Impact of Ecological and Socioeconomic Determinants on the Spread of Tallow Tree in Southern Forest Lands

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Abstract

Based on USDA Forest Service Forest Inventory and Analysis (FIA) database, relationships between the presence of tallow tree and related driving variables including forest landscape metrics, stand and site conditions, as well as natural and anthropogenic disturbances were analyzed for the southern states infested by tallow trees. Of the 9,966 re-measured FIA plots in eastern Texas, Alabama, Georgia and South Carolina, 190 plots (1.9%) were found to be infested by tallow trees during the new measurement cycle (between 2004 and 2008). Logistic regression showed that the probability for a plot to be infested by tallow trees is significantly related to ecoregion, forest type, stand size class, slope and distance to other infested plots and highways. Tallow trees are mainly distributed in the western Gulf section of coastal plains and flatwoods (16.4%), the western section of mid-coastal plains (5.2%) and the Atlantic coastal flatwoods section (4.2%), where oak-gum-cypress, elm-ash-cottonwood, oak-pine and pine (loblolly pine/shortleaf pine) forests dominate. Younger stands or stands near to infested sites are more prone to be infested. Regionally, southeast Texas and southern Louisiana were the most vulnerable areas with the highest abundance of tallow trees.

Keywords: FIA, ecoregion, forest type, invasive species, disturbance.

Introduction

Chinese tallow trees (Triadica sebifera (L.) small), native to Japan and central China, were introduced into the United States in the1770s as an ornamental and potential oil crop species (Bruce 1993). It was introduced into the Gulf of Mexico coastal region by the U.S. Department of Agriculture for establishing local soap industries in the 1900s, and it has thrived in the Gulf

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coast since then (Miller 2003). Tallow tree is a small to medium sized deciduous tree in the *Euphorbiaceae* (*Spurge*) family. A mature tree can produce, on the average, 100,000 seeds per year and these seeds have an enormous ability to germinate under hardy conditions and are readily dispersed to surrounding areas by flowing and impounded waters or by birds (Bruce 1993). Tallow tree grows fast and it generally takes less than 3 years to reach maturity, but its productive phase can be maintained at least 60 years. It is commonly found in alluvial forests, floodplains and riparian woodlands, but can grow in a variety of environmental conditions, disturbed or undisturbed. It can escape from native herbivores due to the high amount of tannins in its leaf or the behavioral patterns of native generalist herbivores (Lankau et al. 2004). Once established, it can quickly form an impenetrable thicket which blocks sunlight and choke native species. These characteristics allow it to outcompete native species and quickly become locally dominant species. Currently, tallow tree has become a major threat to coastal forests in Florida, Louisiana, Mississippi, and Texas.

The objective of this study was to map the distribution of tallow tree in southern states and evaluate the impact of a suite of potential factors on the spread of tallow trees by using GIS, spatial statistics and USDA Forest Service's Forest Inventory and Analysis (FIA) data. The information will be useful for the control and mitigation of the spread of tallow trees in southern forested land.

Methods

Study area

The study area covers the seven southern coastal states including Alabama, Florida, Georgia, Louisiana, Mississippi, South Carolina, and east Texas characterized by diverse and rich species and genetic resources and highly productive forest lands (Conner and Hartsell 2002). As elsewhere in the country, southern forests are experiencing increasingly severe health problems such as the invasion of non-native species, forest fragmentation, increased wildfire risk, outbreak of insects and diseases including southern pine beetle and oak wilt and decline, and wildlife habitat loss (Leininger and Reams 2004.). Among these, the invasion, spread and establishment of non-native invasive species pose the single most daunting threat, in terms of economic cost of species control and mitigation or long-term fundamental change of forest structure and functionality, to southern forests compared to all others combined (Office of Technology Assessment 1993, National Research Council 2000).

Data analysis

From 1999, the southern FIA program adopted the transition from the periodic plan to the annual measurement scheme to monitor both annual and long-term forest change. Most southern states adopted a 5-year cycle with 20% of all phase II plots measured each year. From 2001 to 2008, 36,729 plots were measured in the entire study area with 9,966 plots measured twice in four states (Alabama, Georgia, South Carolina, and Texas). We deleted 324 formerly infested plots from the 9,966 re-measured plots and used the remaining 9,624 plots (190 out of those were newly infested in the recent cycle) to quantify the impacts of potential driving factors on the spread of tallow tree by using the logistic regression. We calculated proportions of infested FIA

plots by the driving factors identified by the logistic regression model. The explanatory variables were either calculated using the FIA database or derived from other data sources, such as the USGS, through spatial analyses (spatial overlay in ArcGIS). Gaussian kernel smoothing was used to estimate the mean probability of tallow trees presence across the study area through the function,

$$\hat{\lambda}(s_o) = \frac{1}{m(A)h_x h_y} \sum_{i=1}^{n} k(\frac{x_i - x_0}{h_x}) k(\frac{y_i - y_0}{h_y})$$

Where *m(A)* is the window size, h_x and h_y are the bandwidth in the two directions of the coordinate system, and *k* is the 1-dimension standardized Gaussian kernel function with the form of,

$$K(u) = \frac{1}{\sqrt{2\pi}} \exp(-u^2/2) .$$

The best bandwidth (*h*) was estimated using the Receiver Operating Characteristic (ROC) curve method (Zweig and Campbell 1993).

Results and Discussion

Out of 36,729 plots measured from 2001 to 2008, 1,240 plots were found to be infested by tallow trees, with a region-wide infestation probability of 3.4%. However, infested plots were mainly

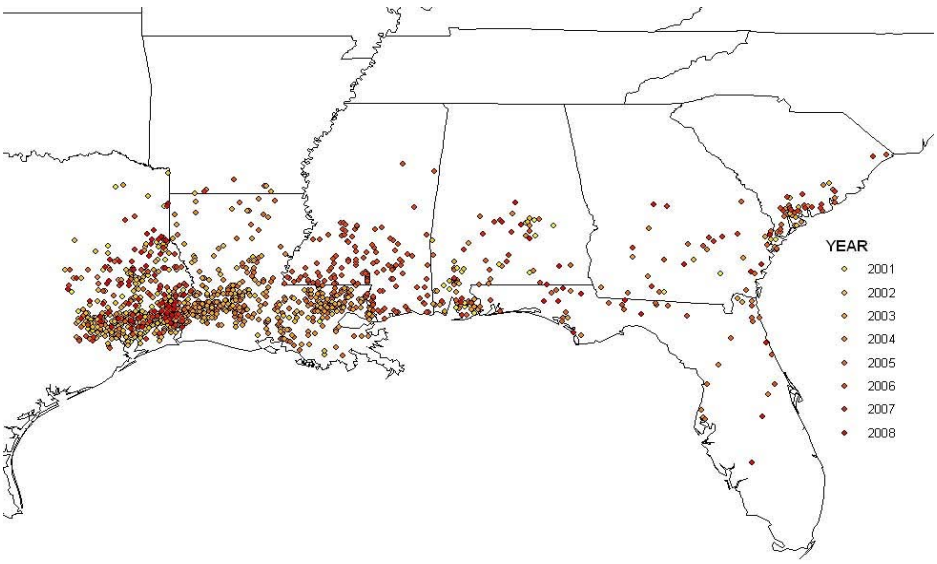

Figure 1. Infested plots by tallow trees from 2001 to 2008 in southern forestlands.

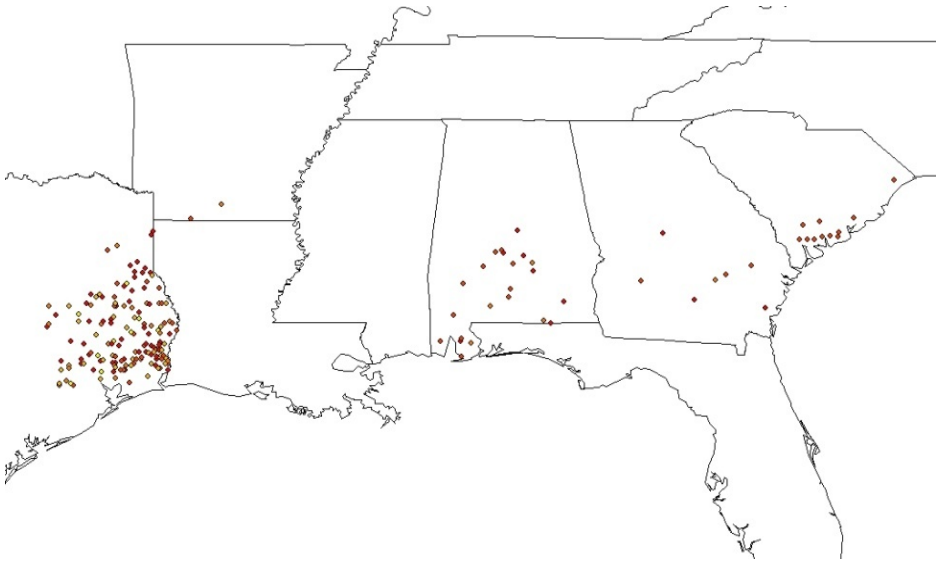

Figure 2. Newly infested plots by tallow trees from 2004 to 2008 in southern forestlands.

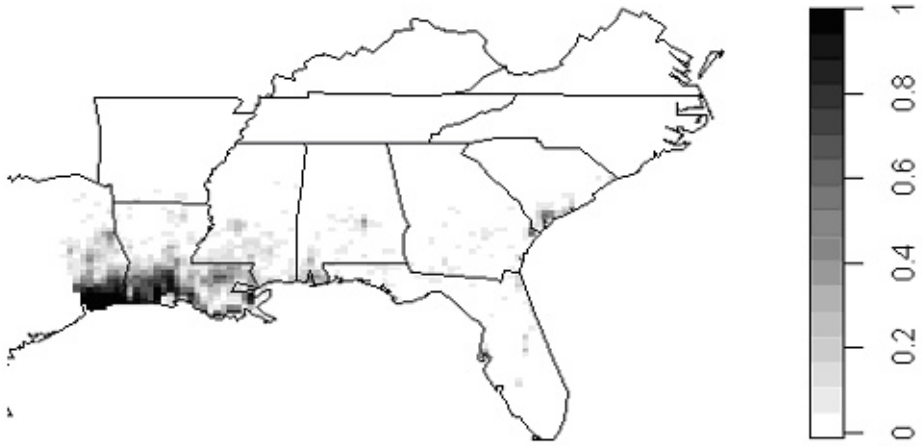

Figure 3. Probability map showing current condition of tallow tree in the southern forest lands.

aggregated in southeast Texas, and southern Louisiana, and scattered along the Gulf coastal regions in Mississippi, Alabama, Georgia, Florida, and South Carolina (Figure 1). Tallow trees are hardly found in inland states such as Arkansas, Kentucky, and Tennessee. For instance, the infestation probability in eastern Texas and Louisiana are as high as 20 and 19%, respectively, or 5 to 15 times higher than other coastal states (Table 1). There were 190 out of 9,966 plots re-measured from 2004 and 2008 found to be newly infested by tallow tree, averaging 0.25% per year in the rate of spread over the whole study area. If calculated by individual states, the rate of spread varies dramatically by state, reaching 1.3% per year for east Texas (Table 2). Obviously, the rate of spread was positively correlated to the presence of infested plots ($r > 0.82$) and the newly infested plots were spatially clustered with those formerly infested plots (Figure 2). The smoothed probability map (Figure 3) quantifies the spatial distribution of infested plots. The hot spots (most prevalent areas) of tallow trees are in southeast Texas and southern Louisiana. Tallow trees are dispersing east along the Gulf coast and spreading inland.

The presence of tallow trees in the southern forested lands is closely related to landscape metrics or geographic characteristics. According to Bailey's ecological classification system (Bailey 2002), tallow tree is mainly distributed in the western Gulf section of coastal plains and flatwoods (16.4%), the western section of mid-coastal plains (5.2%) and the Atlantic coastal flatwoods section (4.2%), where oak-gum-cypress, elm-ash-cottonwood, oak-pine and pine (loblolly pine (*Pinus taeda*) / shortleaf pine (*Pinus echinata*)) forests dominate (Table 3). The fragamentation of coastal forests caused by human activities further expedites the spread of tallow trees in the coastal forests and invasion into the interior forests. The proportion of infested

Table 1. Proportion of infested FIA plots by tallow trees in southern forest lands between 2001 and 2008.

State	Number of infested plots	Number of measured plots	Proportion (%)
Alabama	86	4,302	2.00
Arkansas	7	2,830	0.25
Florida	45	3,155	1.43
Georgia	38	4,473	0.85
Louisiana	406	2,148	18.90
Mississippi	128	3,665	3.49
South Carolina	42	2,516	1.67
Texas	488	2,437	20.02

Table 2. Rate of spread of tallow trees per year between 2004 and 2008.

State	Number of newly infested plots	Twice-measured plots per state	Rate of spread (% per year)
Alabama	21	1,711	0.25
Arkansas	2	1,305	0.03
Georgia	7	1,741	0.08
South Carolina	11	521	0.42
Texas	149	2,224	1.34

Table 3. Proportion of infested FIA plots by tallow trees by major driving factors between 2001 and 2008.

Variable	Classification	Proportion (%)	Data source
Ecoregion	1. Atlantic coastal flatlands section	4.18	USGS
	2. Coastal plains and flatwoods, lower section	1.41	
	3. Coastal plains and flatwoods, western gulf section	16.36	
	4. Coastal plains, middle section	1.17	
	5. Mid coastal plains, western section	5.15	
	6. Others	1.04	
Forest type	1. Loblolly / shortleaf pine group	2.67	FIA
	2. Oak / pine group	2.20	
	3. Oak / hickory group	0.99	
	4. Oak / gum / cypress group	5.69	
	5. Others	3.71	
Slope	1. Flat (0-2%)	5.66	FIA
	2. Gently sloping (3-6%)	1.56	
	3. Sloping (7-10 %)	1.14	
	4. Strongly sloping (> 10%)	0.51	
Stand-size class	1. Large diameter (≥ 11 inches for hardwoods and ≥ 9 inches for softwoods)	2.51	FIA
	2. Medium diameter (≥ 5 inches and smaller than large diameter trees)	1.67	
	3. Small diameter (< 5 inches)	3.90	

plots in forest edges or perforated areas is 2.7 and 2.9%, respectively, or more than 3 times larger than in the forest interior (0.8%). Forest edges and perforated areas experience more disturbances caused by human activities or natural damage, which result in environmental change and resources (e.g., light, soil moisture and nutrients, species composition) reallocation. The perturbation of natural systems will provide competitive advantages of invasive species over native species like tallow tree because of its fast growth and prolific production of seeds (Yates et al. 2004).

Besides geographic factors (e.g., ecoregion and forest type), stand condition and site factors, including stand size, slope, distance to infested plots, and transportation corridors are also significant determinants of tallow tree infestation based on the analysis of repeatedly measured plots through the logistic regression model (Table 4). The major range of tallow trees was dominated by coastal flat terrain where seeds can be easily dispersed by birds or carried by rivers, streams, and storm water runoff to new sites. This may partly explain why tallow trees are so prevalent in the coastal flatwoods and bottomlands and spread faster along the Gulf coast than in other directions.

The nearest distance to infested plots is the most significant determinant ($p < 0.0001$) of whether or not a forest plot will be likely infested by tallow trees. This means tallow trees can invade and establish in surrounding sites in an extremely aggressive manner. Tallow trees germinate and grow well on a range of soils including sandy, clay, well-drained, poorly-drained, intermittently flooded, and slightly saline soils (Scheld and Cowles 1981, Cameron and Spencer 1989, Conner 1994). They often outcompete other native species like loblolly pine and water oak (*Quercus nigra*) by its rapid height growth, which enable them to effectively control the environment following disturbances and result in a strong clustering pattern (Bruce 1993).

Table 4. Significant determinants of spread of tallow trees identified by the logistic regression model based on the 2004-2008 re-measured FIA data[*].

Variable	Degrees of freedom	Wald Chi-square	*p*-value
Ecoregion	5	23.0665	0.0003
Forest type	5	11.4598	0.0430
Stand size	3	15.2292	0.0016
Slope	3	35.2921	<0.0001
Distance to nearest infested plot	1	93.5756	<0.0001
Distance to nearest highway	1	6.2460	0.0124

AIC = 1,268.1; SC = 1,540.7; -2 Log L = 1,192.1

*Akaike Information Criterion (AIC), Schwarz Criterion (SC), and -2 Log L (likelihood) are criteria for model selection. The best model should have the smallest AIC, SC and -2 Log L values.

Even though disturbances are not shown in the logistic model (Table 4), human-induced disturbances like timber harvesting, clearing, and slash burning, or natural disturbances, including fires, storms, and floods have marginal impacts on the infestation process. Managed or disturbed stands tend to have a higher proportion of infested plots. Young stands are usually linked to a set of recent disturbance events, and thus are more likely to be infested.

Management implications

Tallow tree is the most successful invasive species and has significantly modified natural communities in the Gulf coast areas. Effective control or mitigation of tallow trees depends on precise information of its distribution and propagation mechanism. The widespread distribution of tallow trees in certain forest types (e.g., oak-gum-cypress) and its aggressive invading ability (clustering patterns) to surrounding areas make it virtually impossible to eradicate tallow trees from these forest types or ecosystems. But to mitigate its invasion to uninfested forest lands, the research findings suggest emphasis must be placed on newly infested plots, particularly on those locating in the interfaces or ecotones between different forest types or ecosystems. As birds and water are the major dispersal vectors, killing of all viable seeds will be helpful in controlling its invasion into newly infested plots. In widely distributed areas, tallow tree generally grows faster than native trees. Management of tallow trees for biomass production seems promising. But long-term impacts of tallow tree management and utilization on local or regional communities and environment need be scrutinized.

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