



Evaluating the distribution of invasive woody vegetation around riparian corridors in relation to land use

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Abstract

Invasive species have been causing important and irreversible impacts to native species and communities of ecosystems. They distort ecosystem functions by degrading forest lands, wetlands, and agricultural habitats and replace the native vegetation and reduce biodiversity, forest productivity, and suitable wildlife habitat. To address disturbances caused by invasive species occurrence, further information is needed regarding the occurrence, extent, and dispersal of invasive species and how land use may increase the spread of these species. The objective of this study was to find the frequency and dominance of three invasive species common to riparian areas of east Alabama: *Ligustrum sinense* (Chinese privet), *Elaeagnus pungens* (silverthorn), and *Triadica sebifera* (Chinese tallow tree). Surveys of these species in riparian forests in and around Auburn, Alabama were conducted to show the relative extent of these shrubs and their relation to urban land use. It was expected to see the highest levels of invasive species in the city center with decreasing levels radiating outward into rural areas. Another objective was how urban land use may affect the presence-absence and prevalence of these non-native plant species within study sites. The results showed that around the city center and suburban lands, cover of both Chinese privet and silverthorn tended to increase. In contrast, Chinese tallow tree density percent cover showed an opposite trend with landscapes close to city center often having slightly less cover. This study shows that urban land use may be an important association with distribution of invasive plant species.

Keywords Invasive species · Urbanization · Ecological planning · Ecosystem management

Introduction

Invasive species cause important and, under some circumstances, irreversible impacts to native species and communities, and the ecosystem services they provide in most parts of the world (Wang and Grant 2012). They reduce ecosystem functions by degrading forest lands, wetlands, and agricultural habitats (Davis et al. 2000, Jennings and Jarnagin 2002, Parker et al. 2009). They also replace the native vegetation and reduce biodiversity, forest productivity, and suitable wildlife habitat (Ehrenfield and Stander 2010). Once these species

are successful in colonizing a landscape, it is often considerably expensive and difficult to remove them (Trani 2002; Shuster et al. 2005). It has been estimated that over 5000 nonnative plant species have infested native forest and shrub ecosystems in the United States (Parker et al. 2009).

Due to the degradation of native forest ecosystems, the characteristics of exotic invasive species have received increasing interest from conservationists, ecologists, and land managers (Gordon 1998). Also, forest biodiversity is impacted by increased infestation by invasive species (Davis et al. 2000; Stohlgren et al. 2003; Brantley 2008; Kuhman 2009). More importantly, the infestation of invasive species has been shown to significantly threaten plant species listed under the Endangered Species Act in almost half of United States ecosystems (Wilcove et al. 1998).

Riparian zones are one of the most susceptible landscapes to invasion by exotic species (Ehrenfield and Stander 2010). Riparian areas are often forest corridors in otherwise cleared landscapes that act as important transformers and filters of nutrients and sediments from urban and agricultural runoff (Malanson 1993), and facilitate flood control following high rain events (Pimentel et al. 2000). The biotic communities in

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riparian areas are often influenced by the surrounding land use (Campbell 1998; Ehrenfield and Stander 2010) and its effects can be important for sustaining clean waterways and floodplains in urban and rural landscapes.

Urban land use can have a substantial impact on riparian ecosystems, by changing habitats, altering hydrology, and increasing the abundance of invasive species (Mack and Erneberg 2002, Loewenstein and Loewenstein 2005, Wear and Greis 2013). Groffman et al. (2003) stated that urbanization was one of the most threatening factors affecting ecosystems, and despite evidence showing its impact on waterways and floodplains, there are still important knowledge gaps in our understanding of urban impacts. Urbanization has also been shown to fragment the forests surrounding riparian zones that can change habitat conditions (e.g., soil conditions, light penetration) that increase the likelihood of invasive species (Terrera et al. 2015). For example, Caughlin et al. (2012) observed that fragmented forests increased seed dispersal and colonization of the invasive plant, *Ficus microcarpa* in the South Florida, U.S.

The spread of invasive species in riparian areas is an international problem and has resulted in significant loss of native species and forest function in riparian areas worldwide, including eastern Alabama (Brantley 2008). They are important for wildlife habitat, water conservation, biodiversity, and recreational activities (Merriam and Feil 2002; Mehrhoff et al. 2003; Battaglia et al. 2009). To address the impact of invasive species, managing agencies and municipalities need reliable information regarding the occurrence, extent, and dispersal of invasive species and how the surrounding land use may increase their spread. It is also essential to inform and assist land owners to identify and report emerging invasive species (Pizarro et al. 2010).

The objective of this study was to determine the frequency, dominance, and distribution of three invasive species common to riparian areas of east Alabama: *Ligustrum sinense* (Chinese privet), *Elaeagnus pungens* (silverthorn), and *Triadica sebifera* (Chinese tallow tree). Surveys of these species in riparian forests in and around Auburn, Alabama were conducted to show the relative extent of these shrubs in relation to surrounding land use. We expected to see the highest levels of invasive species in the city center with decreasing levels radiating outward into rural areas.

Methods

Study site selection

This study was conducted at 46 riparian forests adjacent to first and second order streams throughout Auburn, Alabama, the USA. Auburn has a total land area of 150.4 km² with a population of 53,393 (UCB 2010). The climate is humid, with a mean annual precipitation and snowfall of 134.6 cm and 2.5 cm, respectively (NOAA 2015).

To find potential study sites, riparian areas were initially identified using current aerial photographs and stream maps attained from the City of Auburn (2014). To apply at least 10 research plots, riparian areas had to be forested with a minimum stream length of 200 m. Because this study emphasized urban and suburban land use, emphasis was also placed on sampling sites throughout the city proper including residential areas representing a wide range of ages of houses. Also, sites tended to be located in common areas or areas that were publicly accessible. Each stream was visited prior to field sampling to verify conditions, determine accessibility and confirm overall suitability. Of the approximately 70 streams initially visited, 46 were deemed suitable for sampling.

Riparian surveys

Because of the large number of sites to be sampled, a survey method was developed to rapidly assess the prevalence of the target invasive shrubs within each site while also assessing forest conditions in the plot and the surrounding area. The survey developed was based on other plant community rapid assessment surveys (Belleme et al. 2002, Lundgren et al. 2004, Forsyth et al. 2004) and designed to collect data on invasive species cover, growth stage and density using a modified version of the Braun-Blanquet method (Belleme et al. 2002). For each site, 10 plots were established and a survey sheet was completed for each of the three target invasive species. Data collected included target species total cover by growth stage and density. Supporting data included surrounding land cover (immediate 200 m surrounding the area), forest community form of each plot, cover by strata in each plot (understory herbaceous, shrub/sapling, subcanopy/canopy trees), visual indication of flooding (extremely rare, occasional flooding, regular flooding), and the diameter at breast height (DBH) of the largest Chinese privet in each plot. The canopy cover of each plot was also measured for all study sites.

Surveys were conducted between May and September of 2014. For each site, a transect was extended along the length of the site. Transects were arbitrarily started within the available riparian zones depending on accessibility of the area. For each site, 10 sampling plots (10 × 10 m quadrats) were established in the riparian zone. Plots were evenly spaced along the transect. The length of sites ranged between 200 m and 700 m depending on the length of stream. The width of the buffer zones was 200 m (100-m extending in both directions perpendicular to the stream). Whenever feasible, plots were located on alternating sides of the stream so that riparian conditions were evenly sampled on both sides. Plots were established so that one side of the plot was aligned with the edge of the stream channel. Plots were set up by using a field tape and the corners of each quadrat were established by using marking flags to create boundaries of a plot. For each target invasive species, visual estimates of cover, number of stems,

and the growth stage of the species (seedlings, saplings, mature and old growth) were recorded. The growth stages of each target species were surveyed to correlate how long woody species have been spreading through each study site. The criteria for growth stages were determined for seedlings (< 1.5 m tall), saplings (< 2.5 cm DBH), mature (2.5–10 cm DBH), and old growth stage (> 10 cm DBH). Percent cover ranges were recorded as trace (less than 1%), low (1 to 5%), moderate (6 to 25%), high (26 to 50%) and majority (51 to 100%). Cover per plot was calculated using range mid-points (e.g., a moderate cover [6 to 25%] was calculated as 15%) and averaged across all sampled plots for the transect. Plots were assessed for the history of flooding occurrence based on visual evidence (moist soils, sediment deposits, flow paths). Site flooding was estimated as extremely rare, occasionally flooded, and regularly flooded/ saturated. For questions like community form, a dummy variable was created which represented the presence (1) or absence (0) of the flood condition and the proportion of each category was calculated. The frequency (number of plots per transect) occupied by each target species was also calculated using collected data. Finally, the DBH (1.5 m) size of the largest Chinese privet in each was measured using a tree caliper.

Forest strata in each plot was evaluated by estimating the proportion of cover provided by mature trees (canopy trees >10 cm DBH), immature trees (subcanopy 2.5–10 cm DBH), shrubs/saplings (<2.5 cm DBH), herbaceous/ruderal, and lawn/pasture in the plot. For each strata, a dummy variable was recorded which showed if it was present in a plot (1), otherwise it was zero. Photographs of each plot were taken to document conditions in the field.

City of Auburn spatial analysis

A spatial analysis was conducted to determine land-use within the vicinity of the survey sites. The location of each study site was indicated on digital maps, and the 200 m buffer zone surrounding the transect was delineated (Fig. 2). The digital maps were created in ESRI ArcGIS version 10.2.

For determining land use change of the sites, a 2011 land use/land cover (LULC) map was used by overlaying first and second order streams with major roads in the Auburn, metropolitan area (Fig. 2). The GIS data were derived from AlabamaView website in 2014 (AlabamaView 2014). The digital LULC map indicated the following land cover types: a) urban, b) agriculture and pasture, c) industrial, d) forested and non-forested, e) wetlands, and f) transportation. For each study site, land use type within the 200 m buffer zone was determined. Also, for each study site buffer area, the number of houses and road length was calculated and normalized per ha. Gravel, paved, and driveways of houses were considered as roads. The most current digital aerial photographs were derived from city

of Auburn website in 2014 (webgis.auburnalabama.org), were used to confirm land use changes within the 200 m buffer zones. The information derived from spatial analyses then used in the data analysis section as a visual assessment.

Data analysis

To evaluate relationships among variables from the riparian surveys, Pearson correlation and regression analyses were applied using SAS 9.3. Correlations were tested for the three target species separately and used to assess for potential relationships between cumulative total invasive shrub cover and the various shrub growth stage covers. These results were also used to evaluate the tendency for different growth forms to co-occur within riparian areas. If the Pearson correlation coefficient (r) was >0.5 (or <-0.5), then it was considered a strong relationship between two variables.

Linear regression analysis was used to assess for potential relationships between urban land use (road density and house density) in the surrounding 200 m buffer and the various measures of target species cover and frequency. Similarly, the amount of forest cover in the 200 m buffer was also used as an independent regression variable to assess potential relationships between forest cover and invasive species. Then, GIS maps created in spatial analyses were used to overlay the different land use types for each study site. Total cover and cover by growth stage of each target species were examined as dependent variables. Regression results were considered significant if the p -value of the parameter was significant at $p < 0.05$ and $p < 0.10$. Also, the R-square (R^2) of regressions were used to show the explanatory power of the independent variables (forest cover, house density, road density) on measures of invasive shrub cover and growth stage.

Results

Riparian conditions and surrounding lands

Most riparian sites showed some indication of either occasional or regular flooding. Within the 200 m buffer zone, land cover contained both mature and immature forests. Cover by shrubs and sapling was also significantly high and the dominant vegetative cover type within surrounding was shrubs and saplings.

Invasive species surveys

Chinese privet

Chinese privet was found in all 46 study sites and was the most prevalent of the target invasive species. Chinese privet density was high on most plots. Half of the plots contained 5–

20 individuals and 48% had >20 stems. On average, total Chinese privet cover was $28.8 \pm 12.0\%$. At most sites, Chinese privet cover was estimated at >80% privet.

Pearson correlation results showed a strong and positive correlation between Chinese privet cover and the mature growth stages of Chinese privets indicating that this form was mostly associated with study sites that had high cover of Chinese privet. Only housing density had a statistically significant and positive relationship with total Chinese privet cover (Table 1, Fig. 1). Housing density also had a positive and significant relationship with sapling form and mature form cover. There was a significant relationship between road density and percent cover of Chinese privet seedlings. Cover of old growth privet was positively related to all land use variables.

Silverthorn

Silverthorn was the second most prevalent target species in this study (Table 1). Like Chinese privet, all 46 study sites contained some silverthorn. Average total cover by silverthorn was $17.5 \pm 11.9\%$. Cover by the various growth stages were $6.6 \pm 3.3\%$ for seedlings, $4.3 \pm 2.5\%$ for saplings, $3.7 \pm 2.4\%$

for mature, and $3.0 \pm 2.4\%$ for old growth cover. The number of silverthorn per plot ranged from 5 to 20 specimens for most of the study sites (63%). Densities of >20 were recorded at 24% of the plots and densities of 1–5 individuals were recorded at 13% of the sites.

Housing density in the 200 m buffer was positively associated with total cover and cover of all the various growth stages (Fig. 1, Table 1). House density was also positively associated with seedling, mature and old growth cover of silverthorn at $p < 0.05$ level. There was also a positive relationship between old growth stage and total forest cover at $p < 0.10$ level.

Chinese tallow tree

Chinese tallow tree was the least common target species recorded and cover averaged $1.6 \pm 0.8\%$ across the study sites. While Chinese tallow generally had less cover throughout Auburn, seedlings of Chinese tallow were found at 63% of the study sites. For the various growth stages of Chinese tallow, average cover was $0.9 \pm 0.5\%$ for seedlings, $0.2 \pm 0.3\%$ for saplings, $0.1 \pm 0.2\%$ for mature, and $0.4 \pm 0.4\%$ for old growth specimens. Density of Chinese tallow was low across

Table 1 Results of regression analyses for relationship between target invasive species' cover variables and land use in the 200 m buffer. ($n = 46$)

Chinese Privet			Silverthorn		Chinese Tallow Tree	
Variables	R-Square (R^2)	Parameter Estimate/ (Pr > t)	R-Square (R^2)	Parameter Estimate/ (Pr > t)	R-Square (R^2)	Parameter Estimate/ (Pr > t)
Total Cover (%)						
Housing Density	0.285	1.41** (0.001)	0.189	1.867** (0.004)	0.134	0.387** (0.049)
Road Density	0.042	0.002 (0.684)	0.062	-0.008 (0.605)	0.035	0.027 (0.451)
Total Forest Cover	0.032	0.095 (0.278)	0.058	0.180 (0.433)	0.051	0.096 (0.276)
Seedling cover (%)						
Housing Density	0.101	0.581 (0.113)	0.138	0.526* (0.051)	0.061	-0.008 (0.260)
Road Density	0.087	0.049* (0.067)	0.089	0.046* (0.064)	0.077	0.003 (0.844)
Total Forest Cover	0.061	0.047 (0.470)	0.074	-0.019 (0.725)	0.038	0.011 (0.654)
Sapling cover (%)						
Housing Density	0.143	0.602** (0.019)	0.930	0.108 (0.140)	0.119	0.004 (0.314)
Road Density	0.032	0.004 (0.536)	0.032	0.024 (0.396)	0.083	0.009* (0.078)
Total Forest Cover	0.086	0.051 (0.195)	0.031	0.041 (0.408)	0.031	0.015 (0.563)
Mature growth cover (%)						
Housing Density	0.127	0.835** (0.009)	0.101	0.564* (0.077)	0.127	0.019 (0.210)
Road Density	0.060	0.009 (0.330)	0.054	0.008 (0.797)	0.041	0.001 (0.419)
Total Forest Cover	0.078	0.049 (0.191)	0.037	0.034 (0.495)	0.062	0.017 (0.184)
Old-Growth cover (%)						
Housing Density	0.221	0.385** (0.014)	0.231	0.748** (0.034)	0.172	0.096* (0.061)
Road Density	0.094	0.027* (0.086)	0.086	0.061 (0.248)	0.094	0.019* (0.097)
Total Forest Cover	0.102	0.062* (0.058)	0.110	0.035* (0.083)	0.105	0.047* (0.065)

House density is calculated as (#/ha), road density is calculated as (m/ha), and total forest cover is given as percentage (%). ** shows significant at $p < 0.05$ and * shows significant at $p < 0.10$ level

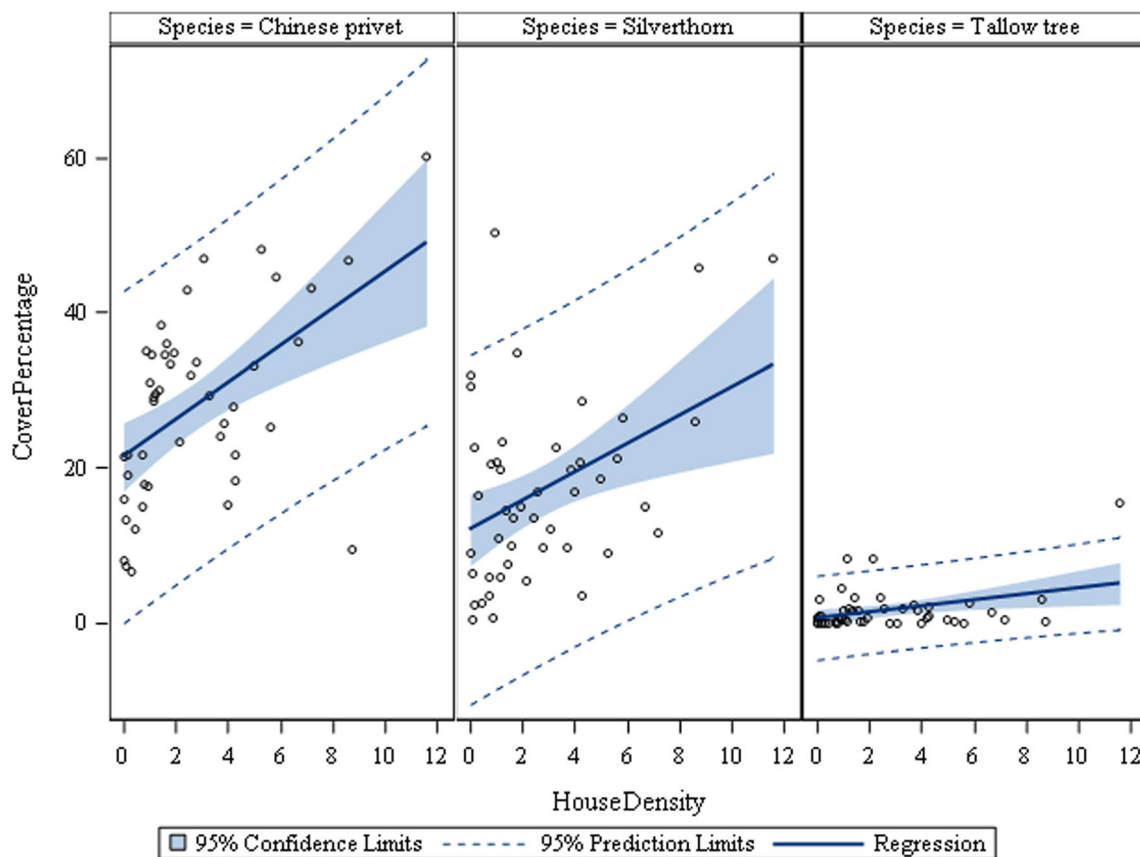


Fig. 1 Regression results and scatter plot for total cover % of target invasive species and housing density in the 200 m buffer zone

all sites with most sites (89%) containing 1–5 individuals, and 3% of study sites did not have any Chinese tallow tree.

There was a significant relationship between housing density and percent cover of Chinese tallow and percent cover of old growth tallow tree (Table 1) at $p < 0.05$ level. A positive relationship was also detected between sapling cover, old growth cover and road density ($p < 0.10$). There was a positive association between old growth cover and total forest cover at $p < 0.10$ level (Table 1).

City of Auburn spatial analysis

Overall, of the three target species, Chinese privet was the most prevalent species with an average percent cover (26–50%) (Fig. 2). Most incidences of high cover (>26%) were located in the more densely populated city core and surrounding suburban areas. Sites outside the urban core were also populated with Chinese privet but the percent cover in these areas were typically <26%.

The cover of silverthorn recorded was most commonly in the 6–25% range (Fig. 2). Across the Auburn area, the most incidence of high silverthorn cover (26–50%) was located in the more densely populated city core. Sites outside the urban core were also occupied by silverthorn but the percent cover in these areas tend to be <25%.

In contrast, Chinese tallow tree was the least dispersed species (Fig. 2). Unlike the other species, the occurrence of Chinese tallow tree was more common in sites outside the Auburn urban core. Visual evaluation of Chinese tallow tree cover across the Auburn area indicated that most incidence of low cover (<1%) were located in the more densely populated city core.

Discussion

The occurrence of Chinese privet, silverthorn, and Chinese tallow tree in riparian areas in the Auburn region were all associated with urban land use. There was a positive relationship between housing density (#/ha) and total percent cover of Chinese privet at $p < 0.05$ level which was shown in the Table 1. Silverthorn abundance was also positively related to housing density ($p < 0.05$), and silverthorn seedling cover was also positively related to road density ($p < 0.10$) (Table 1). The least prevalent species was Chinese tallow, but it was also positively related with housing density at $p < 0.05$ level (Table 1). These results are consistent with other studies that have detected a positive relationship between urban land use and distribution of invasive plant species (Borgmann and Rodewaldi 2005; Parker et al. 2009; Pizarro et al. 2010;

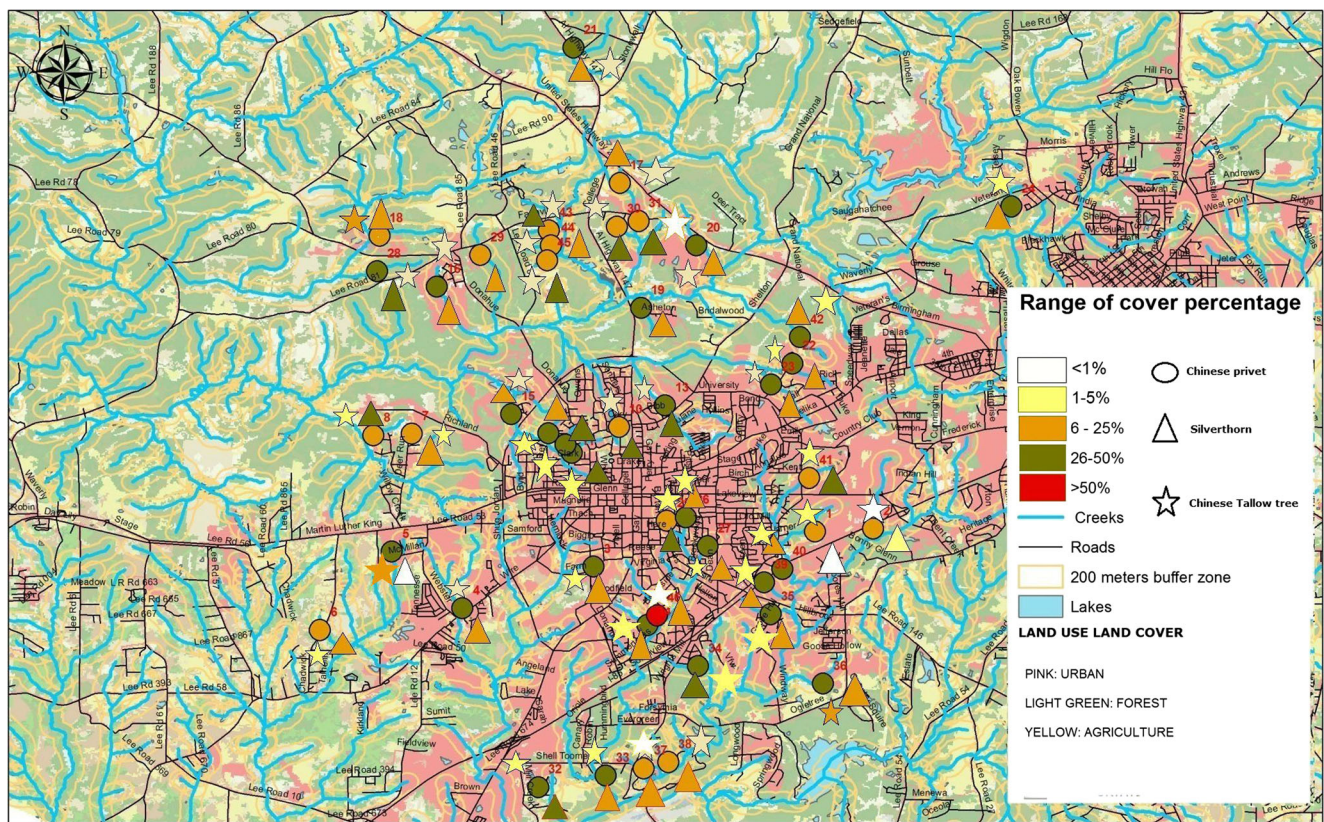


Fig. 2 Locations and total cover ranges of surveyed target invasive plants and LULC in Auburn

Terrera et al. 2015). For example, Pizarro et al. (2010) found that housing density was significantly associated with abundance and spread of invasive plant species.

Furthermore, the growth rates of Chinese privet can be used to estimate the colonization. For instance, the growth stage contributing most to privet cover was old growth except seedlings, but the relationship wasn't particularly strong. Forest cover was only correlated with the old growth stage of Chinese privet. Road density was only correlated with seedling and old growth stages of privet. Road density and housing density did not exhibit similar patterns for privet. This result may have occurred because houses may have been established before road networks developed around farmlands and rural areas. Also, major roads may occur on lands that were distant to riparian corridors.

Housing density was most correlated with abundance of target invasive species. The cover of invasive species can be mostly associated with residential land use in riparian areas, and forested landscapes with low canopy cover are more infested than landscapes with low housing density (Borgmann and Rodewald 2005). Also, urban development and distance to developed land could predict the percent cover of Chinese privet around urban areas (Greene and Blossey 2014).

Urbanization could be a key factor that is associated with the increasing prevalence of invasive species cover

in riparian areas. In coastal regions of southeastern United States, population growth leads to increased residential development and forest loss (Nagy and Lockaby 2011; Barksdale and Anderson 2014). Similarly, urban land use leads to greater impervious surface area around riparian areas which can result in high surface run off and increased erosion (Paul and Meyer 2001; Chadwick et al. 2006). The increased surface run off and increased erosion can spread more seeds of the target invasive species which can increase the invasion. Also, the bird dispersal can be considered as another reason of the increase in spread of target invasive plants. More importantly, determining the relationship between the abundance of invasive plants and urban land use may provide useful information to managers and private land owners seeking to effectively manage invasive shrubs.

Our results show some association between urban land use variables and the distribution of invasive plants in riparian areas. Although housing density had the highest explanatory power in relation to cover of target species in this study, there are also other factors that explain the prevalence of invasive plant species. Some other factors that we did not measure such as soil disturbance and microbial communities, light exposure, non-native predators, and native plant richness could be also associated with urbanization and its relation to invasive plants. For instance, Sung et al. (2011) examined the relationship between watershed urbanization and its relation with woody

invasive plants in Austin, Texas and concluded urban land use promotes invasion by invasive plants by leading hydrologic drought in riparian areas.

Furthermore, the density of Chinese privet showed some evidence of a positive trend with residential and suburban land use (Fig. 2). Likewise, the abundance of silverthorn exhibited some trends with suburban and urban lands (Fig. 2). Both Chinese privet and silverthorn were significantly abundant within landscapes closer to the city center. Further out from the city center and suburban lands, cover of both Chinese privet and silverthorn tended to decrease. In contrast, Chinese tallow tree density percent cover showed an opposite trend with landscapes close to city center often having slightly less cover (Fig. 2). This result may be because tallow tree has been introduced more recently than other target species within study sites. This result may suggest that new developments may have been established close to riparian areas already with high cover of Chinese tallow tree. Without these two sites, there would probably not be a relationship between housing density and Chinese tallow tree cover. Also, more exotic species can be observed than native forest communities on young forested lands associated with urban and agriculture land use (Parker et al. 2009). As a result, it is assumed that urban and agriculture land use was highly impacted by richness and prevalence of invasive shrubs in this study.

Until the twentieth century, agricultural products such as corn, cotton, and cattle were the primary economic resources for Auburn, yet after 1940s, farm owners started to abandon agricultural lands due to industrial development in the city (Siebenthaler 2014). Moreover, rural depopulation and abandoning farm lands can facilitate invasive species to remain for decades within agricultural landscapes (Pandi et al. 2014). Soil disturbance and increase in historical land use change can be highly associated with invasive species introduction and expansion in landscapes throughout abandoned agricultural lands (Mattingly and Orrock 2013). Similarly, Auburn is surrounded by abandoned agricultural lands converted to urban areas which were possibly occupied by invasive plant species in the past and may have been areas of introduction and spread of target species surveyed in this study.

This study shows that urban land use and specifically housing density may be an important association with invasive shrubs species. To protect native species and associated landscapes, controlling the spread of invasive species can be a key factor. Therefore, houses established around the riparian areas may be considered as a major source of increase in invasive plants because of increase in plantation of the invasive species on gardens. More importantly, people living in urban areas should pay more attention while choosing species for their gardens which can also help to reduce distribution of invasive plants around urban ecosystems. One improvement to this

study could have been to use more riparian streams for the surveys. All in all, this study may be a benchmark for future studies. If more riparian surveys are implemented, it can possibly increase the explanatory power of the survey.

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