivation dates back to at least the 1800s. At this time, trees were planted on homesteads as far north as Michigan, though they did not necessarily flower (Treseder 1978). Horticulturalists have produced over 100 cultivars of *M. grandiflora* and two hybrids, the Freeman hybrids, from crosses with *M. virginiana,* which has a slightly larger native range (Little 1971). Based on native trees' resemblances to the Freeman hybrids, there is some evidence for natural hybridization between *M. grandiflora* and *M. virginiana* within these species' native ranges (Treseder 1978).

In Chapel Hill, *M. grandiflora* has been cultivated since at least 1922 (the date of the oldest NCU herbarium specimen of the species, collected in the University's Coker Arboretum). Additionally, there is a reference (Battle et al. 1930) to planted "Magnolia" trees occurring in the late 1800s on the Senlac homesite bordering Battle Park. Without reference to species, we assume the trees to be *M. grandiflora,* considering its popularity during this time period (Gardiner 2000, Treseder 1978). Excluding the Senlac home, development of residential area proximal to the study area began in the 1920s (Giencke et al. 2007), and planted *M. grandiflora* trees are now common on these nearby properties.

Sampling procedures

We gathered data on *M. grandiflora* trees in the fall or winter of 2005, 2008, and 2009. For every *M. grandiflora* tree over 1.4 m in height, three pieces of information were gathered: (1) geographical position using a mapping-grade Trimble handheld GPS unit (2- to 5-m accuracy under ideal conditions), (2) diameter at breast height (dbh), and (3) evidence of reproduction (i.e., flowers or fruits on the tree). We also collected this information from areas surrounding Battle Park, including lands of the university campus and residential area (see Fig. 2) in order to determine the size and reproductive status of nearby cultivated trees.

In order to determine the invading population's age, we counted growth rings for eleven trees that spanned the range of diameters we recorded in our survey. We gathered samples from each tree by cutting three tree "cookies" (cross-sections) at the trunk base. We then counted the number of rings for each sample, using a dissecting microscope. Though there was minimal discrepancy between the three cross sections per tree, the widest "cookies" generally produced rings easiest to detect.

We analyzed local trends in climate using a comprehensive dataset of values for daily temperatures and precipitation provided by the Southeast Regional Climate Center of the University of North Carolina at Chapel Hill. The climate data was recorded at the Chapel Hill 2 W weather station, NOAA Station Id: NC311677 (35.91°N, 79.08°W). This station has an elevation of 152 m and is located 3.2 km from the study area.

Data analysis

We used Microsoft Office Excel 2007 to graph the size-class distribution as well as the estimated age of the *M. grandiflora* stems based on their dbh. We used a linear trendline to generate a regression equation relating dbh to stem age; this equation provided us an estimated year for the establishment of every stem with a measured dbh, integral for the following climate analysis.

We also used Excel to sort and graph the climate dataset with respect to the age of the onset of the population and establishment of stems. The graphs incorporated the years from 1975 to 2005, to provide data both before the population established, as well as after we have recordable data (the youngest and unmeasured trees were most recently established). To analyze minimum temperature thresholds of the trees, we used a pivot table to graph absolute minimum winter temperatures for every year from 1975 to 2005. January and February were incorporated into the previous year's "winter" data.

For an analysis of the frost-free period of each year (commonly referred to as the growing season), the climate dataset was reviewed for the number of days between the last and first frosts of a given year. We estimated the temperature of a frost using the common frost indices of 0° C (32° F) and -2.2° C (28° F).

Lastly, we averaged the daily precipitation values for all given years and also graphed this precipitation trend relative to *M. grandiflora* stem establishment.

Data analysis with geographic information system

We evaluated the study area's environmental variables using ArcGIS 9.3.1, released by ESRI in 2008, and available through Washington University in St. Louis. We explored *M. grandiflora* establishment with respect to environmental variables. We used the USGS 2005 National Elevation Data Set entitled "twenty-ftdem" for elevation data, and calculated aspect and slope from the elevation via Spatial Analyst. We then applied the histogram tool within Geostatistical Analyst to compare the frequency of *M. gandiflora* within the study area present at a given environmental variable (stem frequency) to the frequency of the environmental variable across the study area (pixel frequency).

Results

Size-class distribution of stems

We recorded 438 stems of *M. grandiflora* in the 17.5-ha study area; the study area was therefore characterized by 25 *M. grandiflora* stems/ha. Basal area was 0.0453 m^2/ha. The majority of the stems were in the smallest size class (Fig. 3). Eighty-nine percent were less than 4 cm dbh, and 59 percent were less than 1.5 cm dbh. The stems within the study area had a significantly lower dbh than planted trees surrounding the study area. The maximum dbh we observed within the study area was 9.8 cm, whereas the cultivated trees surrounding the study area ranged from 13.8 to 33.9 cm dbh. Though *M. grandiflora* occurring within the study area did not produce reproductive structures, all trees outside of the study area bore abundant fruits and flowers.

Age of population relative to dbh

With respect to the time of *M. grandiflora* establishment determined by the number of growth rings (Fig. 4), the youngest tree for which we took dbh measurements was 5 years old and the oldest of those sampled was 26 years old. There is a strong positive correlation between dbh and tree age (R^2 = 0.84); however, trees with low dbh appear to be more variable in age than larger stems.

Analysis of climatic trends

Minimum winter temperatures have been rising and the growing season has been becoming longer in Chapel Hill for the last three decades (Figs. 5, 6). There

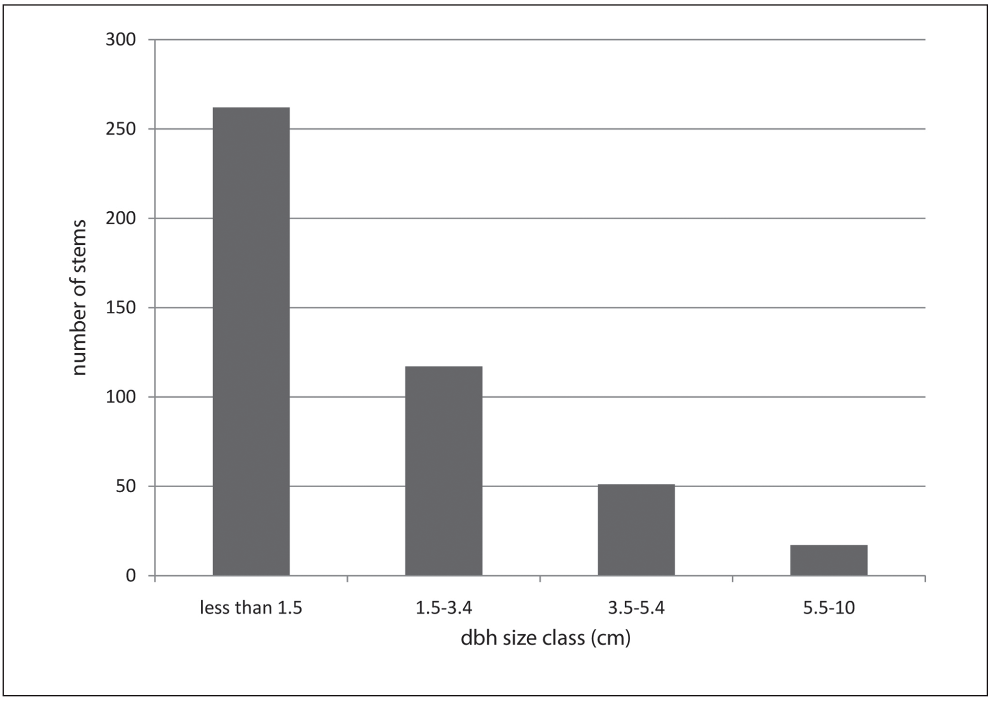


Figure 3. Size-class distribution of *M. grandiflora* stems.

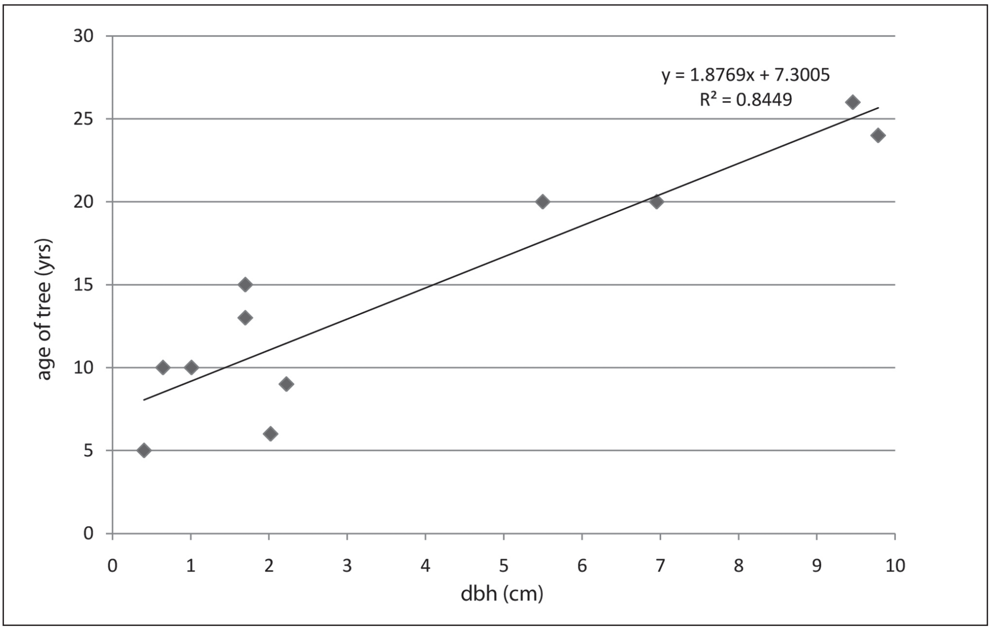


Figure 4. *Magnolia grandiflora* dbh and a corresponding estimated age, as determined by the number of growth rings of a sample of *M. grandiflora* trunk bases.

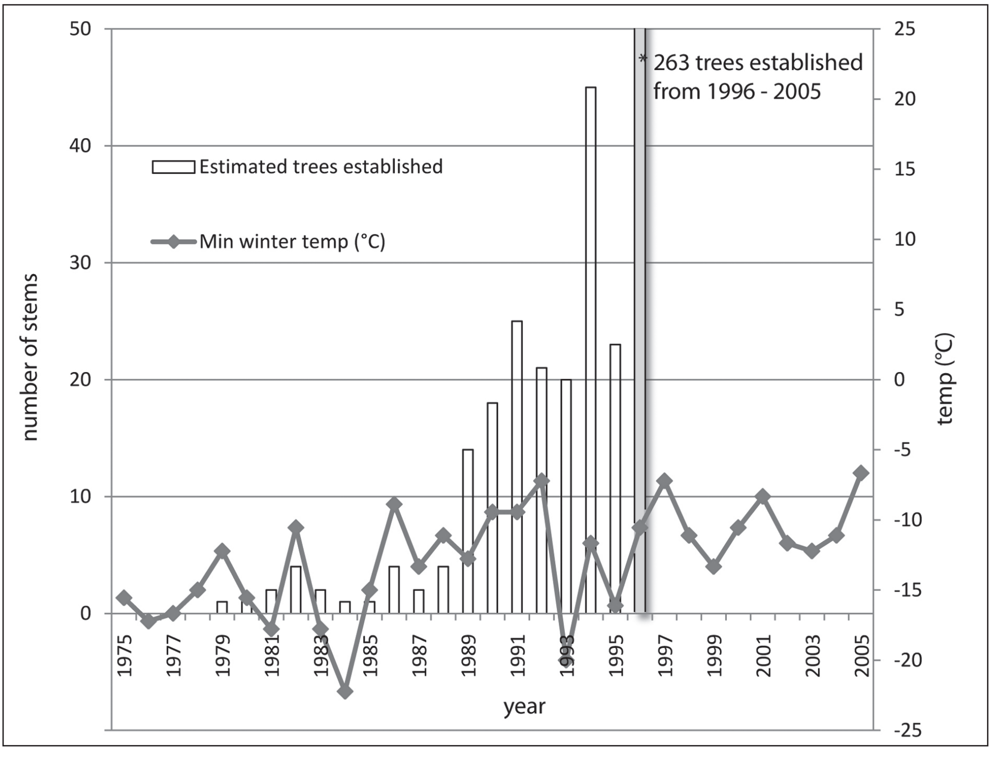
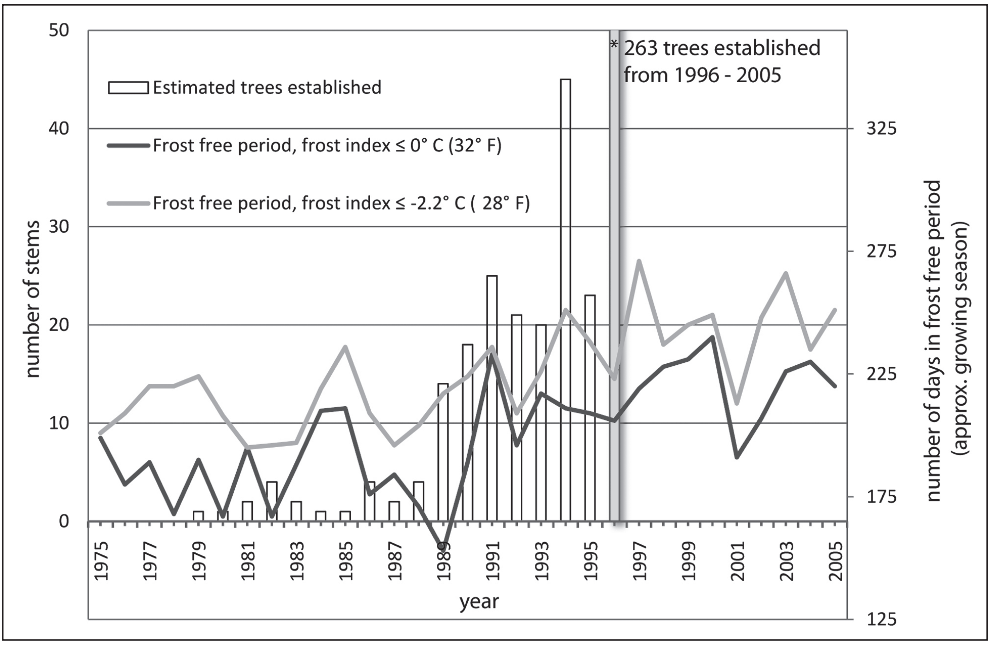


Figure 5. The estimated number of *M. grandiflora* trees established during the initial invasion of the population (primary axis) and the absolute minimum winter temperature for a given year (secondary axis). The number of stems established in a given year was based on a regression equation that calculates age as a function of dbh (see Fig. 4).



is a trend for more trees to become established after a winter with a higher minimum temperature and during years with longer growing-season length than for years with colder temperatures and shorter growing seasons. Note that we could not predict ages for the stems established from 1996 to 2005, although these years show greater winter warmth, longer growing seasons, and a high establishment rate for new stems.

The relationship of establishment to precipitation is less clear. While increasing moisture and increasing establishment does occur between 1986 and 1996, wet years between 1975 and 1986 did not have high establishment (Fig. 7).

Spatial distribution relative to elevation, aspect, and slope

The *Magnolia grandiflora* distribution of stems with respect to elevation, aspect, and slope (Figs. 8, 9, 10) presented no clear trends, besides a modest underrepresentation of *M. grandiflora* stems on south to southeast aspects relative to the frequency of this aspect in the study area (Fig. 9). Counter to the hypothesis that *M. grandiflora* would occur more frequently on warmer slopes, there were

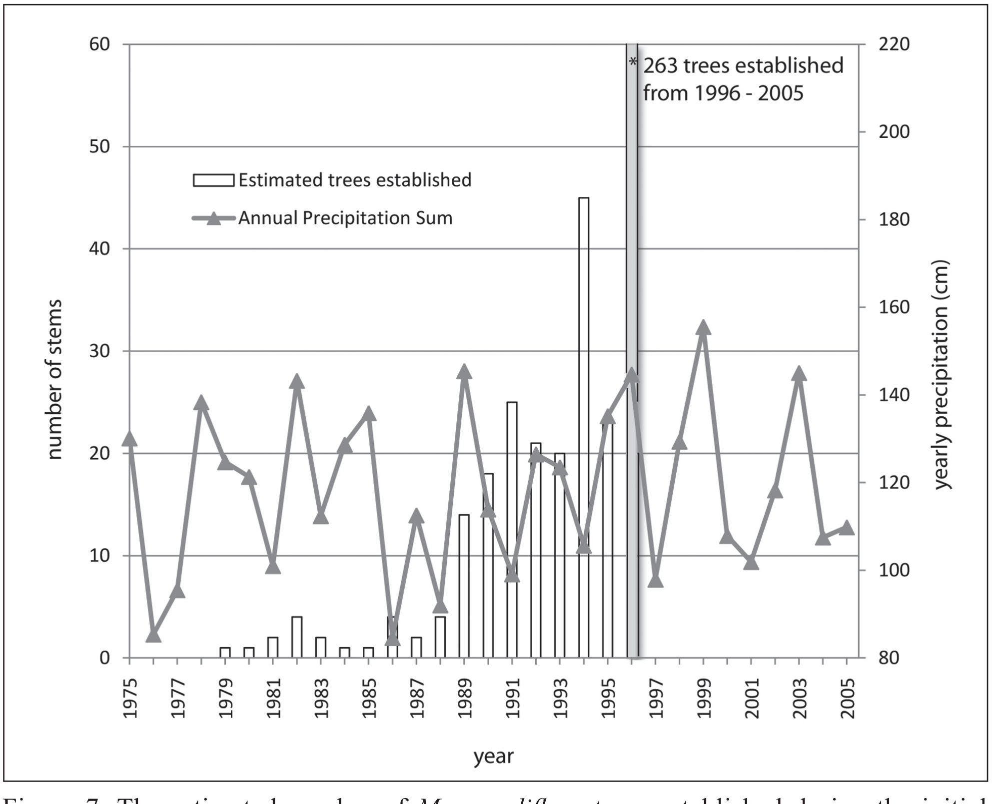


Figure 7. The estimated number of *M. grandiflora* trees established during the initial invasion of the population (primary axis) and the annual precipitation for a given year (secondary axis).

Figure 6 (opposite page, bottom). The estimated number of *M. grandiflora* trees established during the initial invasion of the population (primary axis) and the number of days in a frost-free period for a given year (secondary axis).

fewer *M. grandiflora* on these slopes. Generally, *M. grandiflora* frequencies across the range of values for the environmental variables elevation, aspect, and slope were nearly that expected by chance, relative to the frequency of study area pixels with the respective values.

Discussion

We chose our study area in part because it occurs in an area with a long history of *M. grandiflora* cultivation and therefore a long history of seed dispersal

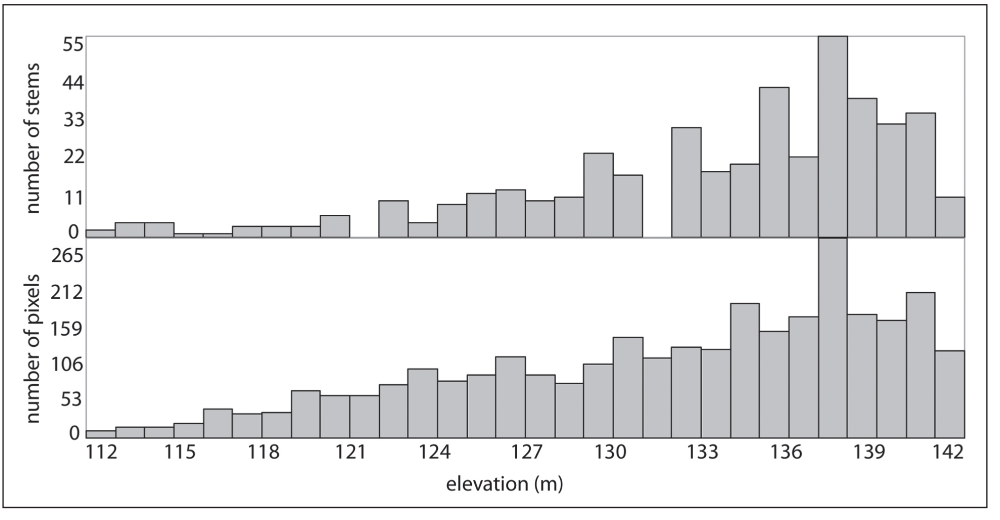


Figure 8. Frequency histograms across a range of elevation values: the number of *M. grandiflora* stems found at each elevation (above) as well as the number of 6- x 6-m pixels (representing the entire study area) with a particular elevation value (below).

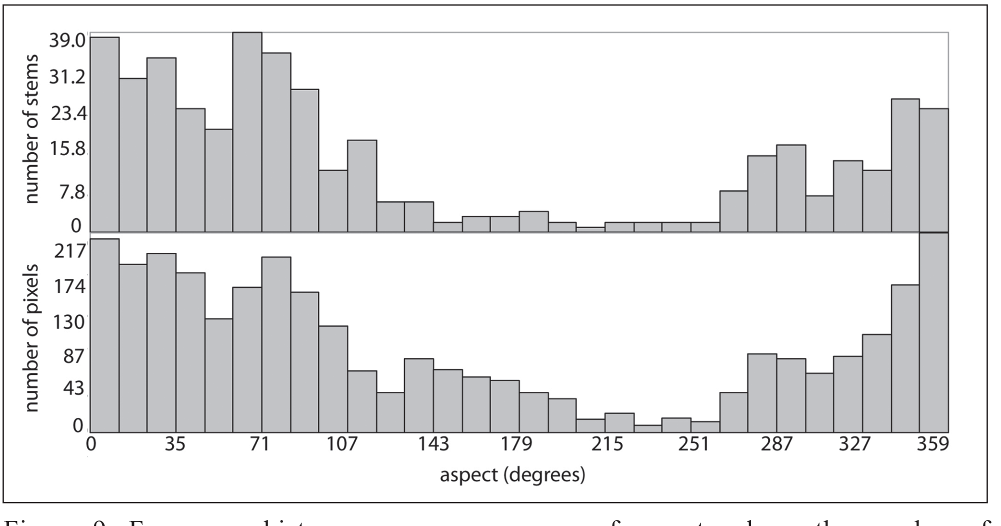


Figure 9. Frequency histograms across a range of aspect values: the number of *M. grandiflora* stems found at each aspect (above) as well as the number of 6- x 6-m pixels (representing the entire study area) with a particular aspect value (below). Aspect is expressed in positive degrees from 0 to 359.9, measured clockwise from north.

occurring into the area where we conducted our research. *M. grandiflora* within the study area were much younger than the period of cultivation of this species on surrounding lands and this population has not yet reached reproductive maturity. The population profile suggests ongoing establishment and a population that will increase in size and age, but this remains to be confirmed in future decades.

The growth rings from the tree of the largest diameter displayed an age of 26 years, and we deduce from this and the structure of the population that invasion began in the last three decades. While *M. grandiflora* establishment does parallel higher minimum winter temperatures and longer growing seasons in the climatic record, we note that the 1930s and 1940s were also warm periods in our study area, and it is unknown whether establishment also occurred in that time period. There is some evidence that stems were not present in the study area during this time period, since no herbarium specimens were collected during this period, despite the frequent use of the area by faculty and students, the presence of much activity through the University of North Carolina Herbarium, and several student projects that used our study area (Giencke et al. 2007).

If, as we presume, invasion occurred in only the last three decades, then potential causes for the recent invasion, besides the climatic warming trend, include: (1) increased seed production of nearby planted trees, since *M. grandiflora* trees become more prolific seed producers with age (Maisenhelder 1970); (2) the recent selection or hybridization for cold-hardy *M. grandiflora* genotypes, which could have been planted proximal to the study area; (3) natural hybridization of *M. grandiflora* and *M. virginiana,* which are both cultivated in the area; (4) further climatic factors not considered (e.g., one explanation of the lack of invasion in the 1930s and 1940s could be drought); and (5) changes in wind or fire disturbance. Unfortunately, we do not have data to fully test these alternatives at present.

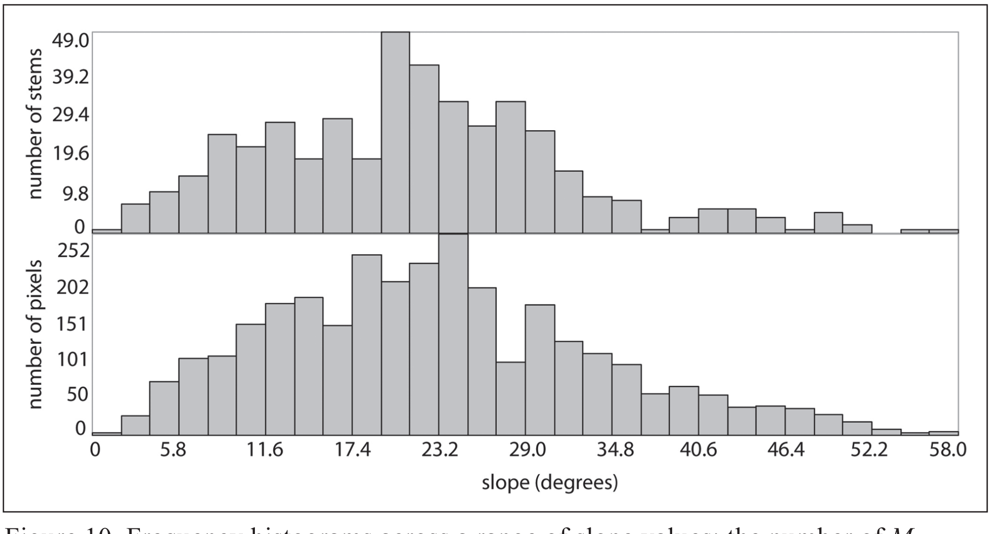


Figure 10. Frequency histograms across a range of slope values: the number of *M. grandiflora* stems found at each slope value (above) as well as the number of 6- x 6-m pixels (representing the entire study area) with a particular slope value (below). Slope is expressed in positive degrees from 0 to 90, representing degrees from horizontal.

It seems unlikely that increased seed production (alternative 1) is a cause because of the long cultivation of *Magnolia* in the study area and the abundance of fruiting specimens in herbarium collections prior to the 1970s. Use of cold-hardy genotypes (alternative 2) is viable, as is potential hybridization (alternative 3). Morphologically, *M. grandiflora* x *M. virginiana* hybrids are detectable by reproductive characteristics (Gardiner 2000, Treseder 1978), which were not present in the naturalized population. Alternative 4 would explain why invasion did not occur in an earlier warm period and would also support that the current invasion is due to warm conditions. Alternative 5 is unlikely because earlier windstorms did not produce invasion, the population we observed is not confined to disturbed patches (this is a deeply shade-tolerant species), and fires have been absent for many decades (a change in fire frequency did not occur in the last three decades, as fire was largely absent since at least 1900; Giencke et al. 2007).

Magnolia grandiflora cultivation has a long history near our study area, and we do not believe that seed dispersal is limiting. However, *M. grandiflora* is not yet as frequent in Duke University's Duke Forest, a larger tract of land about 7 km distant from our study area. This tract is surrounded by much younger neighborhoods with a shorter history of cultivation (Judson Edeburn, Duke Forest Manager, Chapel Hill, NC, pers. comm.). Thus, it is likely that there is an interaction between the factors causing invasion and the local history of cultivation and therefore seed dispersal.

Future research should investigate the *M. grandiflora* range expansion over a wider geographic area in order to understand the importance of cultivation history, seed dispersal, and climatic trends. Studies should also consider whether selection for winter hardiness and hybridization is a cause of range expansion. Lastly, future research should determine whether range expansion will result in *M. grandiflora* becoming a forest dominant, as it does in fire-suppressed forests within its native range, as well as the impact its presence may have on other species.

Conclusion

Magnolia grandiflora is becoming increasingly naturalized north and west of its native Gulf Coast range. This study has shown an association between minimum winter temperatures and increased growing season length over the last three decades with the increased establishment of *M. grandiflora* stems. The association between climate and range expansion in a broad-leaved evergreen in a temperate deciduous forest climate, previously investigated across broad-leaved evergreens in Europe, may suggest that *M. grandiflora* will be a useful climate indicator in the United States and other areas, given its worldwide cultivation. Future studies should investigate whether this trend is induced by the selection for cold-hardiness of cultivars, hybridization with *M. virginiana* and other cold-hardy species, and/or the influence of environmental variables. Additional variables, such as soil type or drought history, may provide additional correlates with the onset of range expansion, and ideally should be tested across several populations and wider geographic areas.

Acknowledgments

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