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Examining the Distribution of Chinese Privet (*Ligustrum Sinense*) in Relation to Historical Land Use

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ABSTRACT

The spread of invasive species in riparian areas is an international problem which has resulted in significant loss of native species in riparian areas worldwide. Land use and land cover patterns are expected to continue to affect the distribution of invasive species, specifically Chinese privet in southeastern United States; however, historical Land Use and Land Cover is a substantial model-based investigation. This study was conducted in riparian areas of Auburn, Alabama, USA. It was expected that the current and historical Land Use and Land Cover may have influenced the occurrence of native and non-native plant species. In this study, we expected to find the oldest populations of Chinese privet coincided with older urban land use change and the youngest populations near lands historically less disturbed and maintained as forest, or only recently disturbed. There was a positive relationship detected between percent cover of Chinese privet and housing density. Additionally, there was a positive relationship between size and cover by all growth stages of Chinese privet. The results also indicated that the age of Chinese privet had stronger relationships with housing density around the city center and suburban areas than agriculture and forested lands in study area.

Key Words: *Chinese privet, riparian forest management, invasive plants, land use change, urbanization.*

INTRODUCTION

During the last century, the environment has been substantially impacted by human activity and land use change in natural landscapes. Worldwide, human population is almost 250% greater than it was in 1950 (Cohen, 2003). Population change is often accompanied by substantial change in land cover. For instance, since the 19^{th} century, there have been four main time periods of prevailing disturbance and recovery associated with land use change in the southeast U.S. These have included agricultural conversion from the 17^{th}century to the 19^{th} century, timber exploitation in the early 20^{th} century, forest restoration and recovery, and urbanization starting in the late 20^{th} (Rusch et al., 2003). Each of these changes in land use and land cover (LULC) have changed the native habitat, altered hydrology, displaced native vegetation, and disturbed soils- all conditions which may ultimately contribute to increased invasive species on the landscape (McKinney, 2006).

Because of the association between land use and invasive species, the distribution of invasive species may provide some indication of historical land change. Johnson et al. (2006) showed that the demography (the age) of dispersed invasive shrubs correlated with historical patterns of urbanization. Mattingly and Orrock (2013) demonstrated that historical LULC change such as agricultural conversion may have caused soil disturbance which resulted in the current increase of invasive plant introduction and reduction of native plant communities. Since the 20th century, native habitats have been disturbed by urban development and agriculture which has caused an abundance of invasive plants to be introduced to riparian areas (Motzkin and Foster, 2002). Moffatt et al. (2004) stated that urban development and establishments of new settlements close to riparian forest lands associated with a decrease in tree basal area, vegetation diversity, soil nutrient levels, and water quality in the U.S.

Knowing how long invasive plants have occupied an area can provide further understanding of their dynamics and persistence (Perkins et al., 2006). By examining the age of plants, it was possible to calculate the propagation and survival potential of invasive species (Perkins et al.,2006). Dietz and Schweingruber (2002) analyzed annual growth rings of woody vegetation to determine age and allow them to predict the tendency for invasion in a landscape. By examining the age of woody vegetation, the approximate time of introduction and establishment of invasive plants can be estimated and compared with related disturbance levels in vegetation and habitat to examine the history of alterations on a landscape (Dietz and Schweingruber, 2002). According to Flory and Clay (2006), by looking at the characteristics and ages of invasive plants, historical land alterations can be examined and future invasions may be predicted. They suggested that the ages of invasive species could be correlated with land use change over time.

Chinese privet (*Ligustrum sinense* Lour.) is an evergreen, invasive shrub which has invaded riparian forests throughout the southern United States, where it can form nearly monotypic stands and displace native plant communities (Hanula et al., 2009). It is a member of the *Oleaceae* family and it was first introduced into the United States from China in 1852 as an ornamental plant (Langeland and Burkes, 1998). According to The National Resources Conservation Service (NRCS, 2014), it is one of the most widely spreading and threatening invasive species in the region (http://www.nrcs.usda.gov).Cuda and Zeller (2000) reported that Chinese privet escaped from cultivation by 1932 and adapted in states such as north Florida, Georgia, Alabama, Kentucky, North and South Carolina, Tennessee and Mississippi. Brantley (2008) reported that it is a shade tolerantand aggressive shrub that disturbs forestlands by displacing native plant specimens in the understory. Also, Chinese privet has occurred more than 1 million ha in riparian forests of U.S. and the relationship between land use and growth range of privet is still ambiguous (Green and Blossey, 2014). Riparian areas are commonly infested by Chinese privet due to its regenerative characteristics which provides rapid spread and colonization, and these shrubs can easily adapt to a wide range of conditionsincluding floodplains of the southeastern United States.

Although current land uses can influence Chinese privet in riparian ecosystems, historical land use change and landscape characteristics may further explain the current distribution pattern of these shrubs. For instance, historical land use can relate to increased pH level of soils and rates of net nitrification which likely promoted Chinese privet proliferation and loss of native vegetation (Holle and Motzkin, 2007). Also, rural depopulation and forest clearing activities around farmsteads resulted in loss of vegetative cover and the introduction of several non-native plants such as Japanese barberry (*Berberis thunbergii*) and leatherleaf mahonia (*Mahonia bealei*) which were often used for short-term restoration and land stabilization by local managers (Ward, 2002). According to Lundgren et al. (2004), historical land use may play an important role in determining where higher nutrition levels occur in the soil which allows privet to outcompete native vegetative cover in riparian areas.

Land use and land cover patterns are expected to continue to affect the distribution of invasive species, specifically Chinese privet in southeastern United States; however, historical LULC may be important as well. This study was conducted in riparian areas of Auburn, Alabama where there have been substantial changes in LULC over the last 50 years. It was expected that the current and historical LULC may have influenced the occurrence of native and non-native plant species. In this study, we expected to find the oldest populations of Chinese privet coincided with older urban land use change and the youngest populations near lands historically less disturbed and maintained as forest, oronly recently disturbed. Another goal of this study was also to predict the succession trajectory of Chinese privet throughout the surveyed riparian areas.

MATERIAL AND METHODS

Dendrochronological analysis

In order to estimate the age of Chinese privet, dendrochronological analysis was used to determine the relationship between DBH and shrub age. Twenty stem sections were collected from Chinese privet specimens in Town Creek Park in Auburn, Alabama, the USA, between June-August 2014. Sections represented wide range trunk diameters (3.7-15.5 cm). The stem sections of larger Chinese privet (DBH >10cm) were collected using a tree increment borer (36.5 cm. length and 1.5 cm. caliper). For smaller privet (DBH <10cm), a handsaw was used to carefully cut the shrub and a cross section of the trunk at DBH height. Cross sections were transported in freezer bags and the tree ring cores in plastic straws. All were labeled with the measured DBH sizes, and stored in a refrigerator at 4^{o}C until processing.

To minimize fungal growth and desiccation, the stem sections were examined within 2 days of being collected in the field. Increment cores were glued on wooden boards and labelled by the DBH size of Chinese privet that they were attained from. Paynter et al., (2003) detailed that analyzing woody invasive shrubs cross sections are often problematic due to diffuse tree rings that can become less perceptible over time. To improve visual detection of growth rings, the fluorescent method has been suggested to eliminate diffuse porous and detect annual growth rings (Lussier et al.,2004). For this method, the cross section of stems and cores were sharply cut and shaved using a hand planer. The surface of each stem sample was painted using a fluorescent-yellow marker to obtain an optimal surface wetness. By applying a white fluorescent light on the yellow marked stem sections, the growth rings of each sample were more perceptible and counted under a magnifying scope. The approximate ages based on the number of apparent tree rings of each specimen were recorded.

Using the annual rings and DBH for each sampled Chinese privet, a best-fit regression analysis was conducted to determine the mathematical relationships between the variables (Figure 1). The oldest sample was 46 years old and was obtained from a 51.68 cm DBH size stem, while the youngest privet was 3 years old with a DBH of 3.05cm. It should be noted that ages were considered approximations because of several issues inherent to dendrochronology and these methods. Also, inaccuracies aging trees can result from false rings and missing rings (Schweingruber and Poschlod, 2005).

Ages of the largest privet on each of the riparian sites were estimated using the mathematical relationship. Based on the regression equation, the oldest Chinese privet was found at an approximate age of 24 years. The youngest specimen was derived as approximately 7 years old. The mean age across all study sites was found 16.4±3.6 years old.

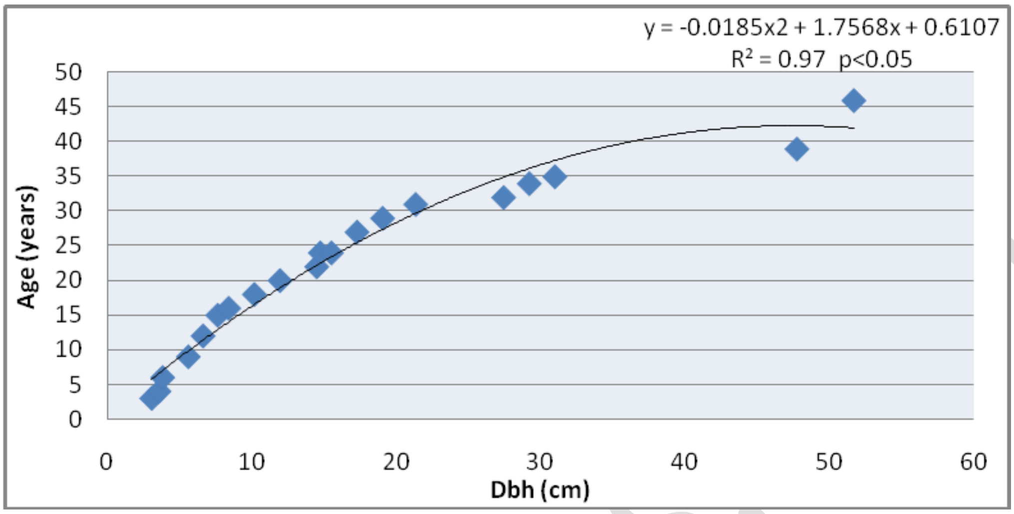

Figure 1: DBH-Age relationship of 20 Chinese privet samples collected from study sites.

Historical LULC change analysis

To evaluate historical LULC, aerial photographs (in years 1966, 1986, and 2011 respectively) of each study site and its 200 m buffer were manually digitized using ArcGIS 10.2. Within each of the buffer zones, the size of buffer zones (ha), the number of residential houses, and the road length (m) were measured by using aerial photographs of Auburn for years 1966, 1986, and 2011. Gravel, paved, and driveways were considered as roads in the measurement. The housing density (houses/ha) and road density (m/ha) were calculated for each study site for 1966, 1986, and 2011.The rate of increase in housing density between the 3 specific years was calculated as follows:

$$H = \frac{housing\ density_t - housing\ density_i}{t-i}$$

where H is the yearly increase in housing density, t, i are the specific years (2011-1966, 2011-1986, and 1986-1966), and denominator shows the number of years between dates. The same formula was modified and applied for calculation of yearly increase in road density derived from digitized maps.

Dominant historical and current land use and land cover was estimated by looking at LULC maps of Auburn obtained from the City of Auburn website (http://webgis.auburnalabama.org). Maps included the extent of urban, agriculture/pasture, industrial, wetland, forested and non-forested land use changes surrounding Auburn, AL for 1976 and 2011. To determine if study site was historically within agriculture, forest, or urban lands (the three dominant types), site was overlaid on 1976 LULC maps. Surrounding land use/land cover classifications were then designated for 1966 and 1986 by checking for consistency with land uses on the 1966 and 1986 aerial photographs if necessary. Historical land conditions were used to better interpret relationships between LULC and Chinese privet through data analyses as described below.

Data analyses

To evaluate the relationship between historical urban measures (housing density (houses/ha)and road density (m/ha) in 1966, 1986, and 2011) and cover % of Chinese privet, best-fit regression analysis was applied using SAS 9.3. Regression analysis was used to find the potential relationships between percent cover (2014) of Chinese privet and urban measures (road and housing density) for 1966, 1986, and 2011. A similar analysis was conducted between privet stand age (2014) and historical urban measures for 1966, 1986 and 2011. To evaluate for potential relationships specific to sites from individual LULC categories (urban, forest, agriculture), regressions between 2014 privet cover and house/road density (in 1966, 1986 and 2011) were stratified and analyzed based on LULC category.

To determine the potential role of historical colonization of privet, best-fit regression was also used to examine the potential relationship of housing density (houses/ha) and road density (m/ha) (in 1966, 1986 and 2011) on the age of the oldest Chinese privet. In both cases, the R-square (R^2) of each regression was compared between years to determine if there was improvement in the explanatory power of the independent variables (housing density, road density) on measures of percent cover and the stand age of Chinese privet. Finally, to examine successional trends related to privet colonization, best-fit regression analysis was used to examine the potential relationship between age of oldest privet and total cover of different growth stages. All regression results were considered significantat $p<0.05$ and $p<0.10$.

RESULTS

LULC change analysis

Annual increase rate and average housing density and road density were determined. Average housing density (houses/ha) was 0.9±1.2 and the annual increase rate was 0.02±0.03 houses/ha between 1966 and 2011.However, mean housing density increased by 0.4±0.7 houses/ha and the annual increase rate was 0.02± 0.03 houses/ha in 1966-1986 period. Average housing density was 1.1±1.2 houses/ha and annually increased by 0.03±0.04 houses/habetween 1986 and 2011. Mean road density increased 17.3±24.2 m/ha at an annual rate of 0.4±0.5 m/ha yearly in the period of 1966 to 2011, while it increased 16.9±15.2 m/ha at an annual rate of 0.8±0.8 m/ha between 1966 and 1986. Average road density also increased by 34.1±24.3 m/ha between 1986 and 2011. Like housing density (houses/ha), the most increase in road density was found between 1986 and 2011.

Relationships between historical urban measures and Chinese privet

There was a positive relationship between cover % of Chinese privet and housing density (houses/ha) for all three observation years although relationships were fairly weak (Table 1).The highest R^2 for housing density (1986) and total privet cover % was found at R^2= 0.32.The R^2= 0.27 was found for housing density (2011) and privet cover %, where it was the lowest for housing density (1966) at R^2= 0.19.Road density (1986) only had a positive and significant relationship at the 10% significance level (p=0.08) and R^2= 0.12 (Table 2).

Table 1: Results of regression analyses for relationship between cover % of Chinese privet, oldest Chinese privet, housing density (houses/ha) and road density (m/ha).

Variable	R-Square	Parameter Estimate	Standard Error	t Value	Pr > |t|
		Total cover %			
Housing Density 2011 (houses/ha)	0.271	0.683**	0.342	1.997	0.019
Housing Density 1986 (houses/ha)	0.327	4.710*	2.982	1.579	0.069
Housing Density 1966 (houses/ha)	0.195	5.235	6.001	0.872	0.304
		Total cover %			
Road Density 2011 (m/ha)	0.062	0.037	0.053	0.698	0.384
Road Density 1986 (m/ha)	0.120	0.239*	0.205	1.166	0.082
Road Density 1966 (m/ha)	0.089	0.204	0.748	0.273	0.631
		Oldest Chinese Privet			
Housing Density 2011 (houses/ha)	0.194	0.617**	0.245	2.518	0.004
Housing Density 1986 (houses/ha)	0.241	1.355**	0.776	1.746	0.032
Housing Density 1966 (houses/ha)	0.169	1.341	1.984	0.676	0.318
		Oldest Chinese Privet			
Road Density 2011 (m/ha)	0.095	0.041	0.104	0.389	0.582
Road Density 1986 (m/ha)	0.148	0.085*	0.073	1.163	0.072
Road Density 1966 (m/ha)	0.084	0.068	0.109	0.624	0.514

**significant at p<0.05 *significant at p<0.10.

Examining trends using mapped urban sites for each year; there was a positive relationship between urban measures (road and house density) and percent cover of Chinese privet. The highest R^2 for housing density (1986) and total privet cover % was found at R^2= 0.56, where $R^2$was 0.52 between housing density (2011) and cover % of privet. There was also a positive relationship between road density (1966, 1986, and 2011) and cover % of Chinese privet. Also, the highest R^2 was between housing density in 1966 and total privet cover % (R^2=0.27). There was also a positive relationship between housing density (1986) and cover % of privet at R^2=0.26. However, both these relationships are suspect as they are driven by one or two points with excessive leverage. Relationships between road density and cover % of privet was insignificant.

The highest R^2 for housing density (1966) and total privet cover % was found at R^2=0.32. There was also a positive relationship between housing density (1986) and cover % of privet at R^2=0.28. Considering road density for 1966 and 1986, they were positively associated with cover % at R^2=0.27 and R^2=0.20, respectively. Although these sites had a positive and significant relationship, it was noted that the highest explanatory power was found for mapped urban sites.

Regression analysis was also used to evaluate the relationship between historical urban measures in 1966, 1986, and 2011, and the estimated age of the largest Chinese privet for all study sites in 2014. For this analysis, the highest R^2 between housing density and the oldest Chinese privet age was found in 1986 at R^2=0.24. The R^2=0.17 between housing density (1966) and the oldest Chinese privet age, while the R^2= 0.19 for oldest Chinese privet age and housing density (2011) (Table 2). Considering only sites that were mapped as urban, the highest R^2 for housing density and the oldest Chinese privet age was also in 1986 (R^2= 0.44). There was a positive relationship between housing density (2011), housing density (1966), and privet age at R^2=0.27,R^2=0.26, respectively. Road density (1986) and road density (2011) were also positively associated with the oldest Chinese privet age at R^2=0.27 and R^2=0.19, respectively. Like housing density, the relationship between road density (1966) and privet age was also weak. For only sites that were mapped as agricultural land use, the highest R^2 for housing density (1986) and the oldest Chinese privet age was found in 1986 (R^2=0.22), where R^2=0.22 between housing density (1966) and privet age. There was a positive relationship between road density (1986) and the oldest Chinese privet age at R^2=0.17 however the relationship was relatively weak.

Relationship between Chinese privet age and cover

There was a positive relationship between size and cover by all growth forms of privet ($p<0.05$) (Table 3). The highest explanatory power was found for the oldest privet age and old-growth stage at R^2=0.49. Also, the oldest privet age had a higher explanatory (R^2=0.31) power on mature form, while the R^2=0.21 for seedling form of privet (Table 2). A significant relationship ($p<0.05$) was also detected between the estimated age of the largest Chinese privet and total cover by Chinese privet (R^2= 0.22).

Table 2: Results of regression analyses for relationship between cover %, oldest privet age, and growth forms of Chinese privet.

Variable	R-Square (R^2)	Parameter Estimate	Standard Error	t Value	Pr > |t|
		Seedling			
Oldest C. P.	0.213	0.062**	0.169	3.091	0.003
		Sapling			
Oldest C. P.	0.271	0.010**	0.136	3.466	0.001
		Mature			
Oldest C. P.	0.314	0.151**	0.219	4.289	0.001
		Old Growth			
Oldest C.P.	0.321	0.321**	0.074	4.315	0.001
		Cover (%)			
Oldest C. P.	0.221	0.041**	0.429	3.863	0.001

Note: Oldest C. P. refers oldest Chinese privet **significant at $p<0.05$.

Chinese privet and historical LULC relationship

By categorizing study area based on its historical conversion between years (e.g., forest in 1986 to urban in 2011) or lack of change (e.g., urban in 1986 to urban in 2011) it was possible to further examine the relationship between privet cover and LULC. The results of the relationship between LULC change over time and mean % cover of Chinese privet are represented in Table 4. Since 1966, the highest average % cover was found for sites with land use change from agriculture in 1986 to urban in 2011. These sites had a mean privet cover of 44.9±16.4% between 1986 and 2011. In the same period, 22 sites changed from agriculture to urban land use and had an average 33.6±11.8% cover of Chinese privet, where there were only 3 sites found which converted from agriculture to urban at average 30.5±8.4 % cover of privet (Table 3 and Table 4). Sites which stayed urban over time also had higher privet density than sites stayed forest and agriculture between 1966 and 2011. Average percent cover of Chinese privet was higher in 1986 and 2011 for all land use change classes than 1966-2011 and 1966-1986.

Table 3: The mean (±SE) % cover of Chinese privet in 2014 based on land use change categories between years (F→F is forest to forest, A→A is agriculture to agriculture, U→U is urban to urban, F→U is forest to urban, and A→U is agriculture to urban land use change.

Years	**F→F**	**A→A**	**U→U**	**F→U**	**A→U**
1966-2011	23.8±18.4	18.6±0.9	30.4±12.3	22.5±9.1	33.6±11.8
1966-1986	22.2±11.2	28.4±10.1	30.4±12.3	21.6±9.2	30.5±8.4
1986-2011	23.8±18.4	18.6±0.9	33.4±13.2	29.2±9.5	44.9±16.4

Table 4: Results of regression analyses for relationship between cover % of Chinese privet in sites designated as urban, forest, and agricultural land use (based on LULC maps) and housing density/ road density.

Total Cover % of Urban Sites					
Variable	R-Square	Parameter Estimate	Standard Error	t Value	Pr>|t|
Housing Density 2011 (houses/ha)	0.52	3.030**	0.460	6.590	<.0001
Housing Density1986	0.56	6.190**	1.483	4.280	0.001
Housing Density1966	0.24	4.710*	2.196	1.900	0.089
Road Density2011 (m/ha)	0.21	0.224**	0.072	3.110	0.004
Road Density1986 (m/ha)	0.24	0.291*	0.165	1.850	0.090

Road Density1966 (m/ha)	0.22	0.227*	0.121	1.920	0.089
		Total Cover % of Forested Sites			
Housing Density1986	0.25	7.588*	4.003	1.960	0.078
Housing Density1966	0.27	5.771*	3.027	1.870	0.091
Road Density1986 (m/ha)	0.15	0.273	0.208	1.340	0.211
Road Density1966 (m/ha)	0.13	0.431	0.350	1.250	0.238
		Total Cover % of Agricultural Sites			
Housing Density1986	0.28	5.061**	2.011	2.170	0.044
Housing Density1966	0.32	17.596**	6.291	2.870	0.010
Road Density1986 (m/ha)	0.21	0.596	0.262	2.320	0.032
Road Density1966 (m/ha)	0.27	0.622	0.243	2.540	0.021

*Significant at $p<0.10$, **Significant at $p<0.05$.

CONCLUSION

In this study, using Chinese privet (one of the region's most common invasive species), we explored potential relationships between historical land use and colonization of Chinese privet in Auburn, Alabama, the USA. Specifically, urban sites had the highest explanatory power for the relationship between urban measures and total percent cover of privet. This relationship may show that increase in urban sites can have an important influence on distribution of Chinese privet in riparian forests by causing surface runoff, flooding, and fragmentation which can lead privet seeds to disperse and recolonization of species over time. The consequences of urban disturbance such as increase in impervious surface, distortion of waterways, flooding, and soil degradation can create harsh conditions which may also promote privet to thrive. It was interesting to note that relationships between urban measures (house and road density) and percent cover by privet were improved when sites were separated based on their mapped land use. This would suggest that the response of privet to housing and roads may follow different patterns depending on surrounding LULC. These patterns were certainly less clear when sites from different LULC categories were lumped together.

Since the oldest Chinese privet detected in our study sites was approximately 23 years old, this suggests that housing density around 1986 may partially explain early Chinese privet colonization and spread within riparian areas of this study. Also, there has been significant development in Auburn since 1986 which likely increased the introduction of Chinese privet as an ornamental species used for hedge planting. It should be noted that some agricultural lands and forested lands also had higher cover. Looking at more recent land uses (2011), where nearly all sites have become urbanized, urban areas now capture a full range of Chinese privet cover. Newer developments likely caused more disturbances such as fragmentation, hydrologic distortion, and open space landscapes that may have influenced the spread of seeds and further colonization of Chinese privet in Auburn, AL.

Looking at the age of Chinese privet in relation to historical land use, sites that had been occupied the shortest time by privet (i.e., the most recently colonized) were often on agricultural and forested lands. Housing and road density in 1986 were the best predictors of privet age. This suggests that sites with urban and agriculture land use may have been more densely occupied by oldest Chinese privet than forested sites. The reason of this could be that some urban sites which were historically used as agriculture may have been invaded by privet and colonization has increased over time.

Furthermore, as Chinese privet gets older and colonization exceeds 20 years, it would be expected that the density of this species will increase substantially as younger growth stages persist under mature and old growth privets, and Chinese privet begins to dominate the riparian forest. The information provided here can be used to predict the trajectory of Chinese privet growth and cover in riparian areas over time. Our observations are consistent with Johnson et al. (2006) who reported that early successional habitats were more prone to be occupied by an increasing density of invasive shrubs over time due to expanding development and limited forest managements. Our results are also consistent with Greene and Blossey (2014) reported that there was a positive relationship between Chinese privet density and maximum DBH with privet and its mean percent cover.

This research highlights the potential relationships between historical land use, development, and colonization of Chinese privet in east Alabama. The negative effects of agriculture and urban land use might be a major threat that alters the ecosystem and its functions over time. Chinese privet has been established and dispersed more rapidly and abundantly within riparian areas adjacent to disturbed habitats. The results of this study may be beneficial for managers and land owners to determine initial colonization and spread of Chinese privet and create control points for management activities in further riparian areas. Also, this study can be applied on similar riparian areas which have been under invasion of Chinese privet over time.

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