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SITE CHARACTERISTICS OF *LEITNERIA FLORIDANA* (LEITNERIACEAE) AS RELATED TO POTENTIAL BIOLOGICAL CONTROL OF THE INVASIVE TREE-OF-HEAVEN, *AILANTHUS ALTISSIMA*

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ABSTRACT

Leitneria floridana, corkwood, an uncommon tree native to the southeastern and south central United States, may be threatened by the invasive tree-of-heaven, *Ailanthus altissima*. Field studies were conducted to assess the morphology and site characteristics of *L. floridana* throughout its native range and to determine if *Ailanthus altissima* has invaded *L. floridana* populations. One site in Georgia, Texas, Arkansas, and Missouri, and two sites in Florida were examined. Plants at site #1 in Florida were significantly taller and had a larger trunk diameter than any other location throughout *L. floridana* distribution. Plant density was greatest at site #1 in Florida; however, the amount of *L. floridana* was greatest at site #2 in Florida. Water depth varied at the time of sampling from 0–31 cm across its distribution. *Atteva punctella* (Cramer) (Lepidoptera: Yponomeutidae) was the only herbivore found feeding on *L. floridana*. The following woody species were found associated with *L. floridana*: *Sabal palmetto*, *Triadica sebifera*, *Sesbania drummondii*, *Quercus lyrata*, *Liquidambar styraciflua*, *Carya aquatica*, *Magnolia virginiana*, *Fraxinus pennsylvanica*, *Prunus serotina*, *Cephalanthus occidentalis*, *Taxodium distichum*, and *Ulmus americana*. *Ailanthus altissima* was not found in *L. floridana* habitats. Management of *A. altissima* for the protection of *L. floridana* is discussed.

KEY WORDS: *Leitneria floridana*, corkwood, *Ailanthus altissima*, tree-of-heaven, invasive species management

Corkwood, *Leitneria floridana* Chapm. (Leitneriaceae), is a rare tree native to Georgia, Florida, Texas, Arkansas, and Missouri, with at least one known cultivated population in Illinois (Sharma & Graves 2004, USDA-NRCS 2007). Specimens also have been collected by the Parks Department in Rochester, New York, in 1925, 1927, and 1968 but there is no evidence that the species still occurs there (Koller 1997). *Leitneria floridana* occurs in brackish and fresh water marshes, wet woodlands, swampy prairies, and estuarine shores (Koller 1997; Sharma et al. 2008).

The classification of corkwood has endured substantial debate since its first discovery by Dr. E.T. Leitner in 1835 in the salt water marshes of Florida's Apalachicola River (Koller 1997). Past workers have placed *Leitneria floridana* in Simaroubaceae (Petersen & Fairbrothers 1983; Fernando

et al. 1995; Gadek et al. 1996; Soltis et al. 2000; Judd et al. 2002; Jacobs 2003), but more recently the species has been placed back into Leitneriaceae (Sharma et al. 2008).

Leitneria floridana has a global conservation rank of G3 (vulnerable; either very rare and local or found locally in a restricted range). It has a state rank of S1 (critically imperiled because of extreme rarity) in Georgia and Texas, S2 (imperiled because of rarity) in Missouri, and S3 (very rare and local or found locally in a restricted range) in Arkansas and Florida (Sharma et al. 2008; NatureServe 2009; CPC 2010). It is generally accepted that *L. floridana* rarity is due to habitat destruction, land management practices for recreational purposes, and poor competitive ability (Koller 1997; Rosen et al. 2006).

Tree-of-heaven, *Ailanthus altissima* (Mill.) Swingle (Simaroubaceae), is a dioecious, rapidly growing (1.5 meters a year), medium to large tree (25–35 m) that produces up to 300,000 seeds a year (Sheppard et al. 2006). It is an introduced and invasive species in North America (Ding et al. 2006). Seed was introduced from China to Paris between 1740 and 1750 (Hu 1979; Tellman 2002) and into North America as an ornamental shade tree during the late 18th century from Europe into Philadelphia, Pennsylvania (Feret 1985; Tellman 1997). Multiple introductions into New York occurred during the early 19th century (Davies 1942; Dame & Brooks 1972; Hu 1979). The last historical record of *A. altissima* introduction(s) into the United States occurred during the gold rush in the mid 19th century when Chinese laborers brought the tree into California from Chinese seed stock for its medicinal and cultural value (Tellman 2002).

Tree-of-heaven is established throughout most of the United States from Washington to New England and south to northern Florida, Texas, and southern California (Kartesz & Meacham 1999; Howard 2004; USDA-NRCS 2007), its relative abundance variable throughout its distribution. It is most common near its centers of initial introduction and less common in areas distant from its introduction. It has become established in a wide variety of ecosystems, from oak-hickory to freshwater tidal estuaries (Garrison et al. 1977; Kiviat 2004) and has become a serious threat to habitats throughout its North American distribution. It is registered as a noxious weed in New Hampshire, Vermont, Connecticut, and California (USDA-NRCS 2007). Nationally, the tree has become an economic and ecological pest.

Many invasive plant species produce allelopathic compounds that are capable of suppressing the growth of alternate plant species, reducing competition. *Ailanthus altissima* produces the compound ailathone, which is capable of suppressing more than 90 species (Mergen 1959). The allelopathic properties of *A. altissima* may further threaten *Leitneria floridana* if it encroaches into *L. floridana* habitats.

Investigations into the use of biological control for suppression of *Ailanthus altissima* were initiated in 2004. A weevil, *Eucryptorrhynchus brandti* (Harold) (Coleoptera: Curculionidae), was identified in China and imported to the Virginia Tech's Beneficial Insect Quarantine Facility for testing as a possible biological control agent (Ding et al. 2006). Herrick (2011) and Herrick et al. (2011) studied the life history, development, host range and rearing protocol for this species in quarantine. Results indicate that substantial feeding by *E. brandti* adults occured on *Leitneria floridana* foliage in no-choice tests. However, feeding on *A. altissima* foliage was significantly greater and preferred when adults were given a choice of *A. altissima* and *L. floridana*. Besides *A. altissima, L. floridana* was the only other species among 29 plant species tested that showed feeding by the weevil (Herrick 2011).

Native plant community structure and diversity can be negatively altered by the invasion of non-indigenous species like *Ailanthus altissima* (Westbrooks 2001; Woods 1993; Zimdahl 1995; Olden & Poff 2003; Heady et al. 1992; Rosen & Faden 2005; Rosen et al. 2006). *Ailanthus altissima* occurs in every state that *Leitneria floridana* occurs in. However, it is only known to occur in the same counties in Jefferson and Franklin counties (Florida), Brazoria County (Texas), Jefferson, Craighead, and Mississippi counties (Arkansas), and Ripley County (Missouri) (USDA-NRCS 2007).

In counties where both species occur, it is not known if they occupy the same habitats, how close in proximity they occur, or if the habitats support coexistence of the two species. Therefore, a field survey was conducted of *Leitneria floridana* throughout its native range to gain a better understanding of the species in its native habitat and to determine if *Ailanthus altissima* has invaded or has the potential to invade *L. floridana* habitats. This information will allow us to better address future biological control tactics for *A. altissima* as it relates to *L. floridana* and the use of the potential biological control agent *Eucryptorrhynchus brandti*.

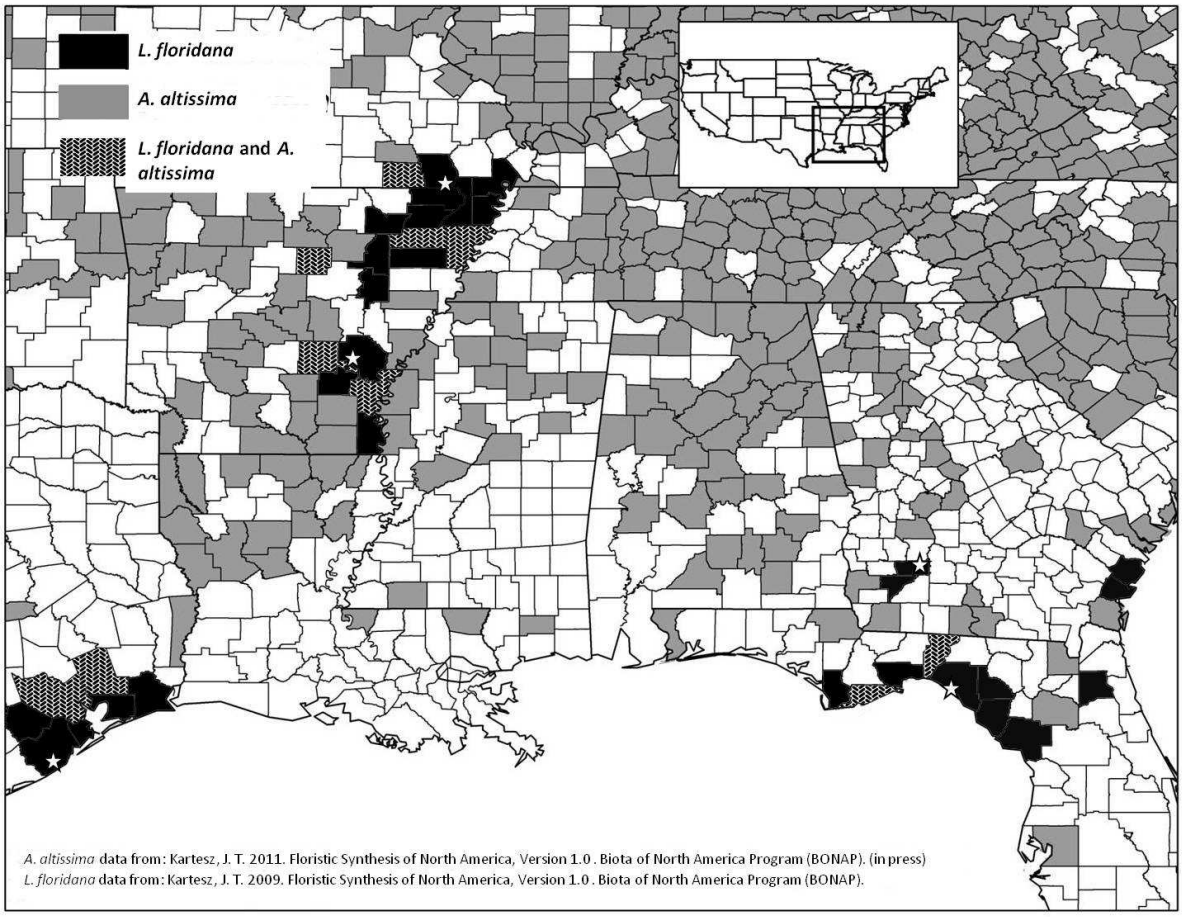

Figure 1. County distribution of *Leitneria floridana*, *Ailanthus altissima*, and sample site locations (star) in the southeastern and south central United States.

Materials and methods.

From 9 September through 5 October 2009 native sites of *Leitneria floridana* were visited in the Joseph W. Jones Ecological Research Center at Ichauway, Dougherty County, Georgia (31° 42' 48" N; -84° 44' 44" W, at 52.1 meters alt.); Big Bend Wildlife Management Area, Snipe Island, Taylor

County, Florida (site #1, 30° 12' 72" N; -83° 96' 92" W, at 7.3 m alt.; site #2, 30° 12' 50" N; -83° 97' 03" W, at 14.6 m alt.); San Bernard National Wildlife Management Area, Bird Pond Unit, Brazoria County, Texas (29° 08' 18" N; -95° 12' 33" W, at 14.5 m alt.); Bayou Meto Wildlife Management Area, Cox Cyprus Lake, Arkansas County, Arkansas (34° 28' 67" N; -91° 63' 14" W, at 53.3 m alt.); and Sand Pond Conservation Area, Ripley County, Missouri (1 site, 36° 50' 35" N; -90° 60' 00" W, at 92.7 m alt.) (Fig. 1). These sites were chosen because they were the most easily accessible or were previously known by herbarium specimens and/or recommended by scientists in the area.

At each site, a 10 m^2 quadrate was established around *Leitneria floridana* stands to estimate the density of the stand. This quadrate size was chosen because *L. floridana* colonies were small and permitted sampling the entire population at most sites. Within each quadrate *L. floridana* height, trunk diameter, trunk taper, alternate woody species, water depth, and number of herbivores per plant were calculated or recorded. Trunk diameter was measured at breast height at site #1 in Florida. Trunk diameter was measured halfway from the base to the top of the plants at the remaining sites because they were shorter than breast height. The trunk taper was classified as described by Brack (1999) and Socha and Kulej (2007): < 0.25 cm/m, neiloid; > 0.26 and < 0.49 cm/m, conoid; > 0.50 and < 0.59 cm/m, quadratic paraboloid; and > 0.59 and < 0.99 cm/m; cubic paraboloid; and > 0.99 cm/m, cylindrical.

To determine if additional *Leitneria floridana* stands and/or *Ailanthus altissima* were present near the *L. floridana* stands, four 100 m transects were established from each quadrate. Ninety degrees from the center of the north, south, east, and west edge of each quadrate, a 100 m transect was established. Plant height, trunk diameter, trunk taper, and water depth were analyzed with analysis of variance and least square means Tukey-Kramer HSD at $\alpha = 0.05$. All other measures were not replicated, so they were not compared statistically among the sites.

Results.

Leitneria floridana at Florida site #1 was significantly taller and had greater trunk diameter than at all other sites, suggesting that the site was older and established before the other sites that were sampled (Table 1). Also, the Florida #1 site was not shaded by overstory vegetation while all other sites were, suggesting that *L. floridana* is a poor competitor in shaded environments. Plant height was similar at Florida site #2, Georgia, Texas, and Missouri sites. However, plants were significantly taller at Florida site #2 than at the Arkansas site. Trunk diameter at Florida site #2 was significantly greater than *L. floridana* sampled at the Georgia, Texas, Arkansas, and Missouri sites (Table 1). Trunk taper at Florida site #1 and Florida site #2 differed significantly from *L. floridana* at the Georgia, Texas, and Arkansas sites but not the Missouri site. Using the trunk taper classification, plants at Florida site #1, Florida site #2, and Missouri have a cylindrical trunk, Georgia and Texas plants have a quadratic paraboloid taper, and Arkansas plants have a cubic parabloid taper.

Leitneria floridana density was at least 3 times greater at Florida site #1 than at the Florida site #2 and Georgia sites, again suggesting that it is an older site. Texas, Arkansas, and Missouri sites had the lowest density (Table 1). Across all 100 m transects, Florida site #2 had the greatest amount of *L. floridana* from the main sampling quadrate followed by Arkansas then Texas. *Leitneria floridana* was sparse or absent within 100 m from the main sampling quadrates at Florida site #1, Georgia, and Missouri sites (Table 1). Minimum water depth was greatest at the Florida site #1 site followed by the Georgia site. Maximum water depth was greatest at Florida site #1 and Georgia site followed by Florida site #2. Standing water was absent in some locations at Florida site #2 and completely absent at the Texas, Arkansas, and Missouri sites. Soil was saturated at sites where standing water was

absent. Mean water depth was similar at the Florida1 and Georgia sites. Water depth was significantly greater at Florida site #1 than at Florida site #2, Texas, Arkansas, and Missouri sites (Table 1).

The only herbivore found (larvae and pupae) was *Atteva punctella* (Cramer) (Lepidoptera: Yponomeutidae) at Florida site #2 (n = 48), Texas (n = 10), and Arkansas sites (n = 7).

Leitneria floridana was the most common species in most of the sites, ranging from 47 to 90% of the total woody stems. However, the Missouri site had substantially more *Quercus lyrata* (51%) than *Leitneria floridana* (20%) (Table 2). Across all sites, *Carya aquatica* was commonly found growing in association with *L. floridana*, excluding Georgia which had *Taxodium distichum* growing as the next most common species. *Ailanthus altissima* was not found at any of the sites. However, the invasive tree *Triadica sebifera* was found in close association with *L. floridana* in Texas (Table 2).

Discussion.

Leitneria floridana grows in small isolated populations and is often inundated by standing water or found growing in previously inundated and moist soils. The majority of locations investigated contain short, wispy plants that are small in diameter. Sharma et al. (2008) suggested that the Missouri population was the most unique phenotypically, based on morphology, physiology, and growth habits. They also reported that plants in Missouri were taller than plants in Florida, but our results indicate that Florida plants were two times taller and the diameter was approximately two times larger than *L. floridana* in Missouri.

Trunk taper, or the breast height form factor, is used by foresters to aid in determining trunk volume and yield (Brack 1999). This measurement also is used as a morphological measure to determine phylogenetic relatedness (Socha & Kulej 2007). Regarding trunk taper, the only similarity that was found with Sharma et al. (2008) was in the cylindrical trunk shape of the Florida plants. These differences in results were most likely due to differences in site location, measurements, and age of the sites sampled.

Future studies need to encompass several sites across the distribution *Leitneria floridana* in each state and during different times of the year to accurately assess the species ecological role within the community it grows in and across its distribution. Genetic analysis would be useful in determining the relatedness of *L. floridana* provenances.

Native plant community structure and diversity can be negatively altered by the invasion of non-indigenous species (Rosen et al. 2006). For example, at a site location similar to ours in Brazoria Co., Texas, Rosen et al. (2006) found decreased species richness within plots containing *Cyperus entrerianus* Boeckeler (Cyperales: Cyperaceae).

Anthropogenic activities contribute toward the invasion of invasive species (Byers 2002). The presence of the invasive tree *Triadica sebifera* in the Texas site suggests that other invasive species such as *Ailanthus altissima* have the potential to invade *Leitneria floridana* habitats.

Ailanthus altissima is encroaching on *Leitneria floridana* habitats (Fig. 1). Although it was not found growing in association with *L. floridana*, site conditions might support its growth in communities adjacent to *L. floridana* colonies. Many of the sites that were visited were inundated with water. It is not known if *A. altissima* can grow in inundated conditions, but it has been reported invading upland estuarine habitats (Kiviat 2004), woodland communities, and it thrives in sites influenced by anthropogenic activities (Kowarik 1995).

All of the sites that were visited in our study were generally isolated; but every site had evidence of anthropogenic activity in the vicinity of *Leitneria floridana* stands. The Georgia, Arkansas, and Missouri sites were close to access roads for recreational purposes, the Florida sites maintain access roads for housing and recreation, and the vegetation at the Texas site was managed for hunting access and quality. Most sites in this study were selected partially for ease of accessibility based on herbarium specimens and local botanists in the areas owing to the presence of anthropogenic activities. The Texas site was the least accessible and did not have any access roads.

While conservation efforts are common for *Leitneria floridana* management (CPC 2010), managers of invasive plant species also need to be aware of such sensitive species and incorporate management tactics to have as little impact on such species. Potential biological control programs against *Ailanthus altissima* must consider its potential impact on *L. floridana* due to their taxonomic affinity. We now know much more information pertaining to the site conditions of *L. floridana* habitats. In addition, *A. altissima* is not present in the immediate vicinity of *L. floridana* habitats. Future studies should focus on the potential allelopathic impact of *A. altissima* on growth of *L. floridana* if they were to occur together. Also, it is not known if *A. altissima* can persist in conditions inundated with water and should be studied.

Based on the habitat that *Leitneria floridana* grows in, and the lack of *Ailanthus altissima* in the vicinity of *L. floridana*, the potential biological control agent *Eucryptorrhynchus brandti* does not appear to pose a significant threat to *L. floridana*. However, ongoing oviposition and larval development studies of *E. brandti* on *L. floridana* will determine if this potential agent should be released from quarantine.

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Table 1. Morphology (mean ± SE) and site characteristics of *L. floridana* sampled at sites in Georgia, Florida, Texas, Arkansas, and Missouri.

	State Sites					
Measurement	**Georgia**	**Florida #1**	**Florida #2**	**Texas**	**Arkansas**	**Missouri**
Plant height (m)	1.14 ± 0.14bc	2.59 ± 0.09a	1.20 ± 0.13b	0.86 ± 0.16bc	0.79 ± 0.15c	0.67 ± 0.24bc
Trunk diameter (cm)	0.67 ± 0.17c	2.57 ± 0.11a	1.30 ± 0.15b	0.45 ± 0.20c	0.39 ± 0.18c	0.59 ± 0.29c
Trunk taper (cm/m)	0.54 ± 0.07c	1.00 ± 0.05a	1.06 ± 0.07a	0.53 ± 0.08c	0.69 ± 0.08bc	0.90 ± 0.12ab
L. floridana/m²	4.3	12	4.8	1.5	1.7	0.7
North transect density (plants/m²)	0	0	1	0	0	0
South transect density (plants/m²)	0	0	4.5	0	1.7	0
East transect density (plants/m²)	0	0	4.8	0	1.6	0
West transect density (plants/m²)	0	0	0	1.55	0	0
Min. water depth (cm)	5.08	30.48	0	0	0	0
Max. water depth (cm)	30.48	30.48	16.19	0	0	0

*Means followed by the same letter across each row are not significantly different at $P \leq 0.05$, Least Square Means Tukey-Kramer HSD test.

Table 2. Percent woody species growing in association with *L. floridana* at sampling sites in Georgia, Florida, Texas, Arkansas, and Missouri.

			State Sites					
Family	**Species**	**Common name**	**Georgia**	**Florida #1**	**Florida #2**	**Texas**	**Arkansas**	**Missouri**
Arecaceae	*Sabal palmetto* (Walter) Lodd. Ex Schult.	cabbage palmetto	0	2.2	7.9	0	0	0
Euphorbiaceae	*Triadica sebifera* (L.) Small	Chinese tallow	0	0	0	18.7	0	0
Fabaceae	*Sesbania drummondii* (Rydb.) Cory	poisonbean	0	0	0	9.4	0	0
Fagaceae	*Quercus lyrata* Walter	overcup oak	3.9	0	0	0	19.4	51.4
Hamamelidaceae	*Liquidambar styraciflua* L.	sweetgum	1.3	0	0	0	0	0
Juglandaceae	*Carya aquatica* (Michx. f.) Nutt.	water hickory	0	8.2	14.3	18.7	12.9	17.1
Magnoliaceae	*Magnolia virginiana* L.	sweetbay	1.3	0	0	0	0	0
Oleaceae	*Fraxinus pennsylvanica* Marshall	green ash	0	0	0	6.3	0	0
Rosaceae	*Prunus serotina* Ehrh.	black cherry	1.3	0	0	0	0	0
Rubiaceae	*Cephalanthus occidentalis* L.	common buttonbush	3.9	0	0	0	0	0
Simaroubaceae	*Ailanthus altissima* (Mill.) Swingle	tree-of-heaven	0	0	0	0	0	0
Leitneriaceae	*Leitneria floridana* Chapm.	corkwood	55.8	89.6	76.2	46.9	54.8	20
Taxodiaceae	*Taxodium distichum* (L.) Rich.	bald cypress	29.9	0	0	0	0	0
Ulmaceae	*Ulmus americana* L.	American elm	2.6	0	1.6	0	12.9	11.4
Total number of species			8	3	4	5	4	4
		Total number of plants per site	77	134	63	32	31	35