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The impact of Chinese tallow (*Triadica sebifera*) on stand dynamics in bottomland hardwood forests

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ABSTRACT

Chinese tallow (*Triadica sebifera* (L.) Small) is an invasive tree species that competes with native species in bottomland hardwood forests in the western Gulf Coastal Plain of the southern United States. While much research has been done on Chinese tallow in coastal prairie ecosystems focusing on its establishment ecology, there is little known about its impacts on stand dynamics in forested ecosystems, where it is a growing problem. A paired-plot design was employed in 23 different stands along the Neches River, near Diboll, Texas, to compare sites with contrasting abundance in Chinese tallow. The objectives were to (1) determine the impacts of Chinese tallow on stand dynamics, (2) examine its impact on the light environment, and (3) determine if edaphic factors were correlated with stand structure on sites with varying stocking of Chinese tallow. Stand structural metrics were measured in 2012 and 2013, and the below-canopy light environment was estimated using hemispherical canopy analysis. Soil samples were collected for analysis in 2013. For all species, stand density was greater in plots with abundant Chinese tallow, while basal area, quadratic mean diameter, and relative density were lower ($p < 0.10$). Chinese tallow presence was negatively correlated with overstory diversity, density of native species, oak density. We observed a greater maximum stand density index for bottomland hardwoods than has previously been reported (1200 trees ha^{-1} at 25 cm QMD). Stand structure was most correlated to soil metal availability, yet relationships were weak ($R^2 < 0.30$), potentially indicating minimal differences in edaphic conditions across our stands. Management to prevent Chinese tallow from replacing native species in bottomland hardwood forests includes proper density management of stands in areas where Chinese tallow is likely to grow and early detection of gap formation to allow treatment of establishing Chinese tallow before it outcompetes regenerating native species.

1. Introduction

The invasion of forested ecosystems by introduced exotic species has become a topic of concern for the ecological function of forests worldwide (Reichard and Hamilton, 1997; Richardson, 1998). One such species, Chinese tallow (*Triadica sebifera* (L.) Small), has increased in abundance by several orders of magnitude over the last century in bottomland hardwood forests in east Texas, altering ecosystems including coastal prairies and forested wetlands (Wall and Darwin, 1999; Hall and Harcombe, 2001). Evidence suggests Chinese tallow that is invasive in the United States displays differences in population genetics when compared to current-day populations found in China which may have allowed it to become more invasive since its widespread introduction in the Gulf Region in the early 1900s (Siemann and Rogers, 2003c). Compared to currently non-invasive Chinese ecotypes, the invasive ecotype found in the United States allocates more nitrogen to growth and reproduction and less to compounds that confer protection from herbivory. Additionally, its ability to sprout at rapid rates, produce a prolific crop of seeds at a young age, and tolerate a wide range of site conditions enable it to establish and thrive in the ecosystems of the southern United States (Bruce et al., 1997; Barrilleaux and Grace, 2000). Known to convert grasslands and forests into Chinese tallow monocultures (Bruce et al., 1995), it is extremely difficult to eliminate Chinese tallow once it becomes established (Miller et al., 2010).

Bottomland oak flats, or low-elevation seasonally flooded backwater areas, are particularly prone to Chinese tallow invasion, as it often establishes at high densities (Wall and Darwin, 1999; Fan et al., 2012). Native oak species are adversely affected by interspecific competition, particularly low light-levels created by a dense mid-story (Lorimer, 1993; Dey, 2002). By contrast, Chinese tallow may be better suited to survive and grow despite competing

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vegetation. Although Chinese tallow is able to grow under varying light environments, it performs better in full sunlight (Jones and McLeod, 1990; Barrilleaux and Grace, 2000; Battaglia et al., 2009). Chinese tallow seedlings benefit from open canopy habitats, allowing them to grow at faster rates on a range of sites (Pattison and Mack, 2009). However, its response to light may be moderated by other site characteristics beyond light availability. The combination of an open canopy and greater moisture availability are positively correlated with Chinese tallow growth (Lin et al., 2004).

Although the species is able to survive in dry areas, mesic environments are most favorable to Chinese tallow for establishment (Jones and Sharitz, 1990). Chinese tallow may increase the amount hypertrophied lenticels and obtain thicker feeder roots as a response to establishing in areas with flood regimes (Jones and Sharitz, 1990; Conner, 1994; Conner et al., 1997, 2001). Additionally, flooding duration does not seem to affect Chinese tallow survival on floodplains in Texas (Siemann and Rogers, 2003b). Thus, it is able to compete with native bottomland hardwood species. The probability of invasion of forests by Chinese tallow increased with a decreasing distance to a body of water (Gan et al., 2009), which is attributable to water being one of the dominant means by which Chinese tallow seed dispersal occurs.

Chinese tallow growth rates are also affected by soil nutrient availability; increased nitrogen, potassium, and phosphorus result in better Chinese tallow growth (Siemann and Rogers, 2003a). Increased nutrition allows for improved height, diameter, aboveground biomass, shoot mass and root mass (Rogers and Siemann, 2002). Through its rapid leaf decomposition rate, Chinese tallow also increases nutrient cycling rates in its immediate environment, self-facilitating its own growth (Cameron and Spencer, 1989). Interactions between light availability and nitrogen addition have been observed for Chinese tallow growth rates, also resulting in morphological variability (Siemann and Rogers, 2003a).

However, whether many of the previous studies on Chinese tallow are applicable at the stand scale in bottomland hardwoods remains in question, as most were conducted in grassland ecosystems, as short-term field experiments, or as greenhouse studies (Cameron et al., 2000; Nijjer et al., 2002; Rogers and Siemann, 2003; Siemann and Rogers, 2003a; Donahue et al., 2006; Zou et al., 2009). More research is needed on the impact of already established Chinese tallow on mature and aggrading bottomland hardwood forests following stand initiation. The data presented in this study directly address this research gap. To evaluate and compare differences between areas of high and low Chinese tallow abundance, a paired-plot design was established within bottomland oak dominated forests located in the Pineywoods Mitigation Bank near Diboll, Texas. Differences in stand structure, stocking, composition, light environment, and edaphic factors were examined over two growing seasons, 2012 and 2013. We hypothesized that (i) areas with a greater Chinese tallow density would have a reduced density of native species and reduced overall stand stocking; (ii) due to Chinese tallow's rapid growth rates, areas with more Chinese tallow would have an altered below-canopy light environment; and (iii) soil hydrology within bottomland hardwood forests would not be correlated with Chinese tallow density, but fertile soils with greater levels of plant available nutrients would prove more conducive to its growth relative to native species.

2. Materials and methods

2.1. Study area

The Pineywoods Mitigation Bank (PMB) is a 7,721 ha forested wetland located along the Neches River in east Texas (Fig. 1). Average annual rainfall within the region is 147 cm with an

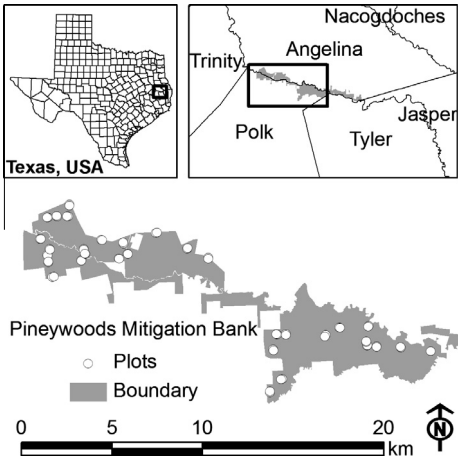

Fig. 1. Map of the Pineywoods Mitigation Bank in Angelina, Polk, Tyler, and Jasper Counties, Texas, USA.

average high of 34 °C and low of 22 °C in the summers and a high of 16 °C and low of 3 °C in the winters. Primarily dominated by mixed hardwood forests, the PMB has abundant willow oak (*Quercus phellos*), laurel oak (*Quercus laurifolia*), and water oak (*Quercus nigra*) in mesic flats. Within the swamps, black tupelo (*Nyssa sylvatica*) and bald cypress (*Taxodium distichum*) are the dominant species. Other abundant species include green ash (*Fraxinus pennsylvanica*), American elm (*Ulmus americana*), and sweetgum (*Liquidambar styraciflua*). Restoration of stand structure, composition, and ecological function is the current management objective for the PMB.

The spatial distribution of Chinese tallow is variable at the PMB; patch sizes range from a few square meters up to several hectares. Chinese tallow regeneration often occurs in irregularly shaped areas of blow-down within mature stands. Of the total of 7721 hectares, 5261 hectares of bottomland forest are in the process of being treated with herbicides to control Chinese tallow, although treated areas have been excluded from this study. Herbicide treatments have been performed since 2009, using basal spray and foliar applications of Garlon® (triclopyr), foliar application of Clearcast™ (imazamox), and stem injection of Arsenal® (imazapyr). All applications have had varying degrees of success based on the specific area in the bank where the Chinese tallow established. Approximately 1000 hectares will be treated annually until 2016.

2.2. Experimental design

A paired-plot experimental design (e.g. Stape et al., 2004) was installed throughout the study area (Fig. 1). Plots were selected so one would have little to no tallow (native plot) while the other in the pair would have abundant Chinese tallow (tallow plot). Plots were replicated among stands (i.e. stands are the experimental unit), but not within each stand (i.e. only one pair of plots per stand). In this study, stands were considered to be contiguous areas with relatively homogeneous composition, stand structure, and soils. However, they were not completely homogeneous, as recent developments in the silvicultural literature are more accepting of within-stand heterogeneity (O'Hara and Nagel, 2013). Stands were previously defined by the Working Lands Investment Partners as management units during winter and spring of 2012. Paired-plots were separated from other pairs by a minimum distance of 305 meters. Identification of a Chinese tallow plot was based on Chinese tallow density. To be considered a Chinese tallow plot, a stand must have met at least one of the following criteria: 2 Chinese tallow trees per 200 m^2 plot > 25.4 cm dbh, 4 trees per 200 m^2