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Contribution of Ecological and Socioeconomic Factors to the Presence and Abundance of Invasive Tree Species in Mississippi, USA

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Received: 8 November 2017; Accepted: 10 January 2018; Published: 17 January 2018

Abstract: Invasive tree species cause increasing damage to the environment and local economies. Previous studies have seldom treated the presence and abundance of invasive species as different phenomena. Using Classification and Regression Trees (CART) analysis, important driving factors affecting the presence and abundance of invasive tree species in Mississippi were identified. These selected factors were spatially analyzed using a spatial lag model at the county level. The empirical results from the spatial lag model showed that: (1) the presence of invasive tree species was more likely at lower elevations, private ownerships, and in counties with higher per capita annual income; and (2) the abundance of invasive tree species was related to stand age, and elevation. The odds ratio revealed that the presence was most affected by per capita mean annual income. This result might reflect impacts from intensified urban development and alteration of the landscape. As revealed by the coefficients, the abundance was most strongly affected by stand age. Thus, management prescriptions designed to monitor and control invasions should target young private forestlands at low elevations in counties with higher per capita mean annual income.

Keywords: presence; abundance; CART analysis; spatial lag model; invasive trees

1. Introduction

Following the sustained exploration and colonization of North America by Europeans over the past 500 years, exotic plant species have been introduced accidently through international trade and have grown at an unprecedented rate in the United States [1]. Some plant species are beneficial while others are harmful. Over 98% of the United States food system comes from introduced food crops such as corn, wheat, rice and livestock species including cattle and poultry with a monetary value of nearly $800 billion every year [2]. However, some introduced plant species have caused ecological and economic losses in agriculture, forestry and other ecosystems. Invasions of non-native plant species can cause ecosystem degradation and biodiversity loss due to changes in nutrient cycling, energy budgets and fire regimes of native plant species [3]. In addition, environmental damages and losses due to invasive exotic species in the United States have added up to $120 billion dollars per year, out of which exotic plants alone account for $25 billion dollars annually [2,3].

Sixty-five percent of the land in Mississippi was covered by forests and the total value of Mississippi's timber crop was $1.4 billion in 2016, which was almost 20% of total production values from agriculture, forestry and animal husbandry [4]. Mississippi forestlands have been invaded by numerous tree, shrub, vine, grass and fern species in different degrees [5,6]. Considering that various invasion patterns and growth characteristics of these species may influence the accuracy of an analysis, this study focused on invasive tree species only. Therefore, identifying factors contributing to the presence and abundance of target invasive tree species and taking effective actions to combat invasions are meaningful and valuable in the state of Mississippi.

The specific objectives of the study are to: (1) identify ecological and socioeconomic factors that influence a set of invasive tree species' presence and abundance on Mississippi forest plots and select the most relevant factors through the classification and regression trees (CART) analysis; and (2) use the appropriate spatial model to quantitatively analyze the contributions of these selected factors at the county level.

Ecological variables, identified in our literature review, influencing the presence and abundance of invasive tree species in Mississippi were elevation, stand age, forest type, type of natural disturbance, site productivity, growing stock and stand origin. Socioeconomic variables assumed to influence the presence and abundance of invasive tree species in Mississippi were road density, type of ownership, population density, per capita mean annual income, and proportion of wildland urban interface.

Elevation was found to have a significant negative effect on the number of invasive species, which indicated that invasions were less prone to occur at higher elevations [7]. Elevation was also found to be negatively associated with the presence of Chinese tallow in the southern United States [8]. This study also noted that nearly 80% of existing tallow invasions occurred at elevations lower than 165 feet. Young forests were believed to usually have higher light penetration, fewer competitors from external disturbance, and better sanitary conditions than old forests while mature forest interiors usually have lower temperatures, higher humidity, and darker environment than outside [9–12]. In the study by Hussain et al. [13], stand age had no effect on invasive trees' presence but had a significant negative effect on the abundance of invasive trees on forestlands in Alabama.

Forest type including longleaf/slash pine group, loblolly/shortleaf pine group (reference group), oak/pine group, oak/hickory group, oak/gum/cypress group and elm/ash/cottonwood group was considered as a potential contributing factor and oak/gum/cypress group was proven to be a positive effect on the occurrence of Chinese tallow at the 5% significance level [14]. Disturbance events such as harvesting or natural disasters could be a factor in promoting the spread of Chinese tallow tree because resources such as light and nutrients were released for colonization and establishment after disturbance [14]. Bellingham et al. [15] surveyed the exotic tree *Pittosporum undulatum* in Jamaican mountain rain forests and concluded that invasion was accelerated after damage caused by hurricanes.

High and medium site productivity levels positively affected the occurrence of Chinese privet and Nepalese browntop [16]. Gan et al. [8] noted that site productivity was not crucial in the early stages of Chinese tallow invasion but higher productivity furthered expansion after initial establishment. Compared to fully stocked, poorly and medium growing stocked plots influenced occurrence of Chinese privet and Nepalese browntop positively [16].

Roadsides are ideal habitats for invasive plant species because these areas provide corridors or create disturbances for invasions [17,18]. Flory and Clay [9] found that densities of exotic shrubs were higher at 0 meter (m) than 10, 20, 30 m from the roads and there were 46% fewer stems of invasive tree species per square meter at 10 m from the road than at 0 m from the road. Gelbard and Harrison [19] measured the populations and coverage of non-native and native plant species on 92 sites at distances of 10 m, 100 m and over 1000 m to road and found that exotic forb species were least abundant in the most distant sites. Private ownership was proved to have a positive effect on tallow tree invasion in southern U.S. forestlands [8]. Private lands might be less closely monitored and managed, more frequently harvested and covered with younger trees [20]. The possibility existed that policy incentives for private landowners to conduct prevention and mitigation were lacking [21].

Human population density has been shown to be a good predictor of exotic species richness [3,22,23]. McKinney [22] incorporated population density as a derivative variable (population/area) to study the effects of human activities on species richness within the United States. Multiple regression analysis showed that population density was the best predictor for net plant species richness gain. Similarly, Qian and Ricklefs [24] discovered that the number of exotic species was more closely related with the size of human population than with ecological conditions. Income was found to be positively related to invasive exotic plant richness while road density and the area of agriculture were not significant [3]. They suggested that income functioned as a proxy measure of socioeconomic activities that favor plant invasions. Hope et al. [25] found neighborhoods with incomes above median family income had twice the invasive plant diversity than those from less wealthy areas.

The wildland-urban interface (WUI) is the place where natural wildland vegetation meets housing. WUI includes two distinct housing patterns: intermix housing, where housing and vegetation co-occur, and interface housing, where housing is close to vegetation [3,26]. Gavier-Pizarro et al. [3] found that housing variables could better explain invasion than environmental and other human variables. Besides, among the housing variables, the amount of low-density residential area and change in housing units between 1940 and 2000 were more associated with exotic tree species at the 5% significance level. Besides, the growth rate of urban land use was greater than parks due to an increase of suburban housing and it opened new habitats for nonnative plant and animal species [27].

2. Materials and Methods

2.1. Target Invasive Tree Species

Information pertaining to the geographic distribution of targeted invasive tree species in Mississippi were extracted using the Forest Inventory and Analysis (FIA) Southern Nonnative Invasive Plant data Extraction Tool (SNIPET). In Mississippi, the FIA panel system of collection on a 7-year cycle was conducted after 2006. To make a comprehensive 7-year cycle estimate of invasion conditions, all invasive tree species recorded on Mississippi forestlands during years 2009 to 2015 were chosen as target species. Tree species targeted include tree of heaven (*Ailanthus altissima*), silk tree/mimosa (*Albizia julibrissin*), princesstree (*Paulownia tomentosa*), chinaberry (*Melia azedarach*) and Chinese tallow (*Triadica sebifera*) in Table 1.

Table 1. Target invasive tree species on Mississippi forestlands from year 2009 to 2015.

No.	Common Name	Scientific Name	Year Introduced to the U.S./Native Range
1	Tree of heaven	*Ailanthus altissima*	1784/northeast and central China
2	Silktree/Mimosa	*Albizia julibrissin*	1745/Iran to Korea
3	Princesstree	*Paulownia tomentosa*	1900s/central and western China
4	Chinaberry	*Melia azedarach*	1830s/Indomalaya and Australasia
5	Chinese tallow	*Triadica sebifera*	1970s/eastern Asia

Sources: Ridley and Oswalt 2017 [5]; Miller 2003 [6].

2.2. Data Sources

Information on road density was obtained from the United States Geological Survey (USGS) [28] for year 2015; population density and per capita mean annual income data were from U.S. Census Bureau [29]; wildland urban interface (WUI) data for 2010 were from the WUI project [30]; and the others were from Forest Inventory and Analysis (FIA) program of the US Forest Service. The definitions of all ecological and socioeconomic factors were displayed below in Table 2.

When presence was the response variable, the proportion of invaded plots for each county was calculated. When the response variable was abundance, the weighted percent cover of each county was calculated by dividing the sum of all percent covers of any invaded plots in a county by the total number of plots in that county.

Table 2. Definition of ecological and socioeconomic factors contributing to the presence and abundance of target invasive tree species in Mississippi at the county level.

Category	Classification	Definition
Ecological factors	Elevation	The average elevation of all plots in county *i*
	Successional age	Average age of all plots in county *i*
	Forest type	
	loblolly pine	The number of plots with loblolly pine in county *i*/ total number of plots in county *i*
	white oak/ red oak/hickory	The number of plots with white oak/ red oak/hickory in county *i*/ total number of plots in county *i*
	loblolly pine/ hardwood	The number of plots with loblolly pine/ hardwood in county *i*/ total number of plots in county *i*
	Natural disturbance	
	ground fire	The number of plots with ground fire records in county *i*/ total number of plots in county *i*
	hurricane, tornado	The number of plots with hurricane or tornado records in county *i*/total number of plots in county *i*
	Site productivity	Average site productivity of all plots in county *i*
	Growing stock	Average growing stock of all plots in county *i*
	Stand origin (artificial)	The number of plots with artificial origin in count *i*/ total number of plots in county *i*
Socio-economic factors	Road density	The length of major roads/the area of county *i*
	Ownership (private)	The number of plots with private ownership in county *i*/ total number of plots in county *i*
	Population density	Number of inhabitants per county divided by area of county *i*
	Per capita mean annual income	Per capita mean annual income by county (US$)
	Wildland urban interface	Area of wildland urban interface/ area of county *i* (km^2/km^2)

2.3. Estimation Methods

Using FIA data source, the distribution map of target invasive tree species in Mississippi was created (Figure 1). Seen from this figure, invaded plots with larger percent coverages of invasive tree species were mainly concentrated in southern coastal Mississippi.

The whole analysis was completed in a two-step process. In the first step, the Classification and Regression Trees (CART) analysis was used to identify the most relevant factors and exclude marginal relevant factors. CART is a great technique for leaving out the factors of marginal relevance and selecting the most relevant factors. At the same time, it can predict the dependent variables [31–33]. In the second step, the statistical analysis of these factors was implemented using the appropriate spatial autoregressive (SAR) models under R programming [34]. There are two SAR models, spatial error model and spatial lag model, corresponding to two dependent forms, error dependence and lag dependence [7].

The spatial error (SAR_{err}) model assumes that spatial dependence influences the error term only. The SAR_{err} model is complemented by adding an extra term ($\lambda W \varepsilon$) to the ordinary least square (OLS) model ($y = X\beta + \varepsilon$) and it has the following form:

$$y = X\beta + \lambda W \varepsilon + \tau \quad (1)$$

where λ is the spatial autoregression coefficient, W is the spatial weight matrix, ε is the error term in OLS model, and τ is the new error term.

The spatial lag (SAR_{lag}) model assumes that autocorrelation occurs in the explanatory variable only and thus includes a term (γWy) for the spatial autocorrelation in the explanatory variable. The SAR_{lag} model takes the following form:

$$y = \gamma Wy + X\beta + \tau \quad (2)$$

where γ is the spatial autoregression coefficient, W is the spatial weight matrix, and τ is the error term.

Lagrange Multiplier tests are usually used to identify the form of spatial dependence. Anselin [32] indicated that the test with the most significant result should be employed.

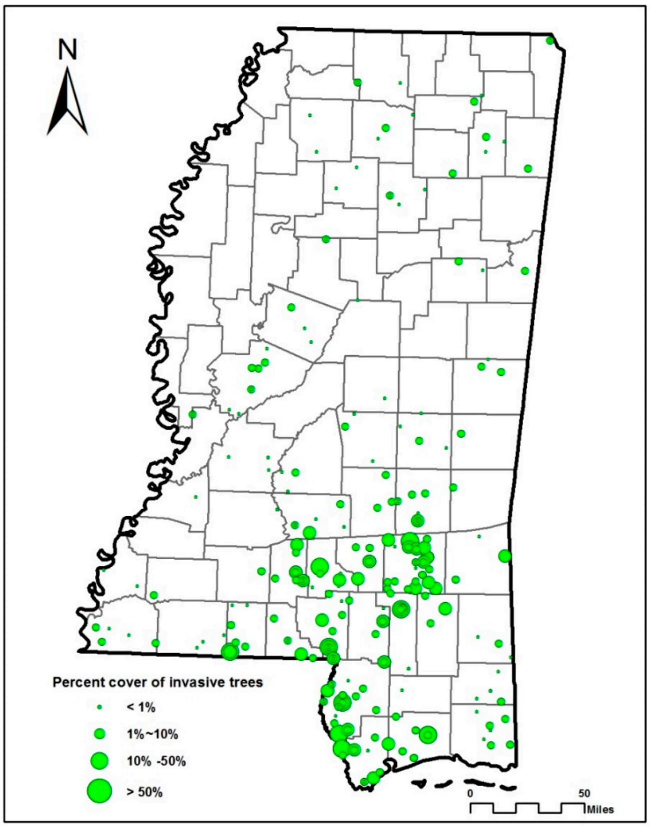

Figure 1. Location and percent cover of invasive tree species per Forest Inventory and Analysis (FIA) plot on Mississippi forestland based on ArcGIS.

3. Results

The CART analysis revealed the major factors affecting the presence and abundance of invasive tree species in Mississippi, displayed below in Figures 2 and 3. When studying the abundance of invasive tree species in a county, a regression tree was used to check the importance of each variable.

3.1. Results from CART Analysis

Using presence or absence as the response variable, a classification tree showing the most relevant factors was presented above in Figure 2. In most circumstances, the more records a variable has, the more important a variable is. The classification tree above showed that the most relevant factors associated with the presence of target invasive tree species in Mississippi included population density, elevation, per capita mean annual income, and ownership. In addition, when population density was less than 25.87 (nearly 26 inhabitants per square kilometer), target invasive tree species were not expected to be observed in Mississippi (Figure 2).

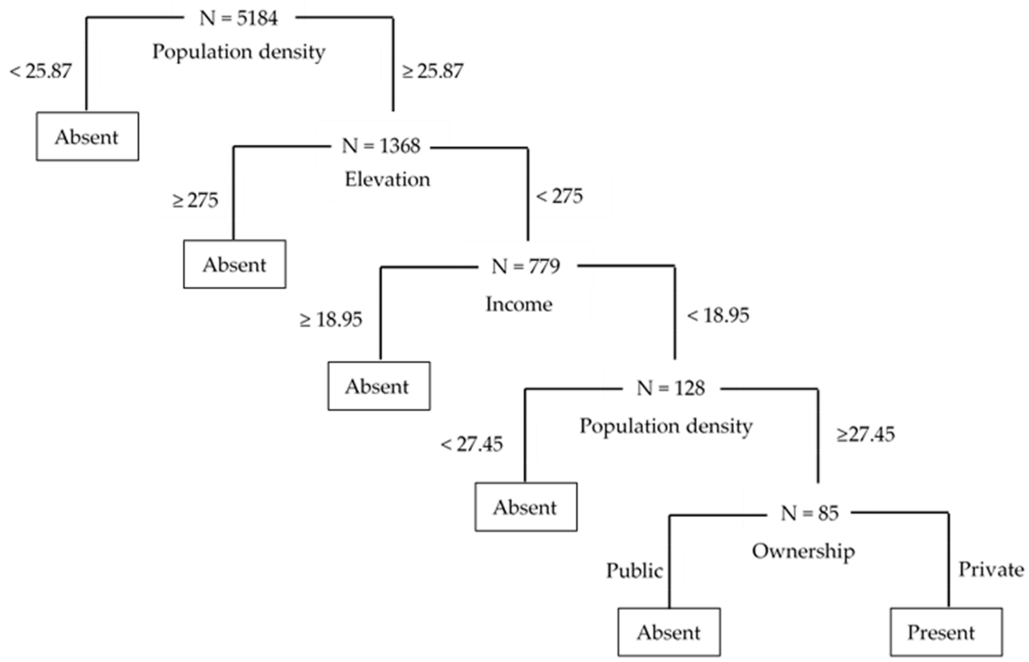

Figure 2. A classification tree to reflect most relevant factors affecting the presence of invasive tree species in Mississippi from 2009 to 2015.

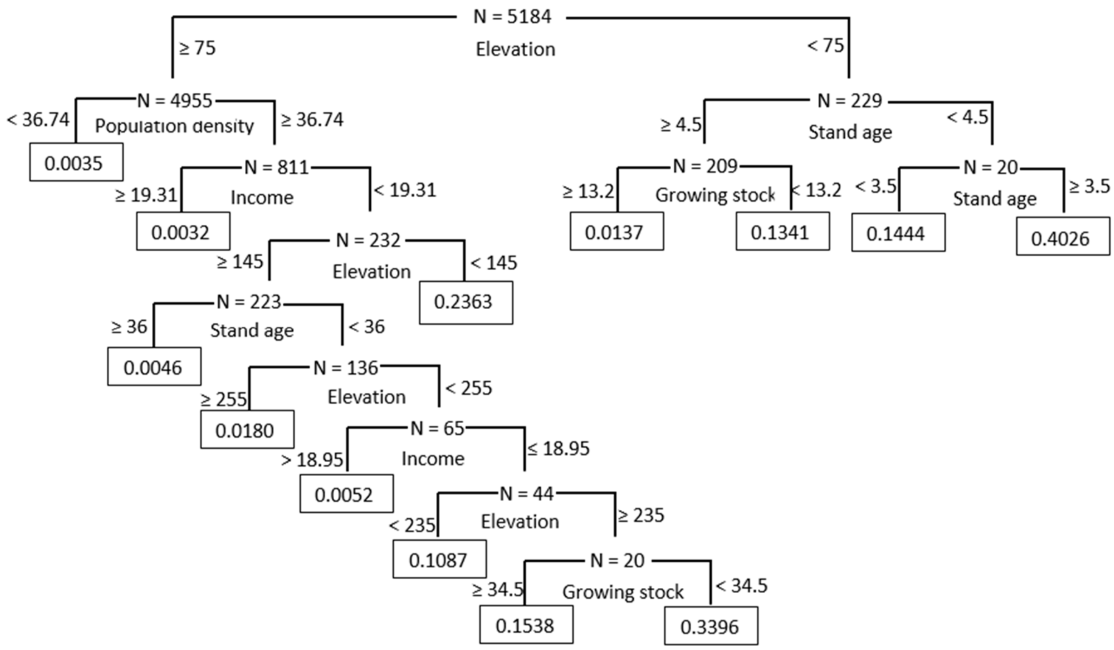

Figure 3. A regression tree to reflect most relevant factors affecting the abundance of invasive tree species in Mississippi from 2009 to 2015.

Using the percent coverage as the response variable, a regression tree showing the probability of a forest site being invaded by selected invasive tree species in Mississippi was presented in Figure 3. The regression tree indicated that the most relevant factors affecting the abundance of target invasive tree species in Mississippi included elevation, population density, per capita mean annual income, stand age, and growing stock. Seen from the first branch of the tree, if a plot with elevation greater than 75 feet was in a county with a population density less than 36.74 (nearly 37 inhabitants per square kilometer), the probability of this plot being invaded was 0.35%.

The classification and regression trees (CART) eliminated the side effects of other variables and presented the most relevant influence factors of invasive trees in Mississippi. However, they were non-parametric, and neither did they incorporate spatial dependencies. The spatial model should be employed after CART.

3.2. Results from the Spatial Lag Model

Lagrange Multiplier tests showed that the p value of lag dependence was less than 0.0000, thus the spatial lag model should be employed. A row standardized weight matrix should be used to address this concern and a contiguity based neighbor criterion would be applied [35].

Using population density, elevation, per capita mean annual income, and ownership as explanatory variables, empirical results of major factors affecting the presence of target invasive tree species on Mississippi forestlands at the county level based on the spatial lag model are shown below in Table 3.

As shown in Table 3, three factors including elevation, ownership and per capita mean annual income contributed to the presence of invasive trees at the county level in Mississippi. The coefficient for elevation was negative and p value was 0.0310, which indicated a negative significant effect. However, the odds ratio of elevation at the county level was close to 1, which meant a minor contribution. The negative coefficient of public owned forests in Mississippi indicated that it negatively contributed to the presence of invasive tree species in Mississippi. At the county level, the odds of public forestlands having invasive tree species was 0.9375 times that of private forestlands. Per capita mean annual income had a positive effect on the presence of invasive tree species in Mississippi at the 10% significance level. Counties with per thousand dollars increase of per capita mean annual income were 95.42% more likely to be infested with invasive tree species, holding other variables constant.

Table 3. Empirical results of major factors affecting the presence of invasive trees at the county level on Mississippi forestlands based on the spatial lag model.

Factors	Coefficient	SE	OR	p Value
Ecological variables				
Elevation	−0.0001	0.00006	0.9999	0.0310 **
Socioeconomic variables				
Ownership (public)	−0.0645	0.0370	0.9375	0.0810 *
Population density	0.0000	0.0003	1.0000	0.9967
Per capita mean annual income	0.6700	0.3264	1.9542	0.0401 **

SE, standard error; OR, odds ratio; Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Using elevation, population density, per capita mean annual income, stand age, and growing stock as explanatory variables, the empirical results of major factors affecting the abundance of invasive tree species at the county level on Mississippi forestlands based on the spatial lag model are presented in Table 4.

Table 4 shows that abundance of invasive tree species in Mississippi was influenced by stand age and elevation at the 5% significance level. The coefficients of stand age and elevation were −1.5629 and −0.0962 respectively, indicating significant negative effects on the abundance of invasive trees in Mississippi at the county level. Comparing the absolute values of coefficients, stand age had the greatest impact on the percent cover of invasive tree species in Mississippi at the county level. The coefficient of stand age at the county level was −1.5629, which suggested that if a forest stand in a county was one year older, the weighted percent cover of invasive tree species across the county would decrease by 1.5629.

Table 4. Empirical results of major factors affecting the abundance of invasive trees at the county level on Mississippi forestlands based on the spatial lag model.

Factors	Coefficient	SE	Z Value	*p* Value
Ecological variables				
Stand age	−1.5629	0.6470	−2.4156	0.0157 **
Elevation	−0.0962	0.0457	−2.1054	0.0353 **
Growing stock	0.0248	0.6438	0.0385	0.9693
Socioeconomic variables				
Population density	−0.0014	0.2008	−0.0069	0.9945
Per capita mean annual income	294.5935	217.1067	1.3569	0.17481

Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

4. Discussion

Among the variables evaluated, elevation had a negative effect on the presence and abundance of invasive tree species in Mississippi at the county level. The negative relationship between elevation and the number of exotic plants has been documented in some studies. Sax [36] found that the distribution of naturalized exotic species in Chile was highly associated with elevation and species richness. Gan et al. [8] also found that the occurrence of Chinese tallow in the southern United States was negatively related to elevation. A possible explanation might be that there are fewer appropriate plant species that could be introduced to higher elevation areas [37]. Lower elevation usually comes with warmer temperatures and less water. In Mississippi, the elevation ranges only from sea level at Gulfport to 806 feet (246 m) in the northeast hills, which doesn't have a lot of variation. With higher elevations, temperature decreases and precipitation increases so fewer invasive tree species are found. Besides, the range of elevation change is small, which supports the idea that elevation didn't play a substantial role even though it is significant.

It was not surprising that stand age had negatively influenced the abundance of invasive tree species at the county level. The negative relation indicated that invasive trees were prone to be abundant in young forests. Older forest communities were believed to be more resistant to exotic plant establishment while younger communities were more vulnerable to invasion in old fields in Minnesota [38]. Light availability might be the limiting factor because it was reported to vary with stand age [9,10]. In young forests, trees have not yet grown to be fully stocked, which creates sufficient sunlight for shade intolerant species. In this research, most of these invasive tree species are shade intolerant. The shade intolerance (i.e., light loving) characteristic of tree-of-heaven predicts that tree-of-heaven grows best in full sunlight, and at times, partial sunlight, and demonstrates best growth on open, disturbed sites. Mimosa grows best in full sun but tolerates some shade [39]. Princesstree is an early successional species that is strongly intolerant of shade [40–42]. One review indicated chinaberry is not shade tolerant, but it is unclear if chinaberry occurs as a shade intolerant or shade tolerant. Although Chinese tallow survives and grows in shade, it generally performs better in sunlight. In a floodplain forest in eastern Texas, Chinese tallow mortality increased from about 0.05% at 10% full sunlight to 5.3% at 0.1% full sunlight [43].

Per capita mean annual income was found to have a positive effect on the presence of invasive tree species at the county level. The original introduction purposes of invasive trees might explain the positive relation between income and presence. Most invasive species including tree of heaven, silktree were introduced to the United States as ornamentals while some were introduced accidentally through international trade such as princesstree. The possibility also existed that there was more gardening activity in higher income areas than lower income area. Besides, there was usually more transportation and commerce in higher income areas, which contributed to the spread of invasion. Due to the geographical advantages, the counties in southern Mississippi are generally more populated and have more commercial activities than those in the north.

Public ownership was negatively associated with the presence of invasive trees at the county level. The negative relationship indicated that invasions were more likely to occur on private forestlands. This finding was consistent with the research of the tallow tree in southern U.S. by Gan et al. [8]. In Mississippi, 81% of forests are owned by nonindustrial private landowners. It is quite possible that most landowners in Mississippi have their jobs and inherit several acres of forest from their parents or grandparents. Their initial intention is likely not to get monetary benefits, neither do they have professional knowledge to manage.

A unique aspect to this study is that our models incorporated socio-economics information. Research studies identified in the literature often study only ecological influence factors of exotic species, while only a few address socioeconomic factors in a meaningful way. Besides incorporating ecological factors, this research considered more socioeconomic factors such as road density, type of ownership, population density, per capita mean annual income and wildland-urban interface in the analysis. Another advantage is the methods and techniques. Many variables were of mariginal relevance and the distribution of ecological data was not normal. Therefore, Classification and Regression Trees (CART) analysis was used to help select most relevant factors, and avoid collinearity without any prior knowledge or assumption of the data distribution.

Another unique aspect to our research was the choice of a spatial lag model. Some previous research incorporated ecoregion as an explanatory variable to minimize the effect of spatial dependency. This research improved on that. The spatial lag model enabled it to eliminate spatial autocorrelation and analyze influence factor spatially. At last, this study treated presence and abundance as two distinct phenomena. Seen from the results above, factors affecting the presence and abundance of invasive trees in Mississippi were not the same. Based on this research, we would expect it would be easier for policymakers to distinguish which counties were more susceptible to invasion and which counties were more suitable for the growth of invasive tree species in Mississippi. If more efforts were focused on these most vulnerable counties, the prevention and eradication of invasive tree species in Mississippi could be implemented in the most cost-effective way.

5. Conclusions

This study identified potential ecological and socioeconomic factors contributing to the presence and abundance of invasive tree species in Mississippi. The classification and regression tree (CART) analysis was conducted to select the most relevant factors and then the spatial lag model was employed to spatially analyze impacts of these factors. Three factors, elevation, ownership type and per capita mean annual income, contributed significantly to the presence of invasive tree species while stand age and elevation influenced abundance. This study concludes that the presence of invasive tree species in Mississippi is more likely to be found in counties with low elevation, higher per capita mean annual income and more private forestlands while greater abundance occurs in counties with lower elevation and younger forests.

Our results have several practical implications for monitoring and mitigation of invasive tree species in Mississippi. Since presence and abundance of invasive tree species are associated with distinct factors, management prescriptions should also differ. Efforts to monitor invasive trees should target counties with lower elevations, more private forestlands, and higher per capita mean annual incomes while efforts to mitigate should be dedicated to counties with low elevation and younger forests. When foresters apply management prescriptions in counties with lower elevation and higher income, they should try to avoid the introduction of invasive species. If these areas have been invaded, more intense and responsive mitigation actions should be taken. The involvement of private landowners in prevention and restoration of infested plots would benefit the ecosystems greatly. Increasing the amount of funds to educate private landowners on the negative impacts of invasive tree species may motivate them to engage in more prevention.

Future research should explore the role of the various categories within private ownership, which could be further divided into industrial and nonindustrial private ownership because industrial and nonindustrial forestlands usually have different management objectives. Future research can focus on individual invasive tree species instead of treating them as a group if policymakers plan to work on one specific species.

Acknowledgments: This study was based on Jun Zhai's graduate work and was supported by Forest and Wildlife Research Center, Department of Forestry, College of Forest Resources, Mississippi State University.

Author Contributions: Zhai and Grebner conceived and designed the experiments; performed the experiments; analyzed the data, and wrote the paper. Grala, Fan and Munn provided analytical expertise, interpretation, and editorial contributions.

Conflicts of Interest: The authors declare no conflict of interest.

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