# CHAPTER 7

# Evaluating Distribution and Impacts of Invasive Plant Species on Southern U.S. Forests

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## INTRODUCTION

Invasive plants cause significant ecological and economic harm in natural and managed forested areas throughout the world (Levine and others 2003). Previous research has documented multiple ways in which invasive plants alter functions of recipient forested ecosystems, including disturbance regimes, primary productivity, nutrient cycling, carbon sequestration, and tree regeneration (Levine and others 2003, Peltzer and others 2010). Unfortunately, invasion events are likely to be more frequent in the future, as the rate of introduction of novel species continues to increase due to human-mediated dispersal through multiple trade networks (e.g., Lucardi and others 2020).

Factors influencing the successful establishment of invasive species are complex and interact with one another at multiple spatial and temporal scales, complicating adaptive management efforts. The major aim in this project was to determine biotic and abiotic factors that are most closely associated with successful forest plant invasions across the Southern United States, which is an area of primary concern with regard to the spread of invasive plant species (Oswalt and Oswalt 2011, Oswalt and others 2015).

Although researchers in this study had an interest in evaluating spatial patterns of potential future invasions within the region, many invasive plant species are already well established in the region and are, presumably, having significant impacts on forests. Many studies have shown that invasive plants pose great challenges to forest regeneration at local spatial scales (e.g., Boyce 2009, Levine and others 2003, Mack and D'Antonio 1998, Merriam and Feil 2002, Oswalt and Oswalt 2011); however, little is known about how those local-scale impacts of invasive plants may collectively influence forest regeneration at a regional scale. A second aim of the work described here was to assess the potential for negative impacts of established invasive plant species on forest regeneration across the region.

Using geospatial and statistical modeling approaches, this study evaluated how biotic interactions, abiotic conditions, and landscape factors affect the distribution of invasive plant taxa within the Southern United States. It also examined, using data from the U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) Program, the potential impact of invasive plant taxa on desirable tree species recruitment within the region.

## METHODS

### Effects of Environmental Predictors on Invasive Species Distribution in the Southern United States

Environmental variables and presence-absence data were compiled for 16 invasive plant species known to have high rates of spread across 52,690 Southern U.S. (Forest Service Region 8) FIA plots that were surveyed between 2015 and 2019 (Lázaro-Lobo and others 2021b). Working directly with FIA personnel, species data from the FIA Database were matched with georeferenced environmental variables from publicly available data sources, including a U.S. Department of the Interior, U.S. Geological Survey (USGS) digital elevation model (DEM); WorldClim climate data;

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Multi-Resolution Land Cover (MRLC) land cover and tree canopy data; MRLC normalized difference vegetation index (NDVI); and USDA Soil Survey Geographic Database (SSURGO). Generalized linear models (GLMs) with binomial distribution of residuals were used to evaluate the effect size of each environmental variable on invasive species occurrence.

## Potential Distribution of Invasive Plants in the Southern United States

This study used an ensemble species distribution modeling (SDM) approach to model the potential distribution of invasive plants throughout the Southern United States, based on the species and environmental data collected above (Lázaro-Lobo and others 2021b). A model ensemble for each species was generated by averaging the output of individual modeling techniques (generalized additive model (GAM), maximum entropy (MaxEnt), and generalized boosted regression trees (GBM)), weighted by their model performance scores (area under the curve (AUC) values).

This ensemble modeling approach resulted in SDM outputs with 30-m-resolution pixels, where pixel values ranged from 0 (low susceptibility to invasion) to 1 (high susceptibility to invasion). Lastly, the mean susceptibility to invasion across the evaluated species was calculated for each cell in the resulting risk maps. This allowed delineation of areas at high risk of invasion (hotspots) in Southern U.S. forests.

## Landscape Characteristics of Predicted Hotspots for Plant Invasions

The web-based Early Detection and Distribution Mapping System (EDDMapS) collects occurrence data of invasive species across different land cover types. This analysis used occurrence points throughout the Southern United States, collected between 2007 and 2018, for 45 major invasive plant species causing negative effects (Lázaro-Lobo and others 2020). As environmental predictors, georeferenced environmental variables were obtained from publicly available data sources (USGS DEM topographic data, WorldClim climate data, and MRLC land cover and tree canopy data from 2011).

To examine the relationship between landscape characteristics and susceptibility to invasion at different spatial scales, this study first modeled the susceptibility of areas within the Southern United States (30-m-resolution grid) to be invaded by each invasive species using MaxEnt. Then, random points were placed in the resulting invasion risk maps and two buffers were created around those points at different distances: medium (0–150 m) and long (0–500 m). Landscape composition and configuration were examined using MRLC land cover data and within the above-mentioned buffers using the ClassStat function of the SDMTools package in R.

## Relative Importance of the Biotic Community, Abiotic Factors, and Landscape Characteristics on Nonnative Species Richness and Abundance

A dataset was collected by visiting 460 sites across the State of Mississippi during 2006–2009 (Lázaro-Lobo and Ervin 2021). These sites were selected randomly from all land in the State that could be accessed, including State and national parks, national wildlife refuges, State wildlife management areas, and national forests. At each site, researchers collected data on the plant species present from the ground layer to the forest canopy (when present), along with soil samples and data on local land cover and use. Using ArcGIS, data on land cover and proximity to transportation corridors were added to the data for each random point.

This study used these data to assess the effect of the biotic community, abiotic factors, and landscape characteristics on nonnative species richness and abundance. It used GLMs, regression tree, and variation partitioning analyses to evaluate how selected predictors interacted to favor or limit nonnative and/or native species richness and percent area cover.

## Impacts of Invasive Plants on Tree Regeneration

Presence/absence data were compiled for 16 major invasive plant species from the above-mentioned 52,690 FIA plots and calculated the number, richness, and diversity of seedlings and saplings for all major tree species present in those same plots (Lázaro-Lobo and others 2021a). GLMs were used to examine the relationship of the selected invasive plant species to tree seedlings and saplings. Principal component analysis then evaluated whether correlations between invasive species and tree seedlings or saplings appeared to be related to overlap in niche associations for each possible pair of species. Niche associations were represented by the same set of environmental variables as for the FIA-based invasive species distribution modeling described above (USGS DEM, WorldClim climate data, MRLC land cover and tree canopy data, MRLC NDVI, and USDA SSURGO data).

## RESULTS

### Effects of Environmental Predictors on Invasive Species Distribution in the Southern United States

Invasive species presence in the FIA database was favored by proximity to pastures, croplands, and developed land cover, as well as by high light availability (low tree canopy cover) and soil capacity to retain nutrients and water. In contrast, soil organic matter generally was negatively correlated with invasive species presence. The effects of climatic variables and other soil properties, such as pH and soil depth, varied in their direction and were species specific.

### Potential Distribution of Invasive Plants in the Southern United States

Most of the examined invasive plant species have the potential to occupy large areas of forest throughout the region (fig. 7.1). The invasive taxa with the greatest potential to establish across Southern U.S. forests were *Ligustrum* spp. (nonnative privets) and *Lonicera japonica* (Japanese honeysuckle) (37–39 percent of the forested area), followed by *Rosa* spp. (nonnative roses), *Imperata cylindrica* (cogongrass), and *Lygodium japonicum* (Japanese climbing fern) (18–23 percent). Each evaluated species is likely to occupy different areas of the Southern United States, with some being restricted to coastal areas, whereas others were more likely to occupy interior areas.

### Landscape Characteristics of Predicted Hotspots for Plant Invasions

Most of the species examined were more prone to invade areas with anthropogenic land cover, such as developed areas and barren lands, than areas that experienced minimal human interference. Landscape heterogeneity and the presence of corridors for propagule dispersal significantly increased susceptibility to invasion by most species. However, susceptibility to invasion by some species increased in landscapes with large core areas and/or less-aggregated patches. Forest understory species and vines tended to respond most favorably to unfragmented forest cover, as might be expected. Thus, even though this study found the expected general landscape patterns for susceptibility to invasion by most species, the influence of landscape composition and configuration on invasion risk can be species specific, and species biology must be considered in predicting responses to land use.

### Relative Importance of the Biotic Community, Abiotic Factors, and Landscape Characteristics on Nonnative Species Richness and Abundance

Landscape attributes were especially important for the arrival of nonnative species, whereas biotic factors seemed to regulate their abundance. The combined effects of different types of predictors (biotic, abiotic, and landscape variables) explained more variation than did any individual category of predictor in all analyses. Nonnative species richness and abundance were increased by low

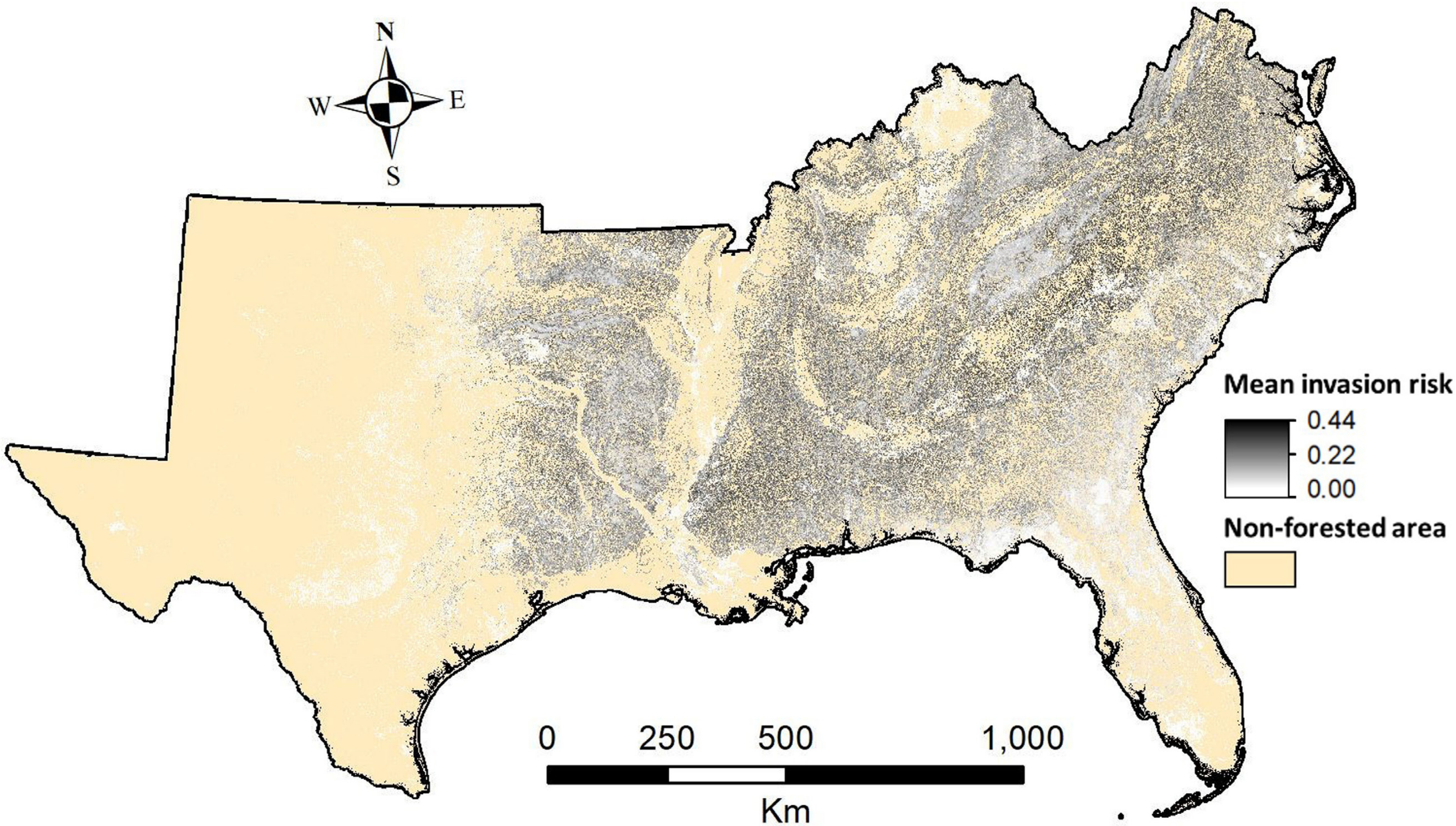


*Figure 7.1—Average susceptibility to invasion by all invasive plants species examined for each pixel occupied by forested areas. Darker colors indicate higher risk of invasion, while lighter colors illustrate the opposite (modified from Lázaro-Lobo and others 2021b).*

values of native species cover and diversity, high degree of landscape fragmentation, human disturbances, anthropogenic land use, and proximity to transportation systems, especially highways. Nonnative species were less common in areas with low anthropogenic disturbance.

### Impacts of Invasive Plants on Tree Regeneration

For Region 8 FIA plots surveyed during 2015–2019, the presence of invasive plants generally was correlated with reduced abundance of seedlings and saplings of desirable tree species (fig. 7.2). Those negative interactions appeared to be independent of environmental niche associations between the invasive species and the desirable trees. Fast-growing native hardwood tree species (e.g., ash (*Fraxinus* spp.), cottonwood (*Populus* spp.), hackberry (*Celtis* spp.), sweetgum (*Liquidambar styraciflua*)), however, had the fewest negative species-wise associations with invasive plants, suggesting that effects of plant invasion on forest regeneration may be mediated, in part, by ecological traits of the tree species present. The invasive plants evaluated in this study also influenced seedling abundance and diversity more strongly than sapling abundance and diversity, which is not unexpected but does reinforce the importance of invasive species management for forest regeneration.

## DISCUSSION

These results provide a general idea of environmental effects on invasive species distribution, landscape susceptibility to invasion, and impacts of invasive plants on tree regeneration. Climate, land use, and soil variables were important factors to explain invasive species distributions at the regional scale, but the direction and magnitude of their influence were species-specific. Results also indicate that most of the focal invasive plants are likely to occupy large, forested areas throughout the study region (fig. 7.1). Thus, incorporating estimates of invasion risk into conservation strategies could prevent further establishment of invasive plants in the Southern United States. These studies also demonstrate that landscape composition and configuration highly influence susceptibility to invasion across the Southern United States. Although highly fragmented landscapes with spatially aggregated dispersal corridors were important for invasive species in general, the biology and ecology of some invaders (e.g., forest understory specialists) still provide important, more refined insight for invasion management. Therefore, this knowledge can inform management plans that consider how invasive species distribution is affected by the proportion of the landscape occupied by the different land cover types, the amount of edge in the landscape, and the degree of aggregation and cohesion of patch types, within the context of larger scale environmental drivers. Regarding the invasive species themselves, the greatest threats to tree regeneration were from Japanese honeysuckle, Japanese climbing fern, nonnative privet species, and Chinese tallow (*Triadica sebifera*), each of

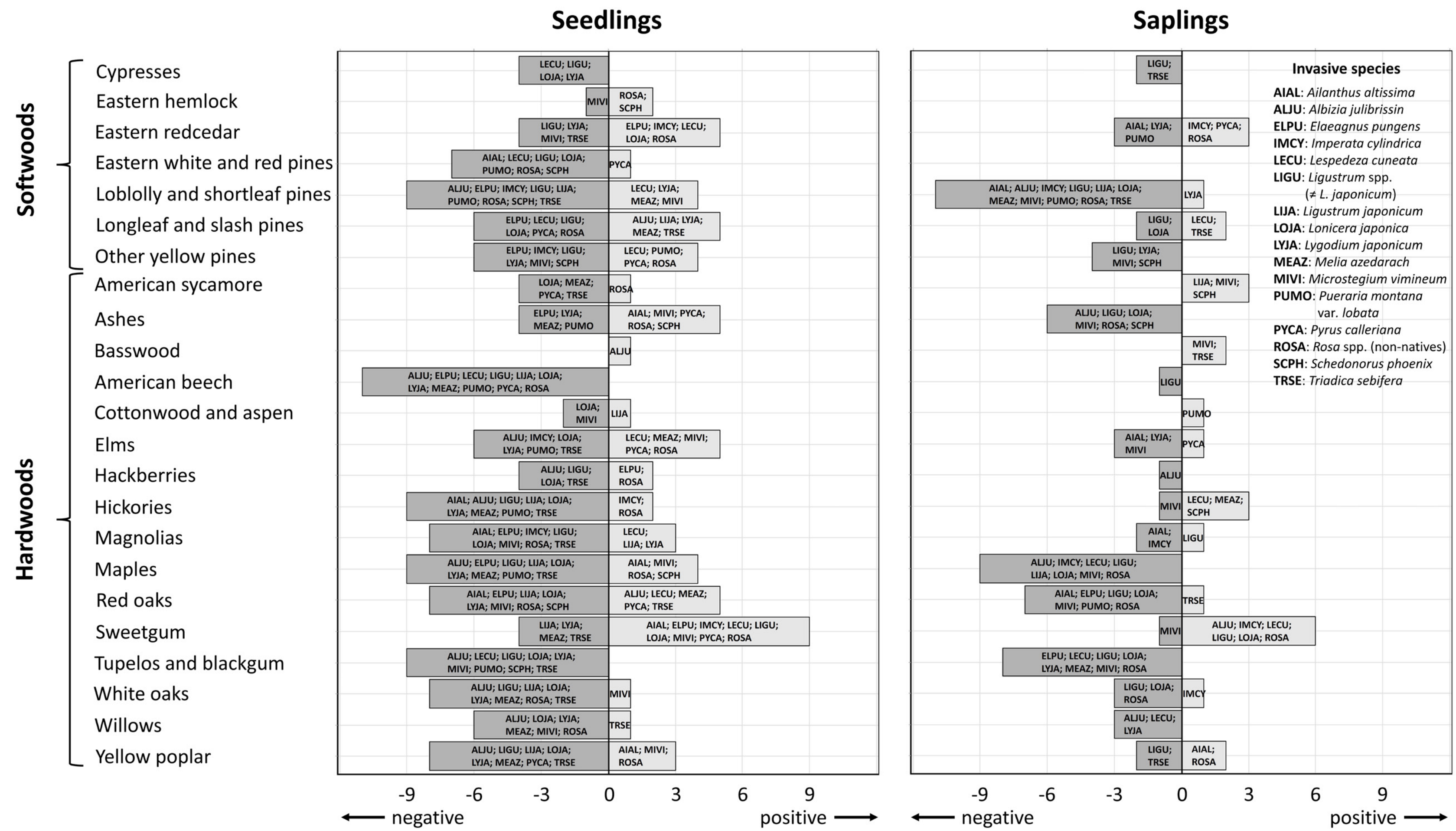


*Figure 7.2—Number of significant relationships (with* p *<0.05) between invasive taxa presence and tree seedling and sapling abundance. Values on the left of the x-axis (negative sign) represent the number of negative relationships, whereas values to the right indicate the number of positive associations. The invasive taxa responsible for the significant relationships are included inside the bars of each tree taxon (modified from Lázaro-Lobo and others 2021a).*

which showed negative correlations with the abundance of tree seedlings in at least 12 tree species. Modeling results also showed that 35–40 percent of the region's forests could be susceptible to invasion by Japanese honeysuckle and nonnative privets; thus, these invasive plants show the greatest potential for long-term, broad-scale negative effects on southern forests, based on this research.

Results also show a hierarchical nature to biotic and abiotic factors in their influence on invasive species distribution and abundance. Land use and land cover can provide significant filters influencing the arrival and establishment of nonnative species. At a finer scale, however, biotic factors may regulate the abundance of nonnative species once they are present within the system. Nonnative species richness and abundance were increased by low values of native species cover and diversity, by anthropogenic land use and disturbance (e.g., developed land cover, agricultural areas, and soil disturbance), by high landscape heterogeneity and edge density, and by close proximity to transportation systems.

In the context of longer time scales, significant potential impacts of invasive plants on tree regeneration exist within the region. This is likely to hamper the sustainable management of Southern U.S. forests (both natural and managed) by the reduction of extant biodiversity, via reduced recruitment success. The seedling stage of desirable tree species in southern forests was negatively correlated with invasive species occurrence. Thus, invasive plant control could be incorporated into management strategies to help ensure the persistence of native forest communities and the ecological services they provide.

## CONCLUSIONS

Integration of multiple environmental variables collected at different spatial scales is pivotal to provide insights into invasive species distributions and landscape susceptibility to invasion. Furthermore, measuring the impact of biological invasions on natural systems illustrates the importance of invasive species within the context of global change.

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