

INVASIVE CHARACTERISTICS OF CHINESE PRIVET (*LIGUSTRUM SINENSE*
LOUR.) IN A BAY SWAMP IN THE FALL LINE HILLS OF EAST-CENTRAL
ALABAMA

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A Thesis

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Science

Auburn, Alabama
August 9, 2008

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Vita

Scott Michael Pokswinski, son of Michael Paul Pokswinski and Leslie May Pokswinski, was born April 29th, 1977 in Everett, Washington. He Graduated from Lakewood High school, Lakewood, Washington in 1995. He attended Skagit Valley College, graduating with an Associate of Arts Transfer Degree in 1997. That fall, He entered Central Washington University, and graduated with a Bachelor of Science Degree in Biology with an Ecology specialization in December 2000. After working as a Marine research intern for non-profit organization, People for Puget Sound, Scott entered graduate school at Auburn University in large part due to George Folkerts. He married Robin Wright, daughter of Dennis Wright and Barbara Weldon on September 5, 1999. His son Riley Scott Pokswinski was born on March 14, 2008

THESIS ABSTRACT

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Master of Science, August 9, 2008
(B.S., Central Washington University, 2000)
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69 typed pages

Directed by George Folkerts and Debbie Folkerts

Exotic species often become invasive because of an ability to occur in many habitat types with a variety of environmental variables. One species of plant that is particularly invasive throughout the southeastern United States and in many habitat types is Chinese privet (*Ligustrum sinense*). Chinese privet can be found in dry upland sites and wet bottomland hardwood forests. In this study, characteristics of Chinese privet populations in a bay swamp and an upland site were compared in order to learn the effects of Chinese privet in bay swamp habitats, and to examine characteristics that make it successful at invading these sites.

Quadrat and belt transect sampling were employed to discern plant density, diversity, and importance values in a bay swamp in east-central Alabama. An upland site was also sampled for Chinese privet in order to compare invasion success. Phenotypic plasticity was detected by comparing leaf measurements from both upland and bay

swamp habitats, by transplanting of plants from the upland site to the bay swamp, and by comparison of biomass allocation. Allelopathy potential was investigated using tomato seed germination bioassays in five concentrations of Chinese privet leaf and root extracts.

Invasion of Chinese privet in the bay swamp was found to be in an early stage, but beyond feasible treatment. The presence of Chinese privet appears to have had a larger effect on evenness than on species richness at this stage of invasion. Results of the belt sampling survey indicate that Chinese privet may be in direct competition with coastal doghobble (*Leucothoe axillaris*). Factors that allow Chinese privet to be a successful invader in many habitat types include high level of phenotypic plasticity in leaves and tremendous propensity for asexual reproduction. Another possible factor is that Chinese privet is potentially allelopathic.

ACKNOWLEDGEMENTS

This thesis is dedicated to George Folkerts. His knowledge, humility, and humanity can not be accurately recognized in a single page. Without George, this thesis and my graduate career would not have been possible. I would also like to thank Debbie Folkerts for undertaking my advisement under difficult conditions. I have learned so much about life and the natural world from both of you. Special thanks go to Robert Lishak and David Teem for acting as committee members. I hope to continue the use of the teaching techniques and skills that I learned from Dr. Lishak. I also appreciate the opportunity to speak and the Alabama Invasive Plant Council supported by Dr. Teem. Courtney Holt and Katy Glynn were valuable assets to the collection of data and the exploration of study sites. Thanks to Rachel Foster for guidance and support. Vic Stegemiller from NOAA was very helpful with GIS applications and an ear to bounce ideas off of. I appreciate the inspiration that I have receive from amateur naturalists like Byron Wagoner and Doug Pokswinski that inspire me and remind me why I have chosen this as a career. I especially would like to thank my family for emotional, spiritual, and financial support throughout my graduate work. Thanks to my wife Robin who supports me in all of my endeavors and has sacrificed greatly during this period of our lives.

Style manual or journal used: Wetlands

Computer programs used:

Maptech Terrain Navigator

Microsoft Office 2003

Word

Excel

SYSTAT 12

SIGMAPLOT 10

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INTRODUCTION

Invasive species can have a detrimental effect on native plants and on the economy (Pimentel et al. 2000), because they are capable of dispersal to new areas and displacement of native species. Lack of control measures in newly invaded areas often leads to development of an unnatural and homogenous habitat from which native plants have been eliminated. As invasive plants and animals have become a world-wide problem, the new science of invasion biology has grown in order to enhance understanding of these invasions. In this emerging science, studies of the mechanisms that cause invasions by non-native plants and animals may provide information that can be used to prevent the spread of these species. Invasive species that are most detrimental are those with a high degree of phenotypic plasticity and the ability to successfully invade many habitat types.

Chinese privet (*Ligustrum sinense* Lour.) is an invasive shrub that is rapidly invading many habitat types in the southeastern United States. This shrub has been studied in a number of habitat types, but not in bay swamps. A bay swamp is a community that surrounds a first order seepage stream and is dominated by an evergreen bay (Wharton 1978). This research is designed to investigate the effects of Chinese privet on this habitat, learn more about the importance and structure of bay swamps, and shed light on the invasive characteristics of Chinese privet.

The effects of invasive plants are of concern to many conservationists, ecologists, natural resource managers, weed scientists, and agriculturalists. As nonnative species are introduced and compete with elements of the native flora and fauna, habitats can sustain a great deal of permanent damage (Merriam and Feil 2002). Some aggressive invasive shrubs have the ability to penetrate habitats quickly, fill the understory, choke out herbaceous growth and reduce recruitment of native seedlings (Lavergne et al. 1999, Fagan and Peart 2004, Loewenstein and Loewenstein 2005).

Biologists are beginning to test assumptions about invasive species. Some have contended that their presence may just be the result of anthropogenic ecological change and that they may not directly cause loss of biodiversity (Didham et al. 2005). This view is not supported by most research and on the basis of simple observations, cannot be true in most cases. Many factors may allow invaders to dominate habitats including aggressive dispersal, as well as ecological changes and evolutionary changes in the invasive species (Facon et al. 2006). Likewise, certain communities may have characteristics that make them susceptible to invasion. An increase in fragmentation or edge habitat (Cadenasso and Pickett 2001), likelihood of disturbance, release from predation or pathogens (Maron and Vila 2001, Keane and Crawley 2002, Mitchel and Power 2003, Torchin et al. 2003), and in some cases, a single triggering factor (Gurvich et al. 2005) may lead to invasion. As a result of release from natural enemies, it has been found that invasive plants may experience an increase in plant vigor in the form of increased biomass and reproductive output (Stastny et al. 2005).

Invasive characteristics of Chinese privet

One of the major invasive shrubs of the southeastern United States is Chinese privet (*Ligustrum sinense* Lour.) (Drake et al. 2003). Chinese privet is a member of the Oleaceae family that was brought to the southeastern United States from China as an ornamental in 1852 (Cuda and Zeller 2000, Langeland and Burkes 1997) and is now listed among the top ten invasive plants of Alabama (<http://www.se-eppc.org/alabama/>).

Chinese privet (*Ligustrum sinense* Lour.) has been described as a large shade tolerant tree or shrub up to 9 m in height with simple opposite leaves arranged along long pubescent branches (Langeland and Burkes 1997). Leaves are ovate to elliptic and have a round, or in some cases slightly indented, tip and measure between 2 cm to 4 cm long and 1 cm to 3 cm wide (Miller 2004). The native range of Chinese privet is along the coast of China stretching from the south, up to the east in wet areas along floodplains, in forests and ravines, sometimes forming dense thickets (Wu and Raven 1996).

In its native range, it is deciduous, but it is semi-evergreen in many non-native habitats (Wu and Raven 1996, personal observation). The flowers are small, white, pungent, borne terminally or axillary on branches (Wu and Raven 1996) and have a four lobed corolla with stamens extending from the corolla. Flowering in the southeastern U.S. occurs from April to June (Miller 2004). Fruits are small, 6-8 mm, drupes containing one to four seeds, green in the summer ripening to a dark purple in early winter (Miller 2004). In the southeastern U.S., Chinese privet often forms dense thickets along fence rows or edges of forests, allowing access to forests and swamps (Miller 2004). Chinese privet colonizes many habitats and is shade tolerant (Miller 2004, personal observation).

This weedy shrub has invaded many habitat types (Cuda and Zeller 2000). Part of its success results from production of large numbers of fruits (Westoby et al. 1983), the dispersal of seeds by birds (Langeland and Burkes 1997) and dispersal by flowing water (Panetta 2000). While the initial, local invasion of plants may be slow, this is offset by the frequency in which fruits are dispersed from source populations (Christen and Matlack 2006). Williams et al. (2000) investigated whether seed dispersal could be further aided by small mammals, but found that most seeds were destroyed by passage through mammalian digestive systems. One exception was the common brushtail possum (*Trichosurus vulpecula*) in New Zealand, which was found to consume the fruits in great quantity with some seeds surviving passage. A number of studies have been conducted on Chinese privet, but none have examined the effect of this shrub on bay swamp communities.

In recent studies, researchers have documented the invasion of this species into a number of other communities. Allen et al. (2004) showed that baygalls in west central Louisiana have transitioned into habitats in which Chinese privet has become a dominant species in the understory. Burton et al. (2005) and Merriam (2003) observed that Chinese privet is now dominating the shrub layer in urban, agricultural and developing areas throughout the southeast. This domination is interfering with recruitment of native shrubs. Loewenstein and Loewenstein (2005) observed that Chinese privet now dominates areas along urban streams that are ecologically important riparian zones.

Studies of the effects of other invasive shrubs on recruitment and survivorship of native plants include research on Amur honeysuckle (*Lonicera maackii* Rupr., Caprifoliaceae) (Luken and Goessling 1995, Deering and Vankat 1999, Gould and

Gorchov 2000, and Collier et al. 2002) and glossy buckthorn (*Rhamnus frangula* L., Rhamnaceae) (Fagan and Peart 2004). These two plants have similar characteristics to Chinese privet. Amur honeysuckle, which is invasive mainly in the northeastern United States, also has a shrubby, multistemmed growth form. It produces large quantities of fruits with nondormant seeds (Luken and Goessling 1995). Glossy buckthorn, which is invasive in moist forest habitats of the northeastern U. S., is a shrubby tree that prevents recruitment of native canopy trees (Fagan and Peart 2004). These studies have concluded that nonnative shrubs can not only out-compete native shrubs to extinction, but crowd out native herbs as well.

Deering and Vankat (1999) investigated physiological characteristics of Amur honeysuckle and life history traits that explain a delayed exponential reproductive explosion. The authors investigated demography and discovered that after germination the shrubs put most of their effort into height growth. This results in the filling of light gaps. After 3 years, resources are partitioned out to radial growth and in a few cases, reproduction. After 5 years, 50% of the shrubs produce seeds and all are reproductively active after 8 years. This explains why habitat damage is typically seen only after 10 years. A similar time lag may be seen in local invasions of Chinese privet. However, this phenomenon cannot explain why it took nearly a hundred years after introduction for the plant to become a major problem. It has been suggested (G. Folkerts pers.comm.) that increasing carbon dioxide levels in the atmosphere may be a factor in the recent explosion of Chinese privet populations.

Luken and Goessling (1995) used seed germination experiments to test the reproductive success of Amur honeysuckle. Seeds were placed in different light

treatments and although some took up to 80 days, nearly all of the seeds germinated. This is evidence that there is no light dormancy in Amur honeysuckle. This may also be the case with Chinese privet. Thus, once seed production reaches a threshold level, the population explodes.

Amur honeysuckle was tested to see if there was an effect on native annuals (Gould and Gorchoff 2000). The authors used 3 sites to test survivorship of annuals. The control site had no Amur honeysuckle; one experimental site had Amur honeysuckle; and in a third site Amur honeysuckle had been removed. Survivorship of native annuals was greater in the sites with no Amur honeysuckle than those containing Amur honeysuckle. Similar results were found by Collier et al. (2002) in that reduced species richness occurred under crowns of Amur honeysuckle.

Like Chinese privet, Amur honeysuckle has been found to occur in edge habitats. In a study by Bartuszevige et al. (2006) it was found that Amur honeysuckle was more likely to colonize edges in a pattern that showed community structure is not as important to successful invasion as physical features of the habitat. This may also be the case with Chinese privet.

Glossy buckthorn, was used to test the influence of invasive shrubs on recruitment of canopy tree juveniles (Fagen and Peart 2004). In this study the authors examined competition for experimental light gaps between glossy buckthorn and a number of canopy trees and found that the shrubs were more successful at filling these gaps, out competing the native trees. The authors predicted that as trees fall, the formerly forested area would eventually be filled with nothing but glossy buckthorn.

Chinese privet is successful in most light levels (Brown and Pezeshki 2000). This may be an important characteristic of invasive shrubs. As openings in the canopy develop, recruitment of shade intolerant species is limited because those gaps may already be filled with Chinese privet. Von Holle (2005) found that invasive species may have increased survival in harsh wet habitats when overstory trees facilitate invasion. This facilitation was hypothesized to come from elevation of soil by the roots of overstory trees. Chinese privet may also take advantage of similar elevated microsites.

Hierro et al. (2005) discussed the importance of studying an invasive species in its native range. Exotics can be studied in both their native and introduced ranges in order to compare habitat use and natural enemies as factors potentially related to invasion. Such a comparison may shed light on how exotics spread in introduced ranges. Release from herbivory in an introduced area may allow success of exotic species. In some cases, it may take time for local herbivores to adapt to exotics as a novel food source (Carpenter and Cappuccino 2005).

Although Chinese privet population explosion is recent (Ward 2002), its' escape from cultivation occurred by 1932 (Small 1933). This equates to exposure to herbivores and pathogens for 76 years. In a study associating Chinese privet to potential arthropod herbivores, Poe et al. (1978) found that scale insects and mite species were often associated with plants that suffered herbivory. Since that time, only herbivory from bobwhite quail (*Colinus virginianus*) and white tailed deer (*Odocoileus virginianus*) have been studied and found to be significant (McCrae 1980, Stromayer et al. 1998).

To make up for lack of natural enemies, traditional biological control has been suggested as a method to control Chinese privet. Cuda and Zeller (2000) proposed using

Ocyromera ligustri (Coleoptera, Curculionidae), a seed weevil native to the home range of Chinese privet as an agent of biological control. While this seed attacking weevil may reduce reproduction in source populations, Chinese privet also is capable of reproducing clonally. Before attempting to release *O. ligustri* as a biological control agent in areas infested with privet, it should be vigorously screened against native flora. Costs and benefits of release should be evaluated to insure that it would be worth economic investment. *Ocyromera ligustri* may or may not be an effective biological control agent; however, other biological control agents may still exist. Ding et al. (2006) have suggested a collaborative effort between the United States and China to search for biological control agents in their respective countries and lists Chinese privet as a high priority.

Morris et al. (2002) compared Chinese privet with a native sympatric plant, swamp privet (*Forestiera ligustrina* Michx.), which has similar growth form and is in the same family (Oleaceae). In this comparison, the authors hoped to minimize confounding evolutionary traits and elucidate characteristics that make an invasive shrub a better competitor than its native counterpart. The authors found a number of characteristics of Chinese privet that may allow it to invade areas that the native upland swamp privet does not. Most notably, Chinese privet grows taller in light limited areas, produces more fruits, and has leaves that persist year round. These characteristics result in shading of competitors, greater reproductive rate and a longer photosynthetic period than swamp privet. Merriam and Feil (2002) documented the effect of Chinese privet on the herbaceous layer in forests and found that few native species could survive in the presence of Chinese privet.

Another possible mechanism of invasion is allelopathy. Lavergne et al. (1999) found that some members of the genus *Ligustrum* show evidence of allelopathy. Volatile compounds produced by allelopathic plants inhibit growth of competitors. This mechanism must be further investigated in invasive species such as Chinese privet.

Bay swamp characteristics

An important but little-studied habitat type in the southeastern United States is the bay swamp habitat. Bay swamps have been described by few authors and a number of similar habitats have been confused with this distinct habitat type (Wharton 1978, Clewell 1981, Nelson 1986 and Ewel 1990). Lack of a clear definition of the bay swamp habitat coupled with the use of many local habitat names has led to confusion with similar habitat types. This confusion is not new (Harper 1914). Habitat names used for similar habitats include: acid seep forest, bay branch, bay forest, baygall, bayhead, Carolina bay, evergreen hardwood swamp, green-head, streamhead pocosin, sweetbay-swamp tupelo-red bay, and titi swamp (Clewell 1971, Nelson 1986, Schafale and Weakley 1990, and Faulkner 2004). Many of these habitats have subtle physical or vegetative features that characterize each one, at least to the authors who study them.

Baygalls are typically fed by well-defined intermittent streams associated with a variable water table and are dominated by evergreen or deciduous shrubs and trees (Allen et al. 2004). Carolina bays are depression wetlands with variable water levels and vary in their vegetation dominance (Wharton 1978). Pocosins are flat interstream wetlands found in the Carolinas and are typically dominated by pond pine (*Pinus serotina* Michx.) and a number of evergreen shrubs (Harper 1914, Schafale and Weakley 1990). Titi

swamps are physically similar but are dominated by species of titi, usually black titi, *Cyrilla racemiflora* L. (Schafale and Weakley 1990). Bayheads have similar vegetation (Gemborys and Hodgkins 1971), but occur as elevated tree islands (Brandt et al. 2003).

A community that is vegetatively quite similar, has similar physical characteristics and is often found adjacent to bay swamps is the shrub bog habitat. Shrub bogs have similar physical characteristics to bay swamps (Wharton 1978, and Ewel 1990). However, shrub bogs usually contain only a single small stream. Shrub bogs also burn more frequently than do bay swamps. A bay swamp with increased fire frequency may become a shrub bog (Wharton 1978).

A greater understanding of bay swamps must be obtained in order to differentiate this habitat from similar habitat types. Lack of a proper definition of this habitat type has led to confusion among those attempting restoration (Gaines et al. 2000).

Bay swamps, as defined in this study, are characterized by acidic, waterlogged soils that are supplied by seepage slopes and usually surround a branching and anastomosing first order stream (Wharton 1978). Productivity is low with low species richness yet vegetation is dense (Ewel 1990, Clewell 1981). This is a result of low evapotranspiration rates in the dominant trees (Wharton 1978, Ewel 1990). Ground water and surface flow is low yet the yearly hydroperiod is long (Ewel 1990). This is due to poor drainage. Soils are typically nutrient poor (Schafale and Weakley 1990) and highly acidic (Wharton 1978, Clewell 1981, and Faulkner 2004). Though there is a thick organic layer on the surface of the soil from peat deposition (Monk 1965, and Clewell 1971) the nutrients in this layer are not available in acidic conditions (Ewel 1990). Fire frequency is low, occurring every 5-10 years. Bay swamps are a climax community

(Ewel 1990, Clewell 1971). Sweetbay (*Magnolia virginiana* L.) dominates in swamps with infrequent fire. Slash pine occurs in fire scarred sites (Clewell 1971).

Low species richness makes the flora of bay swamps fairly uniform. Sweetbay dominates the canopy layer. Slash pine (*Pinus elliottii* Engelm.), loblolly pine (*Pinus taeda* L.), swamp red bay (*Persea palustris* (Raf.)) or loblolly bay (*Gordonia lasianthus* Ellis) may be co-dominants (Clewell 1981). Swamp tupelo (*Nyssa biflora* Walt.) and sweet gum (*Liquidambar styraciflua* L.) are also important canopy species (Clewell 1971, Ewel 1990, Faulkner 2004). With the exception of a few pines, the overstory is dominated entirely by evergreen hardwoods. Understory plants include cat briars (*Smilax* spp.), muscadine grape (*Vitis rotundifolia* Michx.), poison ivy (*Toxicodendron radicans* Kuntze), yellow jessamine (*Gelsemium sempervirens* Aiton f.), wax myrtle (*Myrica cerifera* L.), fetterbush (*Lyonia lucidia* Lam.), Virginia willow (*Itea virginica* L.), coastal doghobble (*Leucothoe axillaris* (Lam.) D. Don), netted chain fern (*Lorinseria areolata* (L.) C. Presl), cinnamon fern (*Osmunda cinnamomea* L.), and red maple (*Acer rubrum* L.) (Wharton 1978, Ewel 1990, Faulkner 2004, personal observation). The fauna of bay swamps is largely unstudied (Wharton 1978).

The objective of this study is to compare characteristics of *Ligustrum sinense* populations in a bay swamp with those at a nearby upland site. The results of this comparison will aid in understanding 1) the importance and structure of bay swamps, 2) the effects of Chinese privet on this habitat, and 3) the invasive characteristics of Chinese privet.

METHODS

Study site

The primary study site is located north of the 196 mile marker on Highway 80 in Lee County, Alabama, hereafter referred to as the Watula Creek bay swamp (Figure 1). This site is an approximately 2.5 km stretch of Watula Creek that sinks into a depression fed by seeps from surrounding upland sites. A branching and anastomosing stream flows through the middle and meanders throughout the swamp. Within the swamp, this stream is made up of a main stem with two or three branches on each side.

The lower portion of the swamp is bordered on the west by an even-aged pine stand that develops into a xeric hardwood forest as you travel north. West of the even-aged pine stand is Lee Road 38 at the crest of a hill. The western roadside was chosen as the upland site for its proximity to the Watula Creek bay swamp, ease of access and level of invasion. This roadside is an east facing embankment that borders a xeric hardwood forest to the west.

The northern tip of the swamp is bordered by a shrub bog and the eastern side is bordered by mostly xeric hardwood forest with an occasional even-aged pine stand. The southern portion of the swamp is bordered by Highway 80. The embankment created by Highway 80 has changed the hydrology of the swamp by funneling all the water into a single channel that flows under a bridge on Highway 80. During construction of this bridge, a portion of the stream was channelized, which most likely altered the down

stream habitats. It appears that the habitat south of highway 80 was originally bay swamp as it has a similar vegetative community, however the altered hydrology and clearing by landowners has interrupted the bay swamps natural ecological processes.

Additional observations were made in three sites with varying degrees of Chinese privet invasion located in southern Baldwin County Alabama. These sites are smaller than the Watula Creek site (around 10 hectares), and were originally dominated by Sweetbay, though one site is now dominated by Chinese Privet.

Vegetation survey

Several bay swamps were visited between September 2005 and January 2007 including 3 sites in Baldwin County and the Watula Creek bay swamp. The 3 bay swamps in Baldwin County had differing levels of Chinese privet invasion ranging from pristine (no Chinese privet) to highly invaded (a full Chinese privet infestation). During this time, careful observations were made and recorded including level of Chinese privet invasion and general bay swamp characteristics (hydrology and survey of vegetation). These data along with historical infestation levels (G. Folkerts pers.comm.) were examined to determine mechanisms that facilitate invasion.

Between June and August of 2007, the portion of Watula Creek bay swamp containing *L. sinense* was sampled in order to determine characteristics of the plant and the habitat that relate to successful invasion and occupancy of this wetland type. Study quadrats and belt transects were randomly selected in areas where Chinese privet was present. The perimeter of the swamp was surveyed using a Magellan GPS 315.

Quadrat sampling was used in Watula Creek bay swamp and some adjacent habitats in order to determine Chinese privet density. In some adjacent habitats and in the chosen upland site where populations of Chinese privet are linear, i.e., roadsides, field edges, and borders between anthropogenic sites, sampling with quadrats and belt transects was not feasible. In these areas density measures were obtained by use of 1 m by 25 m narrow linear belt transects. Only the adjacent area across Highway 80, south of Watula Creek bay swamp, and the upland site were invaded heavily by Chinese privet.

Quadrat sampling inside Watula bay swamp was also used to obtain plant diversity measures, importance values, and to determine if an association exists between sweetbay and Chinese privet. In order to relate environmental variables such as light and soil moisture to vegetation patterns, five belt transects oriented perpendicular to the central stem of the stream were surveyed.

Quadrats of 0.25 m², 0.5 m², 1 m², 2 m², 4m², 8 m², 16 m², and 32 m² were sampled and a species-area curve was generated in order to determine the ideal quadrat size for sampling Watula Creek bay swamp. It was determined that using a quadrat larger than 4 m² yielded few additional species. A rectangle shape was chosen with dimensions of 1.33 m X 3.0 m. A representative hectare was measured out in the southern portion of the swamp. A random number generator was programmed to generate 25 four digit numbers for quadrat placement within this hectare, with the first two digits being the X coordinates and the last two being the Y coordinates. A running mean graph (Figure 2) was used to determine that 25 quadrats were sufficient to sample Watula Creek bay swamp.

Light intensity was measured in the center of each 4 m² quadrat using an Extech model 401025 light meter. Measurements were made under overcast conditions in order to reduce the confounding effects of sunflecks that occur under direct sunlight (Monsi and Saeki 2005).

Plant species were placed into groups of canopy species, shrubs, ground species and lianas (vines). Abundance, cover, and frequency were recorded for all plant species found in each quadrat. Abundance was defined as number of ramets, rather than individuals, emerging from the substrate in order to reduce confusion caused by species that reproduce clonally. Cover was visually estimated as area filled by the crown in canopy, shrub, and liana species and percentage of ground covered in ground species.

Belt transects were 50 m in length and 10 m wide. Transects ran from east to west and were located 25 m, 50 m, 100 m, 150 m and 200 m from the southern border of the swamp. Transects were divided into five 10 m by 10 m transect plots beginning at the stream and measurements of light intensity and soil moisture were taken in each transect plot. It was assumed that soil moisture increased with lower elevation (i.e., in areas closer to the stream). Light measures were taken at three positions in each transect plot and averaged to get a mean light level within each transect plot. To confirm the assumed soil moisture gradient, soil moisture was measured using an E-Sun ETP-300C soil moisture meter at three positions in each transect plot and averaged to get a mean moisture level in each transect plot.

Abundance, cover and frequency of major canopy species, shrub species, lianas and ground species were measured. As with the quadrats, ramets were treated as

individuals when measuring abundance. Cover was measured by estimation of area taken up by each individual in a transect plot. Frequency was simply the presence or absence of a species in each transect plot.

Phenotypic plasticity

Observations were made to compare leaf characteristics and reproductive characteristics between plants from upland and bay swamp habitats. Leaf characteristics measured included color, rigidity, shape and size to test for differences of phenotypic response to the variation of light between the two habitats. Rigidity and color were scored on a scale from one to five, soft to stiff and light green to dark respectively. Length and width were measured on 254 leaves from 5 plants in Watula Creek bay swamp and 254 leaves in 5 plants from the upland site. Measurements were taken using a 120 mm Mitutoyo digital caliper. These measurements and the ratio of width/length as a measure of leaf shape were compared between sites.

Initially, no fruits were found on any large privet plants in Watula Creek bay swamp. This suggested that Chinese privet could not reproduce sexually in the bay swamp. To test this idea, two sexually reproducing plants were taken from the upland site and planted in Watula Creek bay swamp to see if flowers would blossom the following season. The transplantation took place in November 2006. All of the fruits were removed from each plant prior to transplanting. Location of flowers and fruits (axillary or terminal) were recorded on plants found in the upland site and bay swamp.

Biomass allocation

Ligustrum sinense plants from Watula Creek bay swamp and upland site were selected for a study of biomass allocation. Allocation compartments measured included total biomass, total above ground biomass, total underground biomass, leaf biomass, sexually reproductive biomass at the time fruits are mature, and asexually reproductive biomass as reflected by underground lateral root biomass in plants that had produced several ramets. Five plants each from the upland and Watula Creek bay swamp sites were collected and compared.

All plants were carefully removed with rhizomes intact. Leaves, fruits, stems, underground roots and rhizomes were separated and placed in a Blue M Stabil-Therm gravity oven (Blue Island, Illinois) set at 70° C for three days. Biomass was then measured with an Acculab model 333 digital scale. Height and number of ramets were also recorded. In order to compare different sized plants within a small sample size, relative biomass compartment ratios were created for all compartments. Relative biomass was the ratio of the compartment to the overall biomass. A reproduction ratio was calculated as total fruit biomass over total lateral root Biomass. Allocation compartment masses were graphed in order to compare allocation within plants.

Allelopathy potential

Using the methods described in Lavergne et al. (1999), allelopathic potential was tested. Freshly harvested leaves and roots of Chinese privet were crushed with a mortar and pestle and mixed with deionized water at 1%, 2%, 3%, 4%, and 5% concentrations.

Concentration was defined as total mass of leaves to total mass of water. At each concentration, four treatments were used: leaves, roots, 1:1 leaf/root mix, and a control (water only). Each treatment had two replicates.

Petri dishes were filled half way with sand potting medium and the solutions were added until the sand was saturated. Fifty tomato (*Lycopersicon esculentum*) seeds were placed on the sand in each Petri dish. Seeds were left in a south facing window and were allowed to germinate for 13 days. Radicle length was measured from all germinated seeds using a 120 mm Mitutoyo digital caliper. A ratio of mean control values to mean treatment values was calculated in order to determine allelopathy potential. A ratio above 1 indicates allelopathy potential, with a greater value indicating a greater influence of allelopathy.

Data analysis and statistics

Ligustrum sinense densities obtained from quadrat data in Watula Creek bay swamp study site, the upland site and the roadside south of the swamp were compared using two-way ANOVA to determine differences of invasion success at each site. All data were tested for normality prior to analysis.

Diversity was measured inside Watula Creek bay swamp, using the Shannon-Wiener diversity index (H') using the formula $H' = -\sum (p_i (\ln p_i))$ where p_i = proportion of species i to all species. To determine if diversity was lower in the presence of Chinese privet, Simpson's index of diversity (1-D) was used to compare quadrats with and without Chinese privet using the formula $1-D = 1 - (\sum n(n-1))/N(N-1)$ where n = total

number of individuals of a species and N = total number of individuals of all species.

Simpson's index of diversity was chosen for this task because it is statistically consistent and has less sensitivity to sample size (Gotelli and Ellison 2004).

Importance value (IV) was calculated as the sum of relative density, relative cover and relative frequency (Curtis and McIntosh 1951) of vascular plants found in Watula Creek bay swamp. A chi-square test (X^2) was used to determine if sweetbay and Chinese privet had an abnormally clumped distribution.

Measures of light and soil moisture were related to *Ligustrum* density obtained from belt transect data, using regression analysis, in order to compare invasion success at different environmental gradients. The mean cover and density of all plant species with importance values above 35 were plotted along the length of the belt transects in order to observe species relationships.

Color, rigidity, length, width and ratio of width over length of leaves from bay swamps and upland sites were compared using two-way ANOVA.

All compartments and ratios in the biomass allocation study were then compared using MANOVA to find differences between bay swamp and upland site plants.

All analyses of variance, normality tests and regression analyses were calculated using SYSTAT 12.

RESULTS

Vegetation survey

Levels of Chinese privet invasion at the three Baldwin County sites were highly variable. The northernmost site has maintained a pristine, natural community, while the two southern sites have greater level of invasion. The southern sites were located in the path of Hurricane Ivan in 2004. Prior to that time, the two southern sites were in an early stage of invasion.

Chinese privet density was found to be highly variable in all three of the heavily sampled sites. The greatest density occurred at the upland site with a mean density of 2.6 ramets per meter (SD = 2.4). Mean densities of ramets in Watula Creek bay swamp and adjacent area were 2.4 per meter (SD = 3.5) and 0.8 (SD = 1.8) per meter respectively. Other adjacent areas such as even aged pine stands and xeric hardwood forests contained few and in some cases no privet plants throughout. The upland site and the adjacent area were not found to be significantly different from the bay swamp.

Shannon-Wiener diversity (H') measured during July in the Watula Creek bay swamp was 2.16 ($n = 25$). The quadrats sampled without Chinese privet were found to have a slightly higher (non-significant) Simpson's index of diversity than quadrats containing Chinese privet (Table 1).

Importance values indicated that the dominant canopy species in the Watula Creek bay swamp was sweetbay (Table 2). One ground species and two shrub

species had the greatest importance values, netted chain fern (IV = 49.84), Chinese privet (IV = 41.75) and coastal doghobble (IV = 31.79). Other important ground species were *Carex sp.* (IV = 27.82) and *Sphagnum sp.* (IV = 78.61) (when non-vascular plants were included in the calculations). While *Smilax sp.* and muscadine grape appeared to be common, *Rubus sp.* had the greatest importance values for the lianas or vines during the summer months (Table 2).

Chinese privet was not found to have a positively associated distribution pattern with sweetbay as originally hypothesized. The chi-square analysis showed no significantly different association than expected from random patterns ($\chi^2 = 0.01$, $df = 1$, $P > 0.05$). Both plants were found together in 20% of the quadrats, 44% contained only Chinese privet, 12% contained only sweetbay, and 24% contained neither group.

Regression analyses showed no significant association between Chinese privet density or percent cover and the environmental variables measured. However distance from the main stem of the stream (an assumed measure of soil moisture) was nearly significant for density and percent cover (Figure 3) ($P = 0.081$ and $P = 0.052$ respectively). No relationships were found for light between density and percent cover (Figure 4) ($P = 0.206$ and $P = 0.261$ respectively). The greatest percent cover of Chinese privet was found between 30 m and 40 m from the stream (Figure 5). Soil moisture measurements confirmed the assumption that there was a reduced soil moisture gradient as distance from the main stem of the stream increased. On a moisture scale of 1 to 10, the moisture level increased incrementally from 1 to 8 as I approached the main stem of the stream along all belt transects.

When comparing total cover and total density of the four dominant species to their location in the bay swamp, some general trends appear. Percent cover of sweetbay drops steadily with distance from the main stem of the stream (Figure 5). Both netted-chain fern and Chinese privet seem to have a negative association with coastal doghobble. This pattern is illustrated in the percent cover graph (Figure 5).

Phenotypic plasticity

Leaf measures were significantly different among sites for all measured variables (Figure 6). Leaves from the upland site were found to be longer, narrower and less round (width/length) than those from inside Watula Creek bay swamp. Rigidity and color were also significantly different between sites (Figure 7). Bay swamp leaves were lighter and more flexible. One transplanted plant that was placed in a low lying area was not properly anchored and died shortly after transplanting. The other upland plant which had terminally born fruits, thrived, flowered and produced fruits the following season. Subsequent fruits were axillary, rather than terminal.

Biomass allocation

Biomass allocation did not vary among sites for any of the compartments or ratios of relative biomass. In general, mean above ground biomass was found to be significantly greater than mean below ground biomass (Figure 8). Biomass compartment ratios yielded a clearer picture of how Chinese privet allocates resources (Figure 9). The low fruit to rhizome ratio indicates the importance of clonal reproduction.

Allelopathy potential

Radicle measurements varied across all treatments. As extract concentrations increased, allelopathic response (control/treatment) increased exponentially. This effect was strongest in the leaf treatment (Figure 10). The root treatment (Figure 11) did not show as strong a potential for allelopathic effect. The 1:1 leaf/root mix treatment showed a significant result, but when outlier data from the 5% is removed, the result is not significant (Figure 12).

DISCUSSION

Along with fragmentation and development, plant invasion is a major factor degrading bay swamps (Florida Fish and Wildlife Conservation Commission 2005). Habitat fragmentation and development also serve to facilitate plant invasion (Burton 2005, Loewenstein and Loewenstein 2005). An understanding of invasive plant characteristics and resistance to those characteristics must take place in order to properly manage bay swamps. In the bay swamps that I have visited, the most common invasive plant species was Chinese privet.

Based on a comparison of the historical data of the Baldwin County bay swamps (G. Folkerts pers.comm.), Chinese privet is still in the initial stages of invasion at Watula Creek bay swamp. The density of ramets is still lower than that at the neighboring upland site which is not as yet a uniform Chinese privet stand. While the density is low, clearly Chinese privet has established a foothold in Watula Creek bay swamp. The only thing that appears to be keeping the population in check is the intact canopy (Figure 5).

The Watula Creek bay swamp is still fairly diverse (Table 1). No significant differences were found when I compared Simpson's index of diversity between quadrats that contained and did not contain Chinese privet. This suggests that the relatively low level of invasion seems not to have drastically affected diversity as yet. The quadrats containing Chinese privet had lower diversity despite having greater species richness and

nearly twice as many samples. This may illustrate a mechanism by which Chinese privet invades. It may first expand through asexual reproduction via underground runners which skews evenness, and then slowly eliminates other species thereby reducing richness. It is fairly well established that invasive species have a negative effect on diversity (Merriam and Fiel 2002, Miller and Gorchoy 2004, Brown et al. 2006). This effect is likely to appear in the Watula Creek bay swamp as invasion by Chinese privet increases.

Chinese privet was found to have the second greatest importance value in all community categories, exceeded only by netted-chain fern (Table 2). However, the canopy is still firmly dominated by sweetbay. Importance values were calculated during the growing season; but Chinese privet is evergreen in bay swamps and fills a niche more similar to coastal doghobble, which it has surpassed in Watula Creek bay swamp, even at this early stage of invasion. This niche distinction is probably why netted-chain fern, a ground species, has managed to maintain dominance in this swamp as it does not appear to be directly competing with Chinese privet. If sampling had occurred during winter months, Chinese privet would probably have appeared to be the clearly dominant species in the swamp. While asexual reproduction is quite common in Watula Creek bay swamp, the as yet small size of ramets resulted in a measure of relative cover that is less than substantial. The intact canopy, along with the high diversity of the swamp as measured during the summer, is most likely protecting the swamp from a greater level of invasion at this time. This is supported by Tillman's (1999) findings that biodiversity may decrease susceptibility of invasion of ecosystems.

In the case of Watula Creek bay swamp, relative cover seems to be the most important indicator of true dominance rather than relative abundance, relative density, or importance value. This is most apparent when comparing *Sphagnum* importance values to sweetbay. While sweetbay has clear aspect dominance in Watula Creek bay swamp, *Sphagnum* has a greater importance value. This greater importance value is based on small patches of moss in high abundance and density found in only four of the 25 quadrats, negatively skewing the importance values of the true dominants of the bay swamp. Similarly, Chinese privet relative density and abundance were more than double those of sweetbay, but sweetbay relative cover was nearly 3 times as much as Chinese privet. Relative cover as a measure may be useful in the future as a method of rapidly assessing the Chinese privet invasion of a bay swamp.

Observations made on initial visits to the Watula Creek bay swamp led me to hypothesize that Chinese privet had a non-random association with sweetbay. It also appeared that microtopography may have played a role in establishment of Chinese privet. Most small plants were clumped along the roots of sweetbay, where there was a slightly greater elevation than the surrounding area. Since the floor of the bay swamp is frequently flooded, it is hypothesized that small plants would have a greater survivorship at these elevated sites. The small plants would also benefit from hydraulic lift caused by sweetbay during drier periods, including the growing season, when water may be limiting. While hydraulic lift has been evaluated in relatively few plant species, it is likely to occur whenever there is a vertical moisture gradient with a lower water potential (Ψ_s) at the surface (Caldwell et al. 1998). Another possible explanation for this pattern is

that seeds dispersed by birds would most likely accumulate at the base of trees, as resting birds would evacuate gut contents prior to flight. However, the chi-squared distribution ($\chi^2 = 0.01$, $df = 1$, $P > 0.05$) showed that no plant distribution pattern existed apart from what was expected by chance. The reason that the chi-squared distribution did not confirm the initial observation may have come from the large quadrat size. Because a 4 m² quadrat is necessary to adequately locate large trees, it has an increased likelihood of having at least one Chinese privet plant in each quadrat. It may be that microtopography plays a role in the establishment of Chinese privet, but a smaller quadrat size is necessary to measure microtopography.

Light and soil moisture (Figure 3 and 4) do not seem to be related to Chinese privet density or relative cover in the Watula Creek bay swamp. While the mean density and cover were found to be greatest between 20 and 40 meters from the main stream stem, the variation between samples was high ($SD = 8.31$ and 16.12 respectively) and no linear relationship could be found. It may be that the variation in light intensity was not enough to show a measureable effect. The mean light level measured was 1,584 lux, with a maximum of 5,000 lux. However, plants exposed to direct light, as in the case of the upland site, were found to receive light levels between 25,000 to 35,000 lux in overcast conditions. Light levels in this range will most likely have a strong effect on Chinese privet growth.

Belt transect measures were valuable in illustrating possible connections between the most dominant plant species found in Watula Creek bay swamp. Coastal doghobble appears to have a negative association with Chinese privet as measured by both mean

cover and density (Figure 5). This confirms the assumption that Chinese privet competes with coastal doghobble. Both are shrub species and have an extended growth period in the same habitat. Prior to invasion by privet, coastal doghobble was likely to have been common throughout the swamp. Without historical data, I can only assume that it has been forced out of areas currently occupied by Chinese privet.

Other patterns observed include a decline in mean cover of sweetbay as it approaches the edge of the swamp and a relative negative interaction between coastal doghobble and netted chain fern. Coastal doghobble tends to occur near stream channels while netted chain fern is often found up to 20 meters from the main stem of the stream. This may be a naturally occurring distribution, but could also be an effect of Chinese privet competition with coastal doghobble.

Phenotypic plasticity of Chinese privet was indicated by a striking difference in leaf characteristics between bay swamp and upland sites. Chinese privet leaves from the upland site were darker and more rigid than their bay swamp counterparts (Figure 7). Leaf thickness, shape, color, and rigidity often vary in response to increased light (Kutas 1979, Navas and Garnier 2002). Leaf length, width and shape varied as well. Bay swamp leaves were not as long or narrow (defined as width/length) as leaves from the upland site (Figure 6). The narrow shape, and increased thickness of upland leaves may be a response to increased light and lower water availability. In the bay swamp where plants are smaller, have more water and lower evapotranspiration rates due to lower light levels, leaves that are smaller, thinner and more round, may be more adaptive. However, in upland sites, thicker, narrower leaves may be adaptive in that they are less likely to

suffer desiccation. Alternatively, it has been found that stomata density is lower in Chinese privet plants found in shaded habitats than those in brighter habitats (Zhang et al. 2002). A greater density of stomata, increased leaf area and greater quantity of leaves would imply a greater evapotranspiration rate in the upland site and possibly a greater rate of photosynthesis.

As a measure of whole-plant plasticity, biomass allocation yielded no differences between bay swamp plants and upland site plants. However, the data are still quite useful in understanding allocation of resources in this invasive plant. Clearly asexual reproduction via clonal runners is highly important in Chinese privet. A single seed that produces a single plant can eventually lead to at least 6 ramets. While asexual reproduction alone can not lead to a rapid dispersal and expansion rate, it does help each genet to shade out neighboring species. It can be hypothesized that Chinese privet may not have been so successful at invading bay swamps if it did not reproduce asexually. Chinese privet allocates a greater level of biomass in above ground components as compared to below ground components (Figures 8 and 9). This further supports the hypothesis that Chinese privet potentially affects biodiversity by shading out other plants.

Other phenotypic traits noted as differences between upland and bay swamp plants include location of fruits, and general structure of the plant. Flowers and fruits on Chinese privet in Watula Creek bay swamp were often axillary, while flowers and fruits on upland plants were usually terminal. It is interesting that the surviving upland plant transplanted into Watula Creek bay swamp produced axillary flowers and fruits. Prior to transplanting, most of the fruits on this plant were located terminally. Plants found on

upland sites were also highly branched, while bay swamp plants had a tree-like growth structure. It is possible that these characteristics are related to light availability. In the case of flowering, light may stimulate the location on which flowers are born. In bay swamps with intact canopy cover, light may come only through small canopy openings which may explain why plants vary in flower position. The upland site was along a roadside, where the greatest light intensity reaches the ends of the branches, possibly explaining why flowers are terminal. This information comes from cursory observations and only a single transplanted specimen and should therefore be tested with a larger sample.

Laboratory tests for allelopathy potential showed positive results. Chinese privet leaves and roots were shown to inhibit germination and growth in tomato seeds and seedlings (Figure 13). This does not necessarily indicate that true allelopathy exists. Major germination inhibition did not take place except in treatments of 5% or more solid mass. To confirm allelopathy, the allelochemical must be identified and shown to be released by the aggressor. Similar concentrations must be found in the soil around the plant and inhibition of growth and germination must be shown in plants occurring naturally in the community (Willis 1985). Allelopathy is difficult to illustrate because of the many confounding effects of competition (Blum et al. 1999). Furthermore, Chinese privet leaves breakdown very rapidly and their presence accelerates breakdown of other leaves as well (M. Burton pers.comm.). If potential allelochemicals are quickly degraded in the soil or not in high enough concentrations, it is unlikely that allelopathy occurs.

In this study, I have found that Watula Creek bay swamp is still in the initial stages of invasion compared to the upland site and other bay swamps in Alabama. Compared to other sites it seems that community structure (diversity and intact canopy) are slowing the invasion of Chinese privet. Other sites that have had similar historic levels of invasion in Baldwin County, Alabama, have now become nearly uniformly covered by Chinese privet. Once Chinese privet dominates the shrub layer, subsequent disturbance in the form of windthrow events may reduce the canopy, allowing Chinese privet to fill in and prevent succession by the naturally dominant species of the canopy. If multiple windthrow events occur in rapid succession, then a uniform Chinese privet stand may result. It has been found that loss of biodiversity may result in a lowered resistance to invasion by non-native plants (Kennedy et al. 2002).

Further evidence of this invasion potential is the increase in total percent cover of Chinese privet in areas where Sweetbay (overstory) cover is reduced. This is contrary to the assumption that Chinese privet cover would be greatest next to the main stream. Chinese privet cover appeared to follow a similar pattern to netted-chain fern. Both Chinese privet and netted-chain fern may be in competition with coastal doghobble. This pattern may be similar in a bay swamp without Chinese privet, but it may be that Chinese privet may facilitate the dominance of netted-chain fern by reducing coastal doghobble abundance.

In addition, phenotypic plasticity, rapid dispersal of copious fruits, asexual reproduction, rapid growth rate, resilience to disturbance and allelopathic potential enhance the invasion success of Chinese privet and make control by traditional means

nearly impossible. Asexual reproduction is so rampant that a branch weighed down to the ground by a vine may grow roots and form a new ramet. Mechanical removal of privet in the Watula Creek bay swamp is prohibitive given the current density, and difficulty of accessing the entire swamp. Although, Chinese privet is treatable with common herbicides (glyphosate, imazapyr, metsulfuron, triclopyr, or hexazinone) through foliar spray, basal sprays, or treated stumps (Miller 1998, Miller 2004) the cost to treat the entire swamp would be prohibitive and it would be difficult to control without eradication of non-target plants.

Further study and habitat management should include: 1) a search for alternative methods of eradication, including traditional biological control, 2) stringent testing for allelopathy, and 3) attempts to prevent the decline and loss of bay swamps.

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Table 1: Diversity of plants and sample sizes of quadrats in the Watula Creek bay swamp, Lee county, Alabama. Quadrat size was 4 m². Diversity measures are totals of all quadrat data.

	Diversity	Species Richness	Sample size
Bay swamp Shannon-Wiener (H')	2.16	S = 20	n = 25
Bay swamp Simpson's index of diversity (1 - D)	0.85	S = 20	n = 25
Simpson's index of diversity (1 - D) (no privet quadrats)	0.84	S = 15	n = 9
Simpson's index of diversity (1 - D) (privet quadrats)	0.82	S = 18	n = 16

Table 2: Importance values (relative cover + density + frequency) and density (ramets/m²) of vascular plants calculated from quadrat data in the Watula Creek bay swamp, Lee County, Alabama. IV is total of all quadrat measures.

Taxon	IV	ramets/m²
canopy		
<i>Magnolia Virginiana</i>	34.29	0.16
<i>Liquidamber styraciflua</i>	16.35	0.35
<i>Acer rubrum</i>	9.55	0.24
<i>Carya sp.</i>	3.73	0.04
<i>Fagus grandifolia</i>	2.22	0.01
<i>Quercus sp.</i>	1.02	0.02
shrub		
<i>Ligustrum sinense</i>	41.75	2.43
<i>Leucothoe axillaris</i>	37.19	2.03
<i>Itea virginica</i>	3.26	0.08
<i>Ilex sp.</i>	2.44	0.2
<i>Myrica cerifera</i>	1.38	0.01
ground species		
<i>Lorinsaria areolata</i>	49.84	3.07
<i>Carex sp.</i>	27.82	1.18
<i>Toxicodendron radicans</i>	9.62	0.71
<i>Boehmeria cylindrica</i>	6.45	0.15
<i>Osmunda regalis</i>	2.61	0.05
<i>Woodwardia virginica</i>	1.39	0.06
Lianas		
<i>Rubus sp.</i>	32.99	1.53
<i>Smilax sp.</i>	10.73	0.19
<i>Vitis rotundifolia</i>	6.79	0.13
<i>Parthenocissus quinquefolia</i>	1.64	0.05

Figure 1: Topographic map of the Watula Creek bay swamp, adjacent area and upland site, Lee County, Alabama.

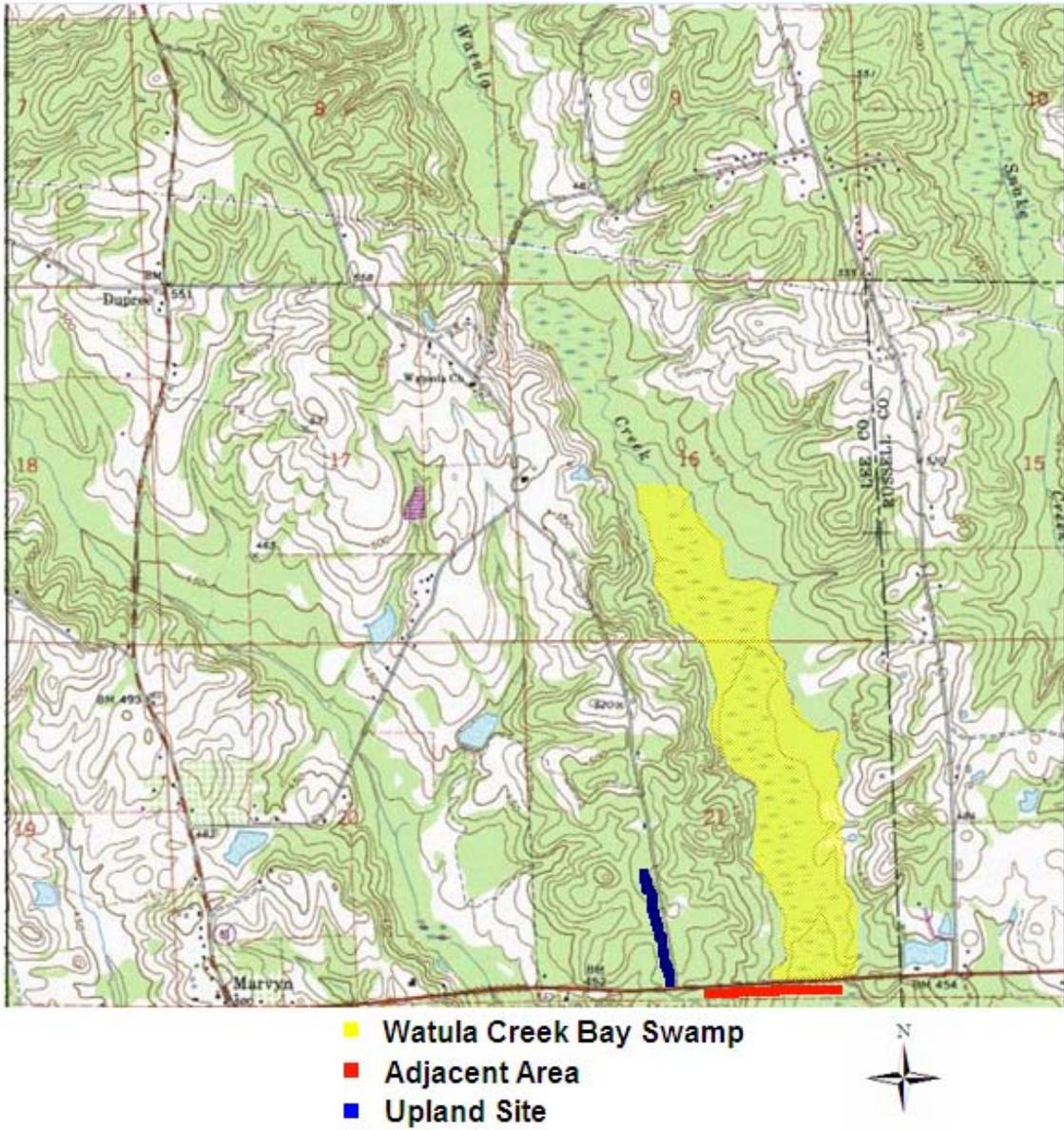


Figure 2: Running mean of Chinese privet abundance showing that 25 quadrats of 4 m² are an adequate sample size in the Watula Creek Bay swamp, Lee County, Alabama.

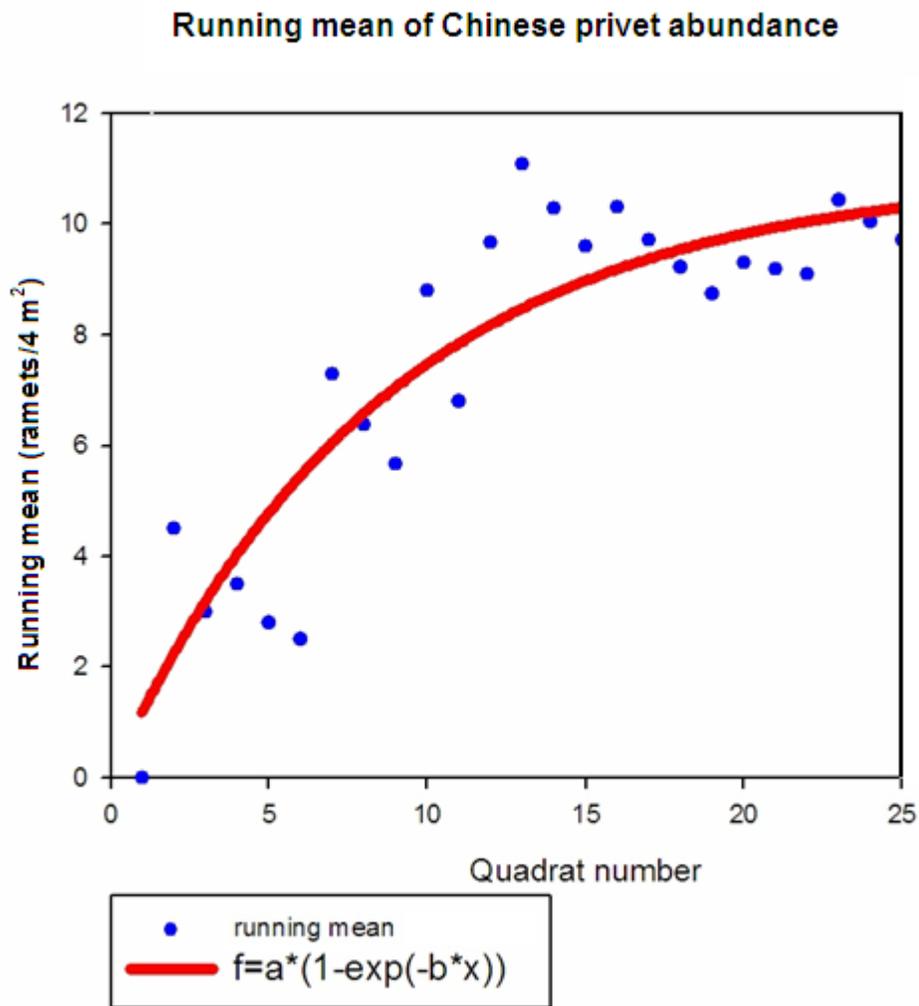


Figure 3: Linear regression of Chinese privet cover and distance from main stem of stream (soil moisture gradient from wet to dry). Upper and lower confidence limits are shown. No significant relationship was found. $R^2 = 0.052$.

Chinese privet cover as related to moisture gradient

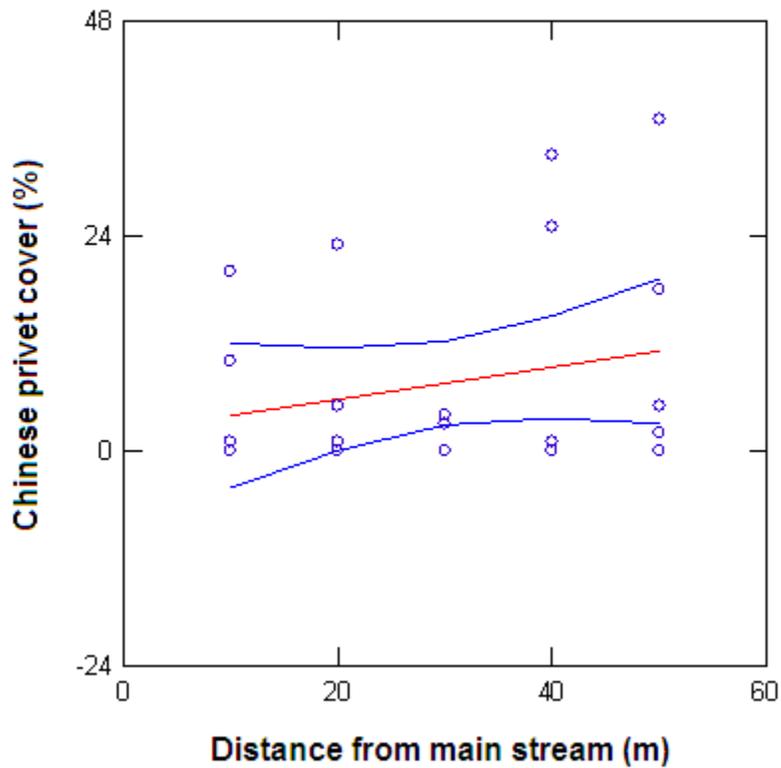


Figure 4: Linear regression of Chinese privet cover and light (lux) measured along belt transects. Upper and lower confidence limits are shown. No significant relationship was found $R^2 = 0.206$.

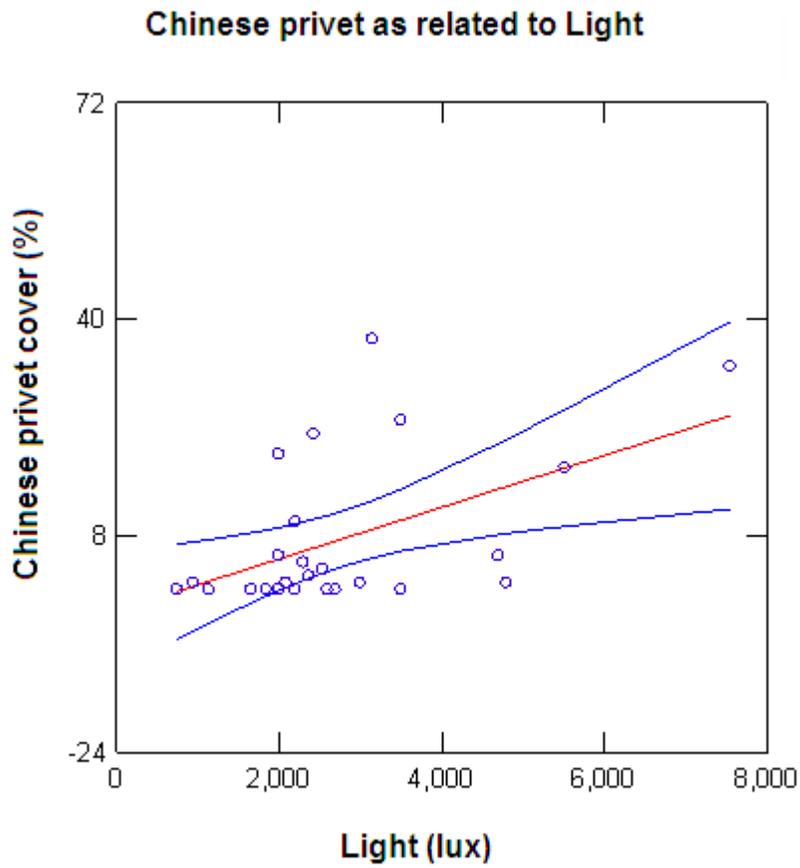


Figure 5: Relationship of plant cover (%) and assumed soil moisture gradient (distance from stream) in the four most abundant species in Watula Creek bay swamp, Lee county, Alabama. Data from all transects were compiled.

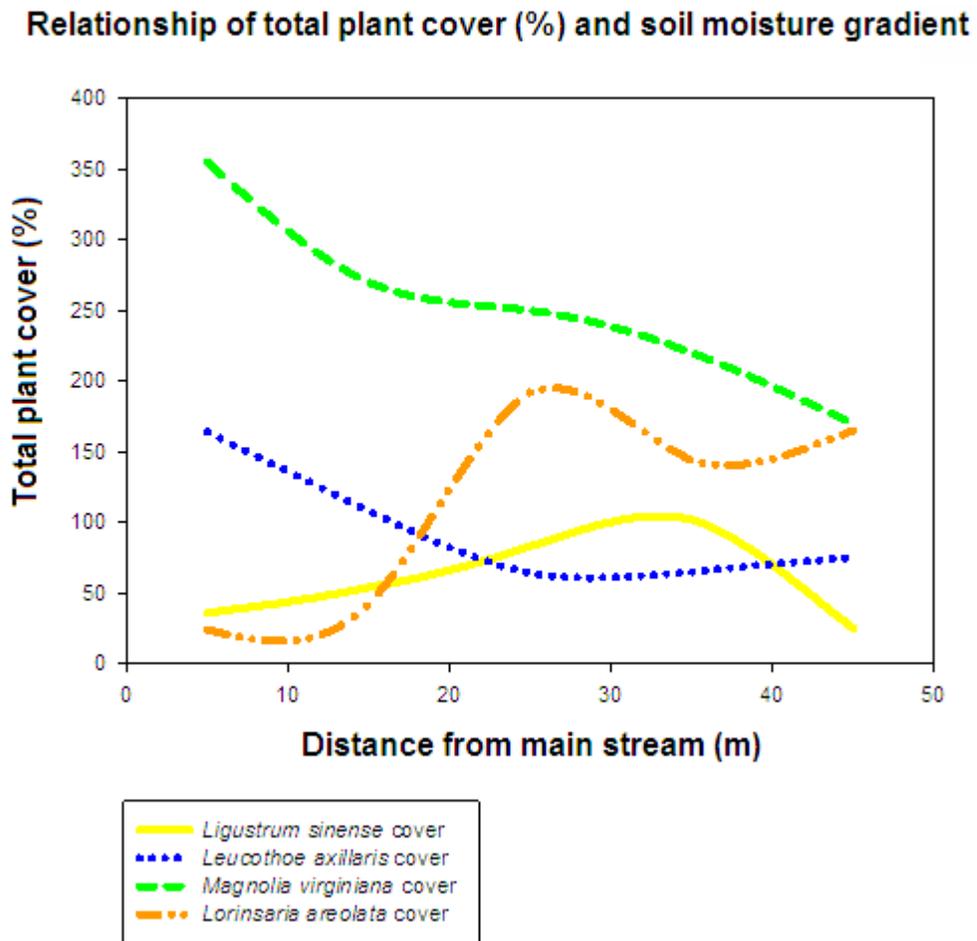


Figure 6: Mean Chinese privet leaf measures from Watula Creek bay swamp and the upland site, Lee County, Alabama. Sample size was 5 plants from the bay swamp and 5 plants from the upland site.

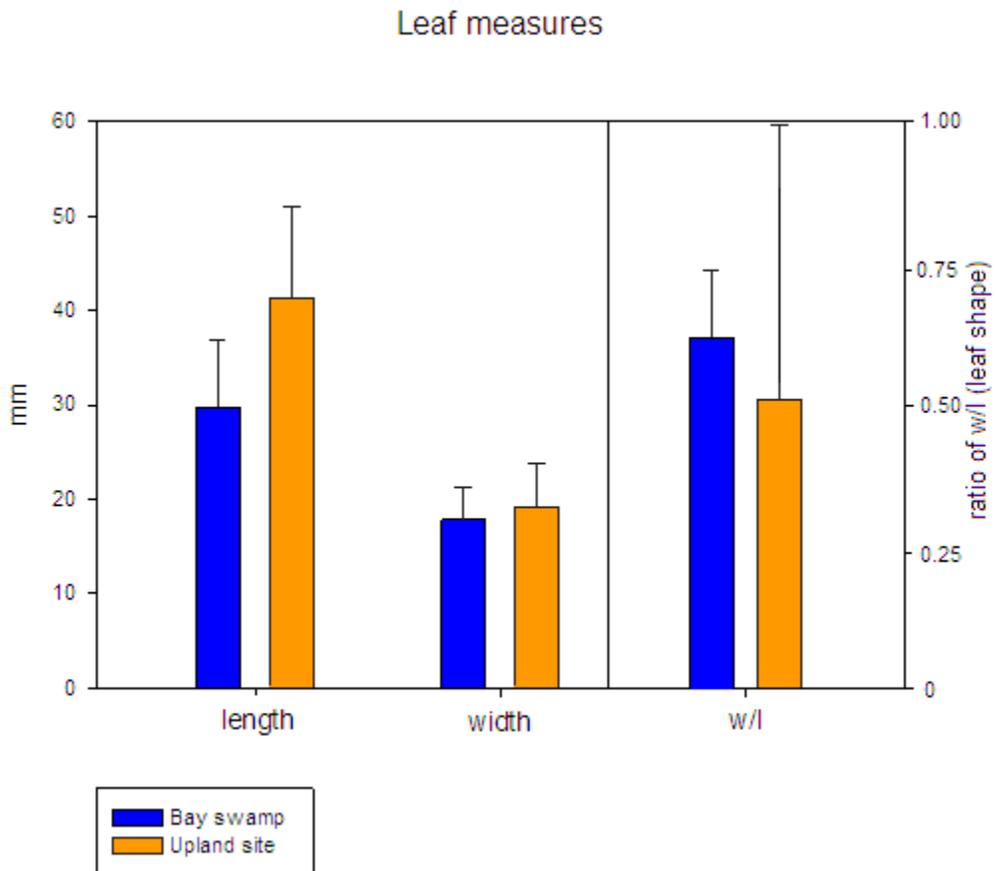


Figure 7: Representative leaves from each site. The leaves from the upland site were larger, narrower, darker and more rigid than the leaves from Watula Creek bay swamp, Lee County, Alabama.

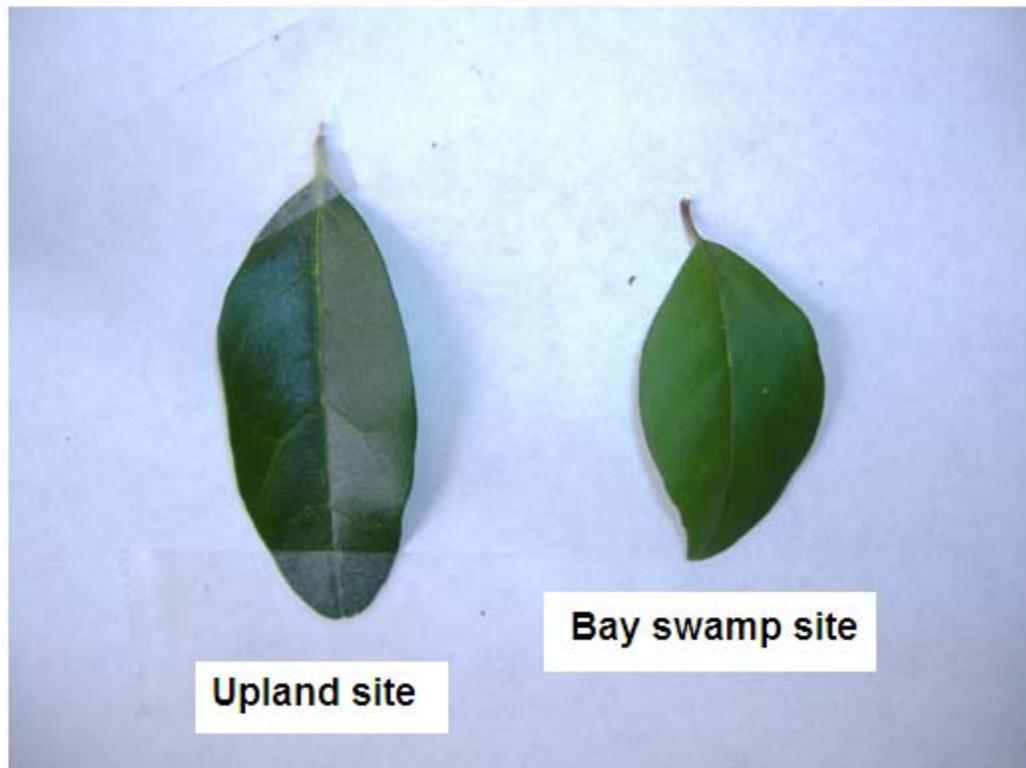


Figure 8: Biomass allocation compartments: Mean dry mass of Chinese privet from all compartments in both upland and bay swamp sites. Measures between sites were not significantly different ($P < 0.05$).

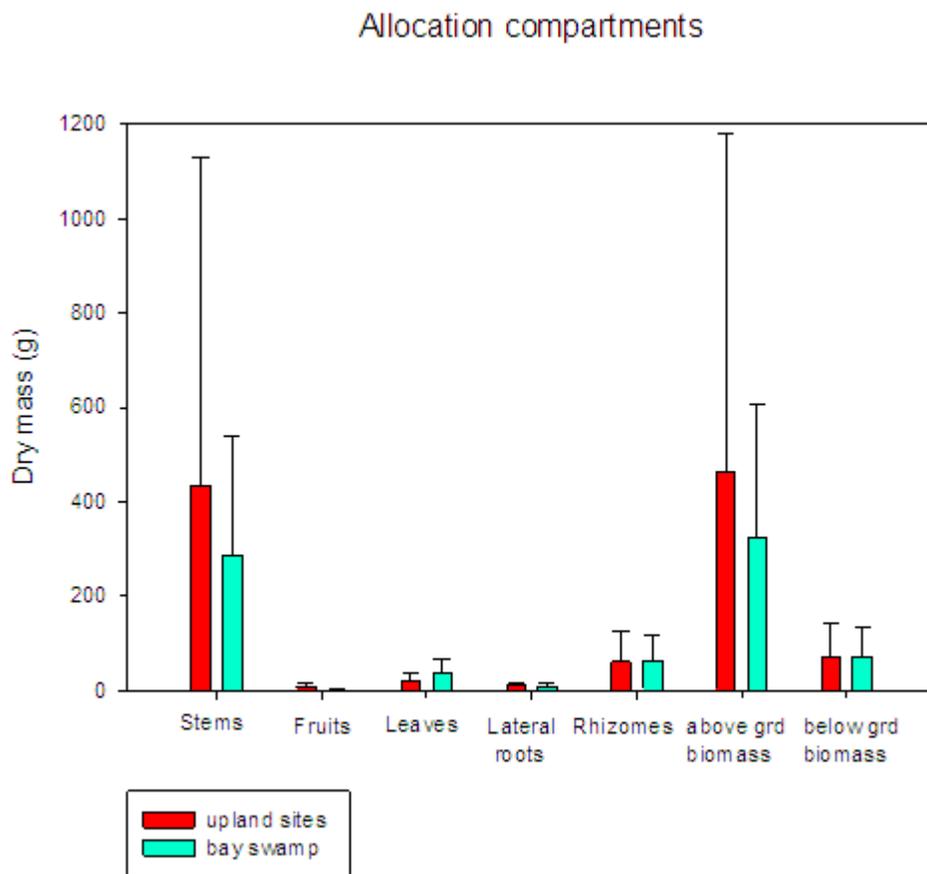


Figure 9: Biomass allocation compartments: Mean ratios (compartment dry mass/total dry mass) of each compartment in both upland and bay swamp sites including mean reproduction (sexual/asexual) ratio. Measures between sites were not significantly different $P < 0.05$.

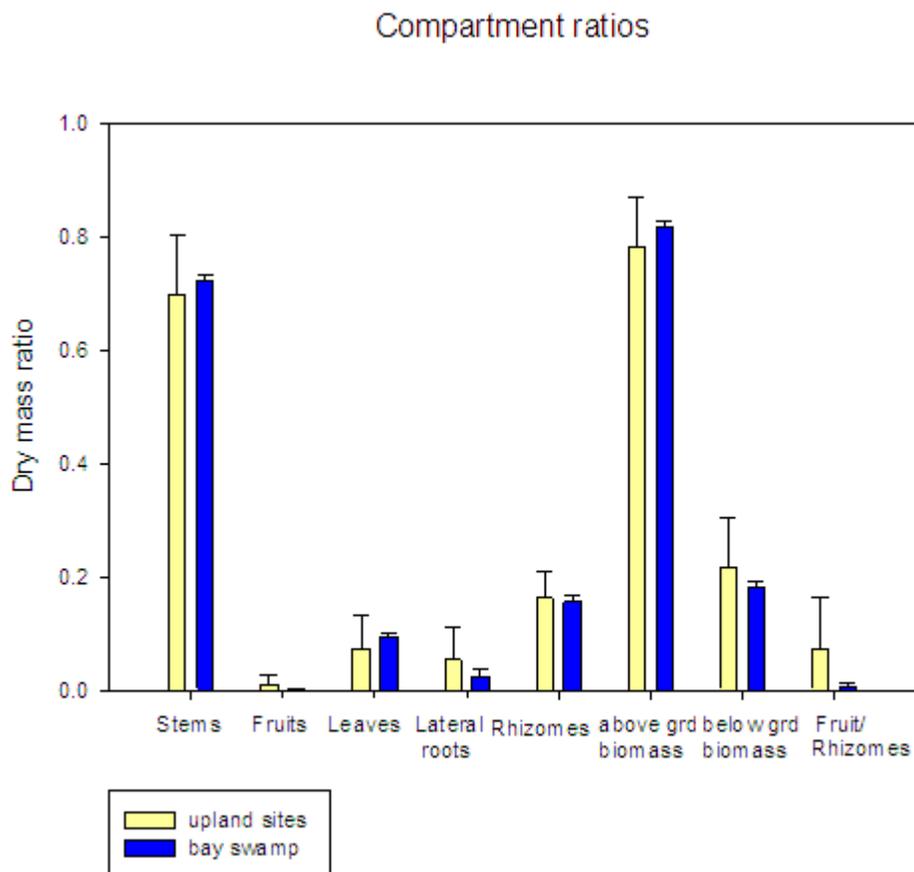


Figure 10: Allelopathy potential: Ratio of radicle length (control/treatment) related to concentration of leaf extract solution in tomato seedlings germinated in Chinese privet leaf extract solution (n=100) $R^2= 0.922$.

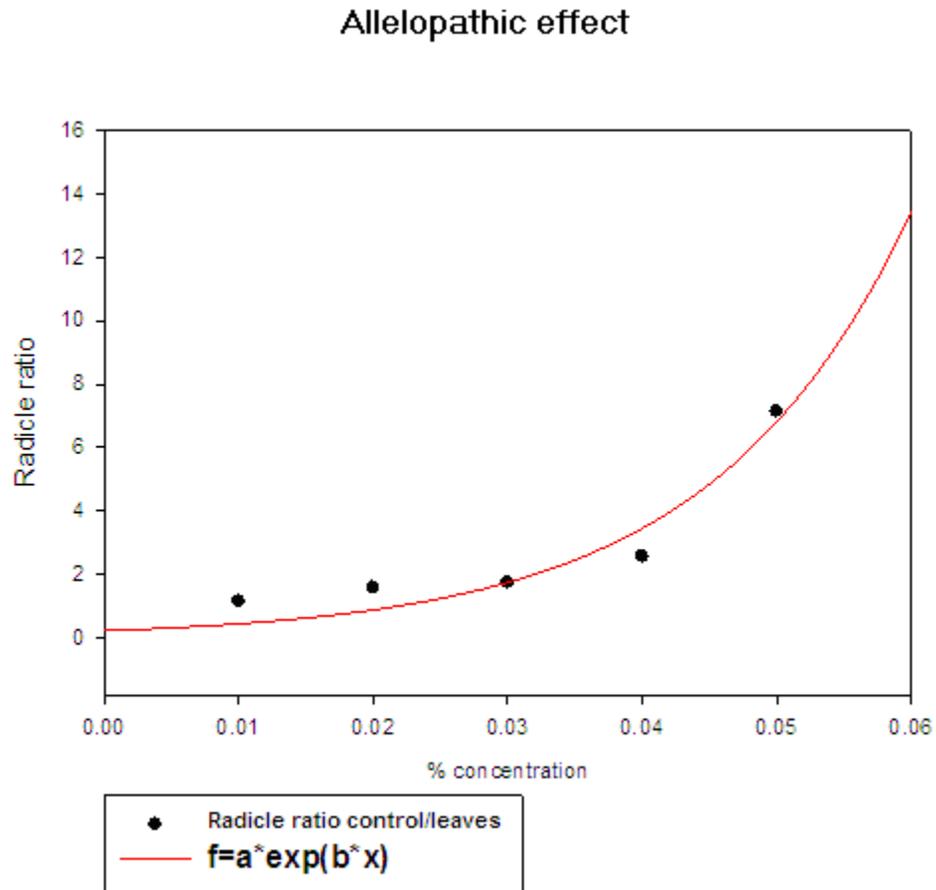


Figure 11: Allelopathy potential: Ratio of radicle length (control/treatment) related to concentration of root extract solution in tomato seedlings germinated in Chinese privet root extract solution (n=100) $R^2= 0.8069$.

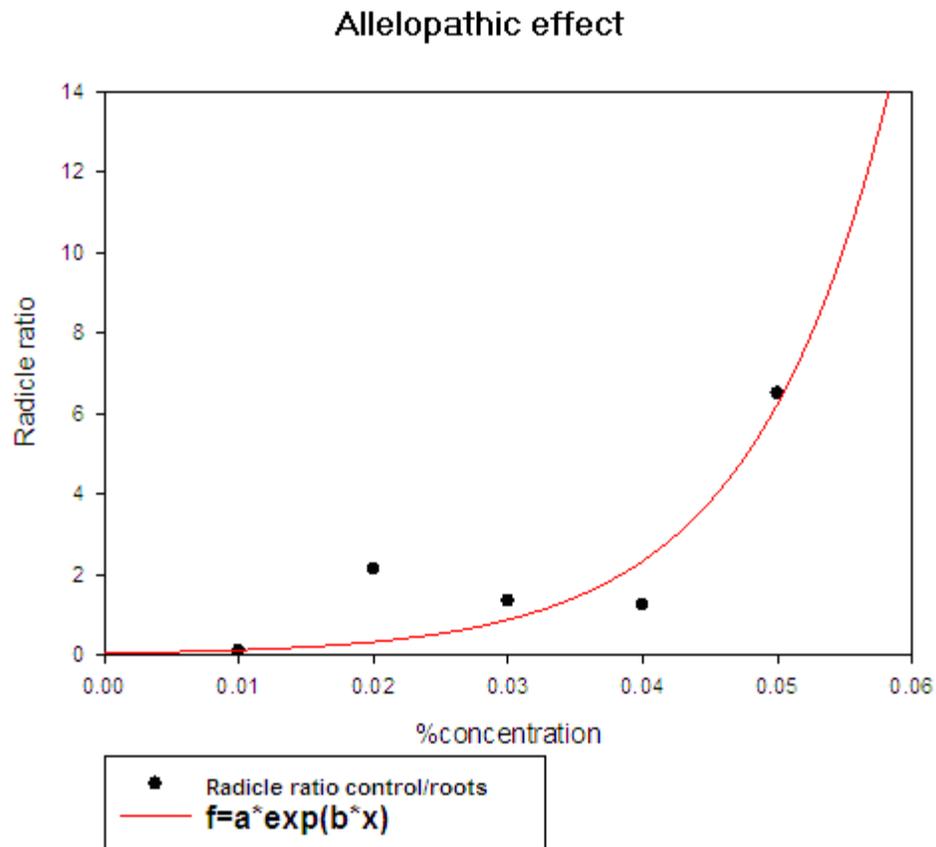


Figure 12: Allelopathy potential: Ratio of radicle length (control/treatment) related to concentration of leaf/root extract solution in tomato seedlings germinated in Chinese privet leaf/root extract solution (n=100) $R^2= 0.8168$ (strong allelopathic effect may be due to outlier data).

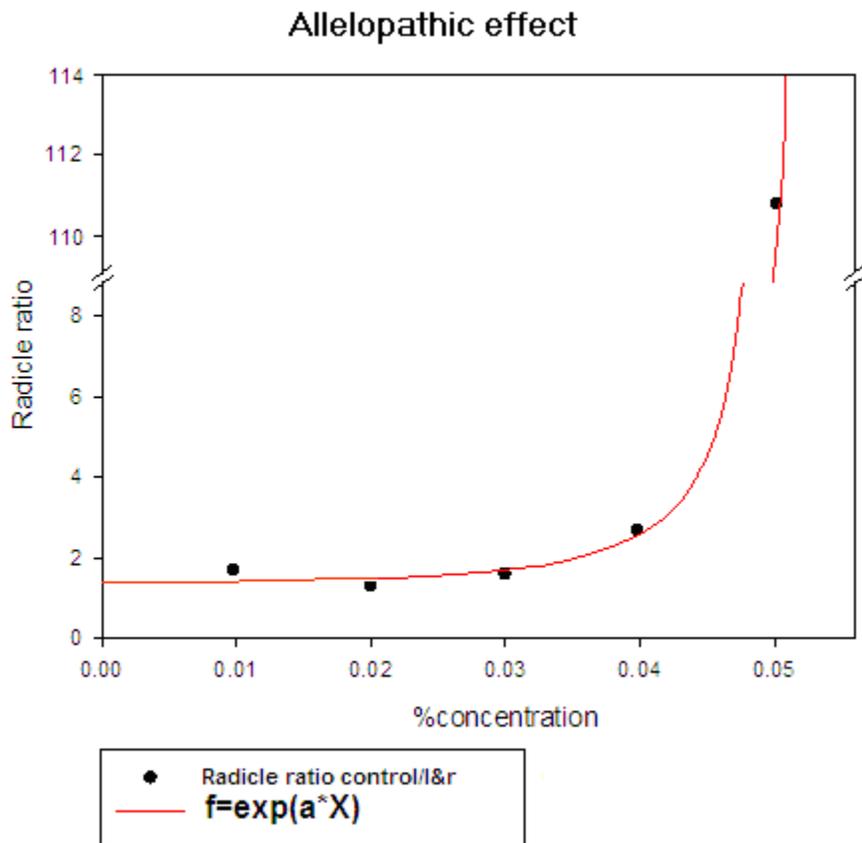


Figure 13: Allelopathy potential: A. Germinated tomato (*Lycopersicon esculentum*) seeds in a control treatment. B. Germinated tomato (*Lycopersicon esculentum*) seeds in the 4% concentration 1:1 leaf/root mixture.

