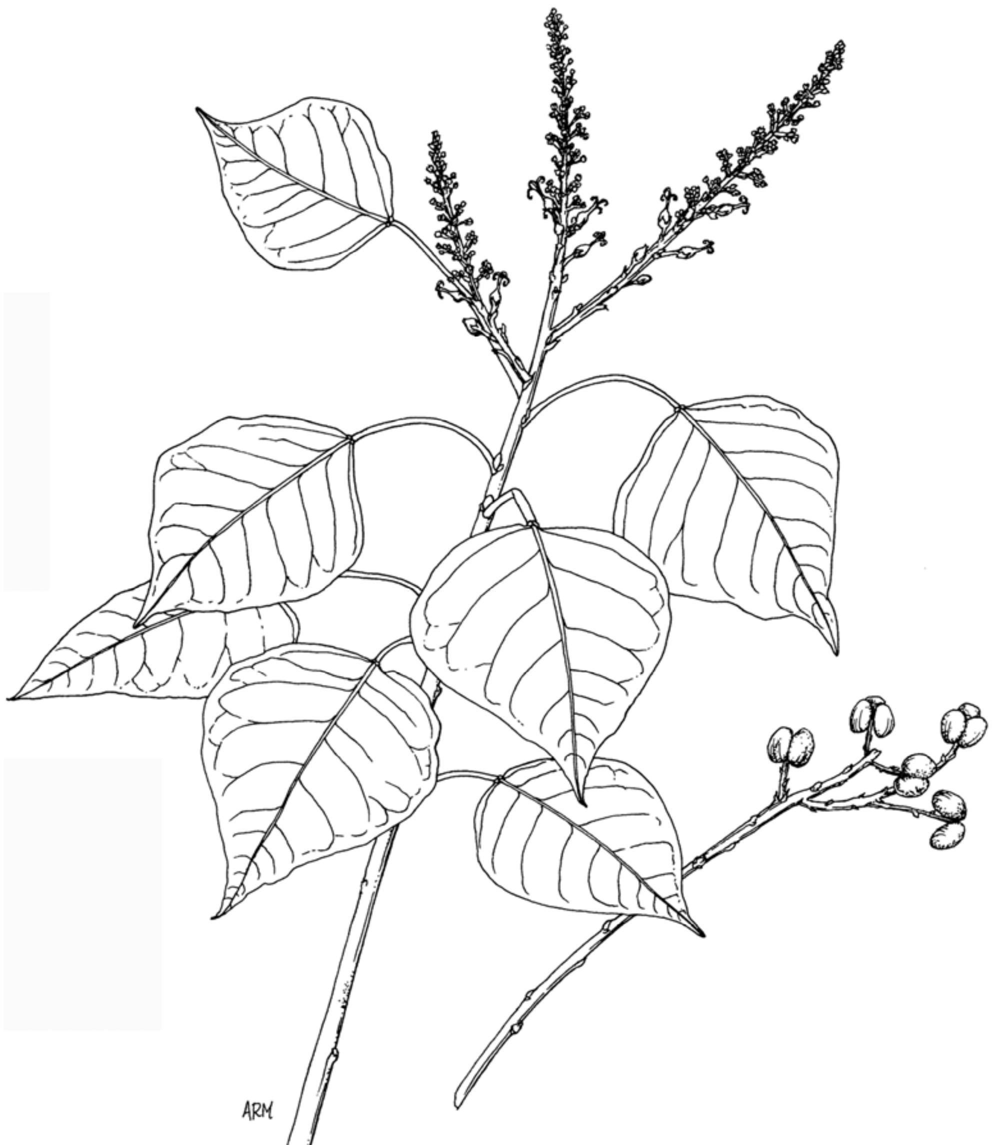
Chinese Tallow Management Plan for Florida

September, 2005



A report from
The Florida Exotic Pest Plant Council's
Chinese Tallow Task Force
Cheryl M. McCormick, Chair

Chinese Tallow Management Plan for Florida

Recommendations from
The Chinese Tallow Task Force

September, 2005

Cheryl McCormick, Tallow Task Force Chair

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The First Edition of the Chinese Tallow Management Plan for Florida was developed to provide up-to-date, comprehensive information and criteria for the integrated management of this pernicious woody invader of Florida's natural areas. The Plan will be updated every five years to reflect changes in the invasive species literature, control techniques, and management philosophies.

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Introduction

The deleterious effects of non-indigenous invasive species on native species, communities, and ecosystems has been widely recognized for decades (Elton, 1958; Simberloff, 1996), and is acknowledged as secondary only to habitat loss and landscape fragmentation as a significant threat to global biodiversity (Walker and Steffen, 1997). Invasive plant species have been shown to modify ecosystem structure and function, reduce native species diversity, and contribute to the extinction of native flora and fauna (Vitousek, 1986; Liebold et al., 1995; Mack et al., 2000). Wilcove et al. (1998) estimates that approximately 400 of the 958 species listed as threatened or endangered under the Endangered Species Act (ESA) in the 1990's were considered to be at risk primarily as a result of competition with, or predation by, non-indigenous invasive species.

The staggering economic burden associate with these species is of major concern, incurring losses totaling over $120 billion annually (OTA, 1993; Pimentel et al., 2005). In addition to economic losses, invasive species compromise ecosystem complexity and biodiversity (Sakai et al., 2001). A number of studies have examined the role of non-indigenous invasive species on native species composition and richness (Cleland et al., 2004), community structure (Williamson 1996; Wilcove et al., 1998; Parker et al., 1999; Sala et al., 2000; Stein et al., 2000), and ecosystem structure and function (Vitousek and Walker, 1989; Mooney and Hobbs, 2000).

Most of the estimated 5,000 non-indigenous invasive plant species that have escaped domestication and now exist in U.S. ecosystems were originally introduced for agricultural, textiles, and/or horticultural purposes (Morse et al., 1995). In Florida alone, approximately 900 non-indigenous invasive plant species have escaped cultivation and are now established in natural areas (Frank et al., 1997; Simberloff et al., 1997).

In FY 01-02, Florida spent approximately $26 million on invasive aquatic weed control (DEP, 2002). The economic impacts associated with just one of Florida's most pernicious invasive plant species, melaleuca (*Melaleuca quinquenervia*), on tourism, recreation, fire regimes, and loss of endangered species is estimated to range from $168 million to $2 billion over a 20 year period (Serbesoff-King, 2003). Although positive strides have been made in controlling melaleuca in Florida, this aggressively invasive tree continues to spread at a rate of

11,000 hectares per year throughout the greater Everglades ecosystem of south Florida (Campbell, 1994).

Problem Statement

Chinese tallow, *Sapium sebiferum* (L.) Roxb. (Euphorbiaceae) is an aggressive woody invader of wetland, coastal, and disturbed habitats, and has been shown to reduce native species diversity and richness, and alter ecosystem structure and function in Florida's natural areas. (Jubinsky, 1993; Gordon, 1997; Simberloff et al., 1997). Chinese tallow was introduced into the United States first as a seed oil crop in the late 18th Century, and then later as an ornamental. Its colorful autumnal foliage and bird-dispersed arilite fruits contribute to its popularity with homeowners. Chinese tallow is an early successional tree with classic r-strategist life history traits that enable it to thrive in unstable or unpredictable environments, including high fecundity, relatively small size, short generation time, and the ability to disperse propagules widely. Like many successful non-indigenous plant species such as melaleuca (*M. quinquenervia*), Brazilian peppertree (*Schinus terebinthifolius*) and Australian pine (*Casuarina* spp.), Chinese tallow is a superior competitor in its new range, has virtually no specialist herbivore or pathogen loads, can readily occupy "vacant niches", and can alter ecosystem processes such as nutrient cycling and stand structure. In Texas, tallow has been shown to convert herbaceous coastal prairies into closed canopy tallow forests within a decade of establishment (Bruce et al., 1995).

Chinese tallow was promulgated as a Noxious Weed by the Florida Department of Agriculture and Consumer Services (FDACS) on June 30, 1996. Propagation was prohibited on July 1, 1996, and commerce and transport was prohibited by January 1, 1998 (Garland, *pers. communication*). The species was added to the Florida Exotic Pest Plant Council's (EPPC) Category I Invasive Species List in 1991. From 1998 to 2004, the Florida Department of Environmental Protection Bureau of Invasive Plant Management (DEP-BIPM) has spent almost three quarters of a million dollars treating Chinese tallow on more than 4,000 acres of natural areas in north and central Florida (Leslie, *pers. communication*).

The number of ecological studies of Chinese tallow has dramatically risen in the past decade, increasing our understanding of the mechanisms underlying the invasion process, and improving management strategies directed towards this species. Nevertheless, there is much work to be done in the future, particularly with regard to development of biological controls, experimenting with integrated management strategies, and increasing funding for management.

Jubinsky (1993) speculates that, based on its exponential growth rate, potential for rapid expansion into sensitive natural areas, and its deleterious effects on ecosystem structure and function, Chinese tallow may one day rival melaleuca in ecological and economic impact and distribution in Florida. Indeed, the Nature Conservancy has designated Chinese tallow as one of the “ten worst alien plant invaders” in the United States (Flack and Furlow, 1996), and the Invasive Species Specialist Group (ISSG) of the World Conservation Union (IUCN) has assigned Chinese tallow the dubious distinction of being one of “100 of the world’s worst invasive alien species” (IUCN, 2005).

The Chinese Tallow Management Plan has been developed to 1) review the relevant literature concerning this species; 2) provide a comprehensive overview of the problem of Chinese tallow invasion; 3) develop a framework for agencies mandated to protect Florida’s natural areas from Chinese tallow invasion, and; 4) inform land managers as to the most effective management techniques.

Goal Statement

The primary goal of the Florida EPPC Chinese Tallow Task Force is to preserve the integrity of Florida’s natural ecosystems from biological deterioration of ecosystem structure, function, and/or biodiversity caused by the invasion of Chinese tallow.

Objectives

The goal of the Chinese Tallow Task Force will be achieved by addressing the following three objectives:

1. Elimination of Chinese tallow from Florida’s natural ecosystems.

2. Achieve an overall reduction of Chinese tallow throughout Florida such that maintaining Florida’s natural areas “tallow-free” becomes economically feasible.

3. Implement successful public outreach and awareness campaigns that encourage and support Chinese tallow eradication and control efforts throughout the State.

Recommendations

In a 2005 convening of the Chinese Tallow Task Force, a six point agenda was developed and agreed upon to systematically advance the objectives of the Chinese Tallow Task Force. These priorities are as follows:

1. Advocate and support efforts by the USDA-ARS to begin exploratory research investigating herbivores and pathogens in Chinese tallow's native range for use as biological control agents in its host range.

2. Encourage and support Chinese tallow control and eradication programs on Florida's public lands.

3. Improve existing control efforts by seeking opportunities to form cooperative inter-agency alliances to secure funding for research and management.

4. Establish cooperative alliances with public support groups to encourage participation in Chinese tallow control programs.

5. Advocate efforts leading to developments in enhanced management options.

6. Utilize the resources available through organizations such as the Florida EPPC to organize a network of professionals to lobby the Florida Legislature and the U.S. Congress to provide financial support and enact legislation encouraging the management of Chinese tallow and other non-indigenous, invasive plant species.

Species Background

Taxonomy

Synonyms:	*Triadica sebifera* (L.) Small	
	Croton sebiferum (L.) Roxb.	
Common Names:	Chinese Tallow	Popcorn Tree
	Chicken Tree	Vegetable Tallow
	Florida Aspen	White Wax Berry

The taxonomic hierarchy of the Chinese tallow tree (*Sapium sebiferum* L. Roxb.) as described by Cronquist (1988) is as follows:

Kingdom:	Plantae	Plants
Subkingdom:	Tracheobionta	Vascular Plants
Division:	Magnoliophyta	Angiosperms
Subdivision:	Magnoliophytina	
Class:	Magnoliopsida	Dicotyledons
Subclass:	Rosidae	
Superorder:	Malviflorae	
Order	Euphorbiales	
Family:	Euphorbiaceae	Spurge Family
Subfamily:	Sapionideae	
Genus:	*Sapium* Jacq.	Tallow Tree
Species:	*Sapium sebiferum* (L.) Roxb.	Tallow Tree

The Euphorbiaceae (spurge) is a large and diverse taxonomic family comprising 326 genera and 7,750 species (Watson and Dallwitz, 1992). Of these, approximately 47 species are native to North America. Members of the Eurphorbiaceae are herbs, lianas, shrubs, and trees, frequently characterized by milky latex that is irritating or toxic. Euphorbs are primarily located in moist tropical habitats, but a number are xerophytic or cactus-like. Members of the spurge family are often cultivated for ornamental (e.g., poinsettia), economic (tung oil), and medicinal (castor oil) purposes. Many species are highly poisonous. The genus *Sapium* contains 21 neotropical species, all of which are monoecious trees with trilocular fruits and seeds with an aril mantle, usually red. Of these, three species (*S. caribaeum*, *S. laurifolium*, and *S. laurocerasus*) are native to the Virgin Islands and Puerto Rico, respectively (Figure 1) (NRCS, 2005).

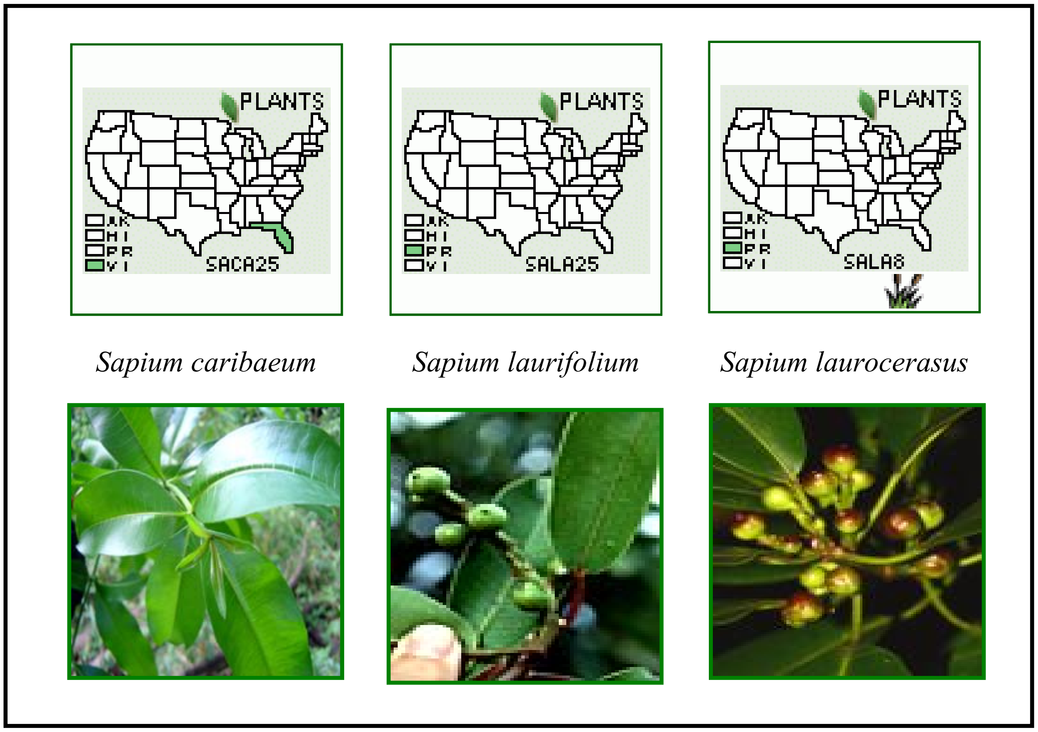

Figure 1. Distribution of native *Sapium* in the U.S. territories. *S. caribaeum* (Urban) is found in the Virgin Islands; *S. laurifolium* (A. Rich.) Griseb. and *S. laurocerasus* (Desf.) are distributed in Puerto Rico (adapted from NRCS, 2005).

Description

Sapium sebiferum (L.) Roxb. is a rapidly-growing, subtropical, monoecious, deciduous, polycarpic tree with caustic milky latex capable of attaining heights of 10 to 13 meters (Bruce et al., 1997). Essentially glabrous, unarmed, weak-stemmed, with arcuate and often drooping slender branches, the stems and branches brittle (Ridley, 1924). Bark is grayish-brown with extensive fissures and, when water-stressed, is characterized by hypertrophied lenticels. Leaves are alternate; blades rhombic, 3-7 cm long, basally biglandular and rounded to acute, marginally entire, apically acuminate; petioles longer than their blades; stipules subulate, caduceus (Correll and Johnston, 1970). The leaves exhibit a wide range of autumnal coloration, which enhances their appeal as an ornamental species. Flowers are reduced, yellow-green, in terminal spiciform androgynous thyrses 5-15 cm in length, the minute bractlet at each node with two persistent bulbous-glandular stipules. Staminate flowers in clusters at the upper nodes, each on a pedicel approximately one mm long, with a cup-shaped irregularly three-toothed calyx approximately one mm in diameter; petals, glands, and rudiment absent; three stamens. Pistillate flowers few, solitary at the nodes; calyx of three triangular nearly distinct sepals; petals, glands, and disk absent. Ovary subglobose, three-celled, triovulate; styles three, free and spreading about half the length, entire, the free portion brown, papillate-fungoidal ventrally. Fruit a trilocular capsule, approximately 1-2 cm long and two cm wide, the walls falling readily upon maturation. Seeds 7-8 mm in length, long-persistent on the placenta after the dehiscence of the fruit; enshrouded in a mantle of chalky-white aril (Figure 2) (Chopra, 1970; Correll and Johnston, 1970; Bogler, 2000).

Chinese tallow has a high degree of phenotypic plasticity, ranging from a "shrub-like" phenotype with low, multi-stemmed, laterally-spreading branches (similar to Brazilian pepper) to tall, linear trees with pendent branch architecture (Scheld and Cowles, 1981; Jubinksy and Anderson, 1996). Trees attain maximum height within 10-12 years (Duke, 1983).

Figure 2. Autumnal foliage, flowers, and mature fruits of the Chinese tallow tree. Because these attractive features are popular with homeowners, the tallow tree remains a valued ornamental tree throughout the southeastern U.S.

Distribution

Native Range

Chinese tallow is native to provinces along the Yangtze River Valley and throughout the southern half of the People's Republic of China, where it is referred to by various names, the common Cantonese name being "u-kau-shu" or "wu-yau-shoe" (Howes, 1949). Tallow is especially abundant in the Anhui, Henan, Hubei, Sichuan, Guizhou, Guanxi, and Zhehiang Provinces, where it typically occupies riparian habitats and sandy estuaries (Howes, 1949), and is actively cultivated for oil production (Figure 3) (Scheld, 1983). In addition to China, the native range of Chinese tallow extends to Japan, Indo-China, India, Vietnam, and the Korean Peninsula. Burkill (1935) report that the species was intentionally established and cultivated in the United

States, Singapore, southern Europe, Italy, France, Martinique, Mexico, Cuba, Brazil, and Jamaica. Distribution records from the Invasive Species Specialist Group (ISSG) of the World Conservation Union (IUCN) also indicate Chinese tallow as being present in Algeria, South Africa, Sri Lanka, and Sudan (IUCN, 2005).

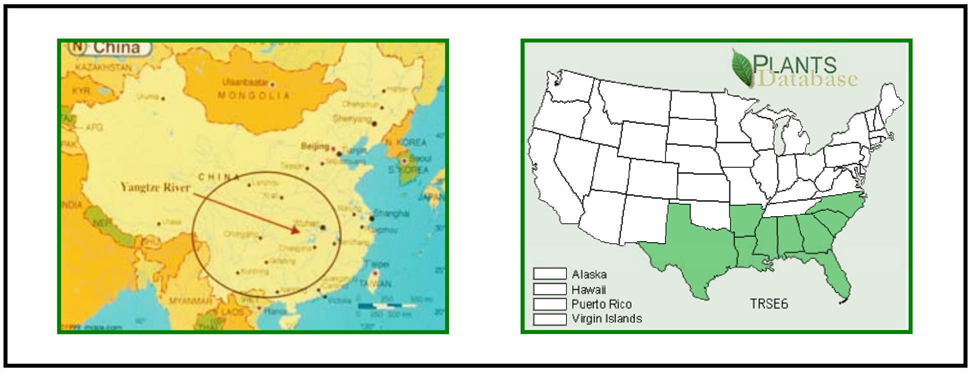

Figure 3. The native range of Chinese tallow (left) and its host range in the southeastern U.S. (right). Images courtesy of USDA (2005) and Wunderlin (2000).

Distribution in the U.S.

The first documented evidence of intentional Chinese tallow introduction into the U.S. occurred in 1772 by Benjamin Franklin, who forwarded seeds from "Cochin China" (now South Vietnam) to Mr. Noble Wimberly Jones, a gentleman farmer and fellow horticultural enthusiast residing in Darien, Georgia. In a letter addressed to Jones dated October 7, 1772, Franklin writes, "… *I send also a few seeds of the Chinese Tallow Tree, which will I believe grow & thrive with you. Tis a most useful plant*." (Bell, 1966). Franklin valued the Chinese tallow tree for its utility, anticipating that the aril-rich mantle would be extracted and fashioned into candles by enterprising Georgians. The first American botanical reference to Chinese tallow was documented by Michaux (1803), who stated that it had been "*cultivated in Charleston and Savannah, but was then spreading spontaneously into the coastal forests*." In 1826, Stephen Elliot protested that the Chinese tallow tree "*bears fruit in great abundance, but though they contain much oil, no use is yet made of them*." (Bell, 1966).

In 1906, the Foreign Plant Introduction Division of the USDA advocated extensive cultivation of Chinese tallow in coastal Louisiana and Texas in an effort to establish a commercial soap industry (Flack and Furlow, 1996). Since that time, range expansion of

Chinese tallow has been primarily attributed to multiple introductions throughout the southeast as a result of its use as an ornamental species in the horticulture industry, as well as its potential for oil seed production (Scheld and Cowles, 1981) and composite manufacturing (Lee et al., 2004). Its current range in the conterminous U.S. extends from Richmond County, North Carolina south through central Florida, west into eastern Texas, and north to Oklahoma and northwestern Arkansas (Figure 3). Jubinsky and Anderson (1996) reported that 57% of Florida's counties contained naturalized populations of Chinese tallow, with a range extending from Escambia County on the Florida/Alabama border eastward to Jacksonville and as far south as Hillsborough County (Tampa). Wunderlin (2000) has documented voucher specimens for 28 of the 38 counties listed by Jubinsky and Anderson, including one specimen from Miami-Dade County. Siemann and Rogers (2003a) note the existence of a voucher specimen from North Kohala, Hawaii; the plant having been collected in 1927.

Although the potential for range expansion in the U.S. remains unknown, Pattison (unpublished, described by Mlot, 2001), used CLIMEX™ models to predict suitable habitats where Chinese tallow might become established. The model demonstrated that the species showed potential for expansion well beyond its current distribution – as far north as Illinois and New Jersey and along the West Coast. This scenario appears unlikely, however, because although Chinese tallow is able to thrive within a wide range of environmental conditions, it is generally limited to frost-free latitudes (Draper, 1982; Bruce et al., 1997).

Ethnobotanical Uses

The Chinese tallow tree has an extensive history in Chinese ethnobotany, providing medicinal products, fuel, and other commodities for over 15 centuries (Howes, 1949; Jubinsky, 1993). Plants of the Euphorbiaceae family are rich in phenolic compounds (especially tannins), and Chinese tallow is no exception. Tannins have been shown to possess anti-cancer activity (Nonaka et al., 1990), enhance nitrogen metabolism, and are often psychotropic (Nagasawa et al., 1980). In addition to tannins, numerous biologically active compounds have been extracted from Chinese tallow (see Table 1).

Medicinal Uses

The Chinese have used the tallow tree extensively in traditional medicines for the past 15 centuries, most generally as a preservative against contagious and infectious diseases (an alexiteric), and as a remedy for treating wounds and sores in general (a vulnurary), especially skin ailments. The leaf and root tissues were traditionally used as a "blood purifying agent" (i.e., a depurative), diuretic, and laxative (Grieve, 1931). Duke and Ayensu (1985) report that the leaves are particularly effective as a suppurative (aids in the discharge of pus) in treating skin ailments, especially skin abscesses. The seeds, which can be lethal to humans and livestock when consumed in modest quantities (Russell et al., 1969), are used as a bowel purgative (hydrogogue) and an emetic (i.e., vomit-inducing) agent (Duke and Ayensu, 1985). The root bark resin is primarily used as a diuretic, tonic for indigestion, and is also useful as a topical treatment for snake bites and relief of swelling associated with skin ulcers (Duke and Ayensu, 1985). The latex (sap) is a caustic vesicant, with blistering similar to that caused by mustard gas (Chopra et al., 1986). Not surprisingly, tallow tree oil is often employed as a purgative, in the manner of castor oil (Scheld, 1983). More recently, potent compounds have been isolated from tallow that have strong anti-viral (Kane et al., 1988) and anti-carcinogen properties (Pradhan and Khastgir, 1973), and have been found to ameliorate symptoms of hypertension (Hsu et al., 1994). It should be noted that not all chemical derivatives of tallow possess beneficial properties. Brooks et al. (1987) demonstrated that phorbol ester derivatives, Sapintoxins A and C, derived from Chinese tallow stillingia (seed kernel) oil, promoted tumor formation and inflammation in mice (Table 1).

Economic/Commercial Uses

The seed kernel is rich in lipids, consisting of approximately 40.5-50.7% fat by weight, and also contains between 8.1-9.2% protein (Duke and Aysensu, 1985). Holland and Meinke (1948) report that the defatted, dehulled seed meal may be used as a livestock feed supplement or to enrich baking flours. A refined oil referred to as "stillingia", derived from the endosperm, is a drying oil used for paints and varnishes (Bolley and McCormack, 1950) . Stillingia became more widely available for commercial use when the post WWII price of exported linseed and tung oils from Argentina and China became economically infeasible (Howes, 1949). Stillingia was also used at one time as a crude lamp oil. Ansari and Nand (1987) report that crushed foliage and fruits, when added to a body of water, is a highly effective piscicide, but that the leaves can be consumed by sheep and goats, presumably with no effect. These conclusions contradict the research of Russell et al. (1969). They report that, by the fifth day of a no-choice feeding trial of terminal leaves and unripened fruits by ruminants (steer and goat), five of seven animals were "severely emaciated" and by the sixth day, one animal had died. Seip et al. (1983) cautions against using the seed oil as a food additive for humans or livestock, based on isolation of skin irritants and tumor-promoting compounds from the kernel oil.

The opaque, waxy outer layer of the seeds is used in the production of soaps, cosmetics, candles, wax paper, and as a source of glycerine (Uphof, 1959; Scheld, 1983; Heywood, 1993), and is separated from the seed by emersion in hot water and skimming off the wax as it floats to the surface. The wax is solid at temperatures below 40° C, and has the consistency of lard. Subsequently, it is employed as a lard substitute in cooking and is used in cocoa butter production (Scheld, 1983; Facciola, 1999). "Tallow residual cake", produced with intact crushed seeds from which the stillingia has been extracted, is used as a green manure, and is particularly useful in enriching soils in tobacco fields (Duke, 1983).

During WWII, tallow tree was used by the Chinese as an emergency source of fuel for diesel equipment (Mason, 1997). More recently, Scheld (1983) and Scheld et al. (1984) have been active proponents for large-scale commercial production of tallow as a cash and petroleum-substitute crop. Scheld et al. (1984) have estimated that tallow is capable of annual yields equivalent to 4,500 pounds of oil per acre, making it "one of the most productive oil-seeds of the world, if not the most productive." Scheld (1983) cites the necessity for developing a system for mechanical harvest as the "major technical barrier" to large-scale commercial production operations.

Black dye produced by boiling mature leaves in alum water was once used to color silk (Howes, 1949) and was also used as a hair dye (Duke and Ayensu, 1985) and in printing inks (Scheld, 1983). The wood is similar to balsa in color, grain and texture, and is well-suited for ornamental carving and the production of Chinese printing blocks. The wood is also suitable for limited furniture production and incense (Duke, 1983). Lee et al. (2004) report that tallow tree fiber, when combined with bagasse (compressed agricultural residue, usually sugar cane) has considerable potential for the production of medium density fiberboard. Based on parameters such as coppice growth, seedling performance, germination and survivorship, Rockwood and

DeValerio (1986) described Chinese tallow, along with Brazilian pepper (*Schinus terebinthifolius*), lead tree (*Leucaena leucocephala*), and mimosa (*Albizia julibrissen*) as "promising species" for large-scale biomass production in Florida. In its native range, Chinese tallow is often planted for soil stabilization and erosion control along canals and rivers.

Honey produced from Chinese tallow is reported to be similar in quality to that derived from goldenrod (*Solidago* spp.), but having more body, and is usually sold as "bakery grade". Though it lacks certain aspects of richness and complexity in palatability, tallow tree honey can be produced copiously and has proven to be an economic boon to beekeepers. In 2004, beekeepers in honey-producing states were paid $1.24 per pound for unprocessed, extracted "extra light amber" Chinese tallow honey, for quantities in excess of 10,000 pounds (USDA, 2004). In an article published in the *American Bee Journal*, Hayes (1979) states "(The Chinese tallow tree)… has become the most successful tree nectar source ever introduced into the United States." Not surprisingly, many beekeeping associations have actively opposed legislative attempts to designate Chinese tallow to state noxious weed lists. For example, when the species was added to Mississippi's state noxious weed list in 2004, officials from the Mississippi Farm Bureau wrote that "should specific regulations affecting tallow tree be proposed, MBA (Mississippi Beekeepers Association) would have the opportunity to comment and have input" (MBA, 2004). Delaplane (1998) advocates extensive planting of tallow as a means of promoting bee conservation in the southeast.

Table 1. Chemicals derived from the tissues of Chinese tallow and their medicinal properties.

Chemical Derivative	Plant Part	Study Reference	Additional Comments
Baccatin	Stem bark Resin	Pradham (1985)	Taxol™, an anti-cancer drug, is derived from Baccatin III, a similar compound.
Methylated ellagic acid	Stem bark Resin	Pradhan and Khastgir (1973)	Anti-carcinogen, anti-mutagen, and anticancer initiator. Ellagic acid is used in alternative medicine to prevent cancer.
Sebiferic Acid	Stem bark Resin	Pradhan and Khastgir (1973)	---
Aleuritic Acid	Stem Bark Resin	Pradhan et al. (1984)	Primarily used in the perfume industry, but is a potential substitute for alpha-hydroxy acids and valued for its antioxidant action on the skin.
Sebiferenic Acid	Stem Bark Resin	Pradhan et al. (1984)	---
Geraniin	Stem (entire)	Neera and Ishimaru (1991)	A popular folk medicine and also an official antidiarrhetic in Japan. Also has anti-viral properties, especially in the treatment of genital herpes.
β-glucogallin	Stem (entire)	Neera and Ishimaru (1991)	A co-enzyme whose bioactivity is not yet fully understood.
Chlorogenic Acid	Stem (entire)	Neera and Ishimaru (1991)	A major phenolic compound in coffee. An antioxidant in-vitro and therefore may prevent cardiovascular disease. Inhibits tumor-promoting activity of phorbol esters.
Tercatain	Stem (entire)	Neera and Ishimaru (1991)	Analgesic properties
Chebulagic Acid	Stem (entire)	Neera and Ishimaru (1991)	May have immunosuppressive effects against cytotoxic T lymphocytes.
Sebiferone	Stem Bark Resin	Liu and Kong (2002)	---
Methyl-gallate	Foliage	Kane et al. (1988)	Shown to possess strong inhibitory effects on herpes-simplex virus.
6-O-galloyl-d-glucose	Foliage	Hsu et al. (1994)	Produces significant reductions in hypertension when administered intravenously into hypertensive rats.
Sapintoxins A & C	Kernel Oil (stillingia)	Brooks et al. (1987)	Significantly toxic compounds, found to promote tumor formation and inflammation in animal trials.
Factors $S_1 – S_8$	Roots (entire) Kernel Oil (stillingia)	Seip et al, (1983)	Topical irritant and tumor-promoting activity shown in mouse skin bioassays.
[(-)-loliolide]	Foliage	Liu et al. (1988)	Immunosuppressive activity; Germination inhibitor and a repellent for ants.
Astragalin	Foliage	Liu et al. (1988)	Anti-dermatitis activity. Reduces severity of existing dermatitis; prevents development of atopical dermatitis when administered orally in mice.

Life History

Phenology

In the southeastern U.S., the onset of new growth begins in February and flower production lasts from March through May (Cameron and LaPoint, 1978). Fruit set begins in July with asynchronous maturity lasting from October to November (Godfrey, 1988). Seeds typically persist on the plants for periods of up to six months (McCormick*, pers. observation*). In the south central provinces of the Yangtze River Valley in China, tallow tree fruits normally ripen beginning in October and lasting through early November, which coincides with the second rice harvest. Consequently, with labor shifted to rice, tallow fruits remain on the trees until after the rice harvest, resulting in considerable degradation of oil quality (Scheld, 1983). Long-term intensive selection programs in some provinces have resulted in entire populations of tallow that delay ripening until late November-December. The result is two annual crops (Scheld, 1983). Upon ripening, the outer capsule walls of the trilocular seed dehisces, exposing the seeds (Bruce et al., 1995). Leaves are deciduous, with abscission complete by the onset of fruit maturation.

Flower and Fruit Production

Duke (1983) reports age to first reproduction as 3-8 years, after which trees may remain reproductively viable for 100 years. In Florida, flowers typically mature in April through June (Jubinsky, 1993). Chinese tallow is dichogamous, a strategy which promotes cross-pollination and genetic variability (Richards, 1986). There are two types of temporally segregated inflorescence types. The first ("eagle claw") produces only staminate (male) racemes in early spring, which fall off and are followed by a second flush of protogynous (female flowers mature first), androgenous racemes. The second type ("grape" variety) produces only protogynous, androgenous racemes. The number of pistillate (female) flowers per raceme typically ranges from 10-15 (Scheld et al., 1980). Chinese tallow is monoecious (male and female flowers occur on the same plant) and is pollinated by insects; a major pollinator is the introduced honey bee (*Apis mellifera*) (Duke, 1983). Although Grace (1997) reports that some individual tallow tree plants grown from seed in a greenhouse flowered during their first year, precocious flowering appears to be infrequent. Scheld et al. (1984) reports that nearly half of the tallow trees on the coastal plains of Texas flowered in their third year.

Seed Production and Dispersal

A mature stand of Chinese tallow can produce copious seed crops in excess of 10,000 pounds of seed per acre annually (Potts, 1946; Bolley and McCormack, 1950; Conway et al., 2000). Hsu (1928) and Lin et al. (1958) indicate that "useful" (i.e., high lipid content) seed crop production may be expected within five years, and that yields do not decline appreciably for 25 to 30 years. Echols (1983) provides evidence for a positive correlation between annual seed crop production and annual precipitation. The number of seed capsules per raceme may vary geographically. Scheld et al. (1980) observed that tallow trees in the Charleston, South Carolina area typically produced 2-3 capsules per raceme, whereas those in the Houston, Texas area produced 3-8. Though some populations in its native range have reportedly produced seeds up to 12.5 mm in diameter, average seed size appears to be less than this (7-8 mm). Fruits are colloquially described as being approximately the size of a pea (Bruce et al., 1997). In their effusive praise of the utility of Chinese tallow as a cash crop, Scheld et al. (1980) suggest that the tallow tree is readily adaptable to, and even appears to facilitate, machine harvesting of seeds, as evidenced by the fact that the majority of harvestable crop is "borne largely in the periphery of the crown, where it is readily accessible by hand or mechanical means."

Toxic secondary compounds in the endosperm (stillingia) reduce its palatability to seed predators, although the aril-rich coating is an attractive source of energy for birds and possibly small rodents. Although the author has observed fire ants (*Solenopsis invicta*) consuming the aril, seed dispersal by ants (myrmecochory) was not documented. The aril coating is degraded by saprophytic fungi, most notably black mold of the genus *Pullularia* (Scheld et al., 1980; Burns and Miller, 2004). Bruce (1993) reports that in advanced stages, *Pullularia* hyphae penetrate the seed kernel, resulting in embryo mortality.

Birds have been shown to be important dispersal agents in upland areas. Renne et al. (2000) demonstrated that birds in coastal South Carolina relied heavily on Chinese tallow as a food source, and that dispersal agent efficacy varied geographically as well as among habitat types. Whereas European Starlings proved to be the most important dispersal agent in South Carolina spoil areas, Northern Flickers were most important in South Carolina coastal forests, and Red-Bellied Woodpeckers contributed most significantly to dispersal of Chinese tallow along forest perimeters in Louisiana (Renne et al., 2002). Arillite fruits are often preferred by birds as winter approaches and energy requirements increase (Herrera, 1982). The lipid-rich coating on tallow tree seeds makes them a highly attractive food source to some species of birds, particularly at a time when few other native lipid-rich food sources are available. Baldwin (2005) found that the species richness (i.e., number of species) of winter bird communities differed significantly between Chinese tallow woodlands and adjacent native bottomland hardwood forests in Louisiana. In general, bottomland hardwood forests supported a higher number of species and had a higher degree of species evenness (i.e., species apportionment). Chinese tallow woodlands tended to support species associated with "edge habitats" whose population numbers were either stable or not declining significantly, and those species (e.g., Yellow-Rumped Warblers and American Robins) that were more efficient at metabolizing tallow tree fruit pulp relative to native species, such as wax myrtle (*Myrica cerifera*), hackberry (*Celtis laevegata*), or deciduous holly (*Ilex decidua*).

Scheld et al. (1980) was vexed with the "problem" of high numbers of birds feeding on potentially valuable tallow oil crops, and commented that, "*the loss to birds could become a significant economic concern, and the attraction and sheltering of large numbers of birds would become a public health consideration. Techniques for dealing with birds will need to be developed*."

Seed Germination

A number of studies have investigated germination requirements of Chinese tallow in an effort to target the seed phase of its life history as a focus of control efforts, with highly variable results. Kuldeep et al. (1993) conducted germination trials under two field conditions – permanently flooded and agricultural sites. They planted 500 tallow seeds (100 seeds with five replicates) at each site in February and May. Seed sown in February germinated on the 35th day, whereas seed sown in May germinated 5-8 days earlier, presumably due to an increase in ambient temperature. At the termination of the trials on the 60th day, germination success for the permanently flood and agricultural sites were 60 and 62%, respectively. Conway et al. (2000) investigated whether imbibition and cold stratification treatments enhanced germinability. Their results demonstrate that Chinese tallow seed is very difficult to germinate successfully under simulated natural conditions, and had very low germination success across all treatments, ranging from 0-10%, whereas Cameron et al. (2000) and Renne et al. (2001) achieved higher germination rates of 26 and 22.5%, respectively, for seed sown in greenhouse environments and ambient temperature/light regimes.

Bruce (1993) reports germination rates of 20-65% in laboratory trials, and Bonner (1974) obtained a moderate germination rate of 38% over a 30-day period of hot-cold heat cycling on moist Kimpak™ media. Nijjer et al. (2002) determined that oscillating temperatures (16 hours of 32°C and 8 hours 16°C) resulted in a significantly higher proportion of tallow seed germination than either constant heat (24 hours of 32°C) or constant cold treatments (24 hours of 16°C). Additionally, their studies suggest that Chinese tallow apparently has no specific light requirement for germination. A higher number of Chinese tallow seed germinated in either constant (24 hours) light or constant dark, compared to oscillating light cycles (16 hours light; 8 hours darkness) (Nijjer et al., 2002). Donahue et al. (2004) found that the addition of mulch reduced tallow seed germination from 34% (217 germinants out of total of 600 seeds) to approximately 0.06% (34 germinants). This suggests that mulching tallow tree stands may facilitate the restoration of Chinese tallow sites by reducing germination through attenuation of day/night variation in surface soil temperatures. Indeed, oscillating soil temperatures may be a significant environmental signal for germination of Chinese tallow, and may be critical in breaking physical dormancy in soil seed banks (Baskin and Baskin, 1998). However, it is unclear to what depth mulch should be applied. In order for this treatment to serve as a successful restoration tool, the mulching treatment should have no significant effects, either on native species or the productivity of the tallow trees (Donahue et al., 2004). Burns and Miller (2004) surveyed environmental characteristics around the perimeter of Lake Jackson, Florida in an effort to elucidate biotic and abiotic correlates of Chinese tallow invasion. They planted Chinese tallow seeds in buried pots along eight transects over an elevation gradient of over one meter, and found that germination success was highest for medium and high elevations (4.5 and 3.2%, respectively) and lowest in low elevations (0.7%). In addition, their work suggests that controlled burning reduced the likelihood of germination (presumably through heat-induced embryo death), and may be used an effective management tool for inhibiting seedling recruitment. However, there may be an unacceptable trade-off if burning increases coppicing and root shoots on mature trees.

Although absolute seed longevity is difficult to establish in orthodox (i.e., desiccation tolerant) seeds with dormancy mechanisms, Zhang and Lin (1994) have speculated that Chinese tallow seed may remain dormant in soil seed bank for up to 100 years with little reduction in embryo viability. In a study of germination using Chinese tallow seed collected over a period of seven years, Cameron et al. (2000) found that germination success peaked after two years, with little loss in germination (3%) by the seventh year. Additionally, they determined that among four collection sites in the southeastern U.S. (Florida, Georgia, South Carolina, and Texas) and one in Taiwan, tallow populations in Florida exhibited the highest total percent germination across years (52.4% ± 5.9), followed by Georgia (30.9% ± 6.3), Taiwan (28.8% ± 3.3), Texas (24.3% ± 2.7), and South Carolina (5.7% ± 3.1), respectively (Cameron et al., 2000).

Cameron et al. (2000) determined that the highest proportion of Chinese tallow seed germinated in January and February (average: 58-59%), with the lowest proportion germinating in the late fall (21-46%). Maximum germination during winter months may enhance Chinese tallow's ability to invade sites, because winter annual plants have died back and many overstory trees are deciduous (Harcombe et al., 1993). Consequently, there is little competition from neighboring plants for resources, and few losses to seed predators and herbivores, which are generally less active during the winter (Cameron, 1977).

Vegetative Growth and Reproduction

Chinese tallow is capable of both vegetative reproduction and copious fruit production. Physiological stress resulting from environmental conditions, herbicide application, or mechanical damage typically result in profuse root coppicing (Scheld and Cowles, 1981; Bruce et al., 1997). Jones and Sharitz (1990) documented substantial production of adventitious roots in Chinese tallow seedlings grown in persistently flooded conditions. Additionally, flooded tallow seedlings produced noticeably thicker roots than native water tupelo (*Nyssa aquatica*) and green ash (*Fraxinus pennnsylvanica*) (Jones and Sharitz, 1990).

Genetic Traits

Scheld (1983) reports that the diploid chromosome count for "wild type" (i.e., non-cultivated) tallow trees is 36 (n=18), but that for cultivated trees under intense selection programs, this number may be as high as 76. He goes on to state that this report by Chinese researchers "*may be the result of a miscount, but is not beyond the realm of possibility considering the strangeness of the Chinese tallow tree in other areas*" (Scheld, 1983). No empirical evidence is cited to support this claim, although it is supported by the work of McCormick and Hamrick (unpublished data), who report that, based on allozyme banding patterns, the species may in fact be an allotetraploid (4n). The ploidy level of plant species is an important evolutionary trait that can reveal much about a species' ability to respond rapidly to changing environmental conditions. Baker (1974) observed that polyploidy was a common trait in the evolution of weedy species. Bennett et al. (1998) analyzed DNA data from 39 weedy species and found that over half (51%) were polyploids. Consequently, the ploidy nature of potentially invasive plant species may prove to be a valuable key diagnostic feature for evaluating risks associated with the transportation, commerce, and use of potentially invasive plant species. A review of the Chinese literature by Scheld et al. (1984) reports that Chinese tallow is characterized by "extreme variability" within the species in its native range (Lin et al., 1958; Shin, 1973). These researchers also state that populations in the Houston, Texas area "appear to reflect a high degree of genetic variability", though they do not report the specifics of published studies to support this claim.

In a 14-year common garden experiment, Siemann and Rogers (2001) examined tallow tree plants originating from populations in China, Georgia, Louisiana, and Texas and compared plant size, foliage chemistry (an indicator of herbivore defenses), and annual seed crop abundance. They concluded that "native genotypes" (i.e., trees from China) were smaller in size, had intermediate seed production, and had the best defended foliage, whereas "invasive genotypes" were characterized by higher growth and low foliar defense. Their data support the hypothesis that, during their introduction phase, invasive plant species may allocate significant resources to growth and reproduction and less to defense (Strong, 1974).

One compelling theory as to why invasive species may initially exhibit limited genetic diversity in their introduced ranges is presented by Crawley (1987) and Mack et al. (2000), who hypothesizes that, during the "lag phase" of introduction, plant species undergo a period of genetic adjustment and may "experiment" with a number of different gene combinations until a successful genotype is reached that results in a high rate of intrinsic per-capita growth rate (and therefore, the highest fitness) under a given set of environmental conditions. The evolutionary genetics of invasive species remains largely unexplored, but can offer insight into mechanisms of invasion, through the analysis of gene architecture (i.e., genetic effects on traits), gene expression, gene interactions, and the genomic arrangements that are associated with invasion events.

Community and Ecosystem Dynamics

Post-Disturbance Effects

Leninger et al. (1997) examined impacts to vegetation structure, composition, and relative abundance in three sites in a bottomland hardwood forest of the Atchafalaya Basin four years following Hurricane Andrew. Their field surveys indicate that tallow trees suffered severe crown damage as a result of high winds, and were the most susceptible to hurricane damage of the 23 species surveyed (22 of which were native tree species). These results concur with those of Doyle et al. (1995), who also documented that Chinese tallow sustained the greatest proportion of stem damage, relative to native tree species, from Hurricane Andrew in coastal Louisiana. The implications of hurricane-induced mechanical damage on recruitment of tallow trees in coastal habitats remains unclear, and should be investigated further, particular in light of recent high-frequency and magnitude storm events. Denslow and Battaglia (2002) described the composition and structure of woody species along a hydrologic gradient in Jean Lafitte National Park, Louisiana, and found that tallow recruitment was common in light gaps throughout the hydrologic gradient. They conclude that if hurricane damage creates light gaps by removing canopy cover and above-ground biomass, the site may experience high levels of recruitment from the soil seed bank.

One the most alarming examples of the rapidity with which Chinese tallow expands its range in post-disturbance habitats is Bull Island, South Carolina. Prior to the arrival of Hurricane Hugo in 1989, much of Bull Island was considered old-growth maritime forest (Conner et al., 2005). Pre-hurricane field surveys of vegetation communities on Bull Island by Helm et al. (1991) concluded that Chinese tallow was confined to "poorly drained swales" that live and laurel oak (*Quercus virginiana* and *Q. laurifolia*, respectively) and loblolly pine (*Pinus taeda*) could not exploit due to frequency of flooding. They conclude that "it is unlikely that this species (tallow tree) will occupy much more area than it does presently, since it is confined to moist soils." Interestingly, they found that richness and percent cover of the herbaceous layer subtending Chinese tallow stands were significantly higher than in either live oak or loblolly pine stands (Helm et al., 1991). A follow-up vegetation survey of Bull Island by Smith et al. (1997) reports that stands of Chinese tallow were completely destroyed by wind and terminal salt damage from Hurricane Hugo (stem density per hectare decreased from 120 in 1988 to 0 in

1992). However, they noted aggressive recruitment of Chinese tallow seedlings into previously uninvaded vegetation communities, such as old growth loblolly forests. Conner et al. (2005) surveyed the Island in 1998, and compared data on vegetation parameters for pre-storm, 1991, and 1998 surveys. They found that Chinese tallow accounted for 9.8 (pre-storm), 4.1 (1991) and 22.6% (1998) of the tree density-frequency-dominance index. They speculate that light gaps stimulating the soil seed bank, coupled with a rise in the water table are responsible for an increase in tallow tree density 20 times that of estimated pre-Hugo density. As of July 2005, vegetation managers at Cape Romaine National Wildlife Refuge estimate that Chinese tallow is present on approximately 25% of Bull Island's terrestrial habitats (Dawsey, *pers. communication*). These and other studies illustrate the potential role of disturbance as a stimulus for rapid population growth and expansion of Chinese tallow.

Effects on Ecosystem Structure and Function

Chinese tallow has become the dominant woody species of remnant Chenier woodlands in southwest Louisiana, significantly reducing species diversity and relative abundance in these old-growth maritime forests. Baseline surveys conducted by Neyland and Meyer (1997) revealed that the degree of tallow tree infestation in the chenieres was positively correlated with soil disturbance. The chenieres are unique coastal communities formed on the ridge of relic beach dunes, and serve as storm barriers limiting saltwater intrusion. Additionally, they serve as important wildlife habitat, especially for migratory songbirds, shorebirds and butterflies. Chinese tallow has been shown to convert herbaceous coastal prairies into closed canopy tallow tree forests within a decade of establishment (Bruce et al., 1995). Consequently, there is concern that this species will displace marsh habitats surrounding the chenieres, irrevocably altering ecosystem structure and function and dramatically changing seral stages of vegetation succession. Harcombe et al. (1993) measured above ground net primary production (ANPP) in a monotypic, 15-year old tallow stand and an adjacent wet coastal prairie dominated by native species and found that the tallow stand had significantly higher levels of ANPP. They also determined that maximum radial growth of tallow trees was 4.5 mm per year for a 17-cm dbh tree on the Texas coastal prairie. Harper (1995) measured radial growth of 6 mm per year in a river floodplain forest in Louisiana.

Bruce et al. (1995) examined tallow tree stands from four age classes (0-5, 6-10, 11-15, and 16-20 years old) ranging in size from 0.2 to 100 hectares in coastal graminoid/herbaceous prairies in eastern Texas. Their results demonstrate that Chinese tallow is self-regenerating up to 20 years and can form closed canopies within 10 years, demonstrating a rapid shift in dominance of vegetation structure as graminoids and forbs were replaced by trees and shrubs. Of the original coastal graminoid/herbaceous prairie, less than one percent remains (Smeins et al., 1991), and this remnant has been designated as a "globally imperiled ecosystem" by The Nature Conservancy (Grossman et al., 1994).

In many cases, the structural integrity of prairie vegetation communities can be maintained by the use of prescribed fire to prevent encroachment of woody species. Chinese tallow has been shown to significantly reduce fuel loads and inhibit the spread of fires that suppress woody vegetation and promote prairie ecosystems through shading and rapid leaf decay (Cameron and Spencer, 1989; Barrilleuax and Grace, 2000). Once naturalized, Chinese tallow forms monotypic canopies subtended by understories consisting of few if any native woody species (but see Helm et al., 1991). Grace (1998) investigated whether prescribed fire can be employed to halt the encroachment of tallow tree invasion in coastal prairie ecosystems of Texas. He concluded that the use of fire to control Chinese tallow in coastal Louisiana prairies is ineffective at best, and may in fact exacerbate infestations, in part due to a number of morphological and physiological adaptations to fire exhibited by the species (see "Management" section).

Effects on Nutrient Cycling and Soil Chemistry

Chinese tallow may have negative effects on leaf litter decomposition rates and species composition of aquatic reducer species. Cameron and LaPoint (1978) studied the effects of foliar tannins on reducers (i.e., shredders, sediment-deposit feeders, scrapers, and filter feeders) in grassland and ephemeral ponds in tallow tree forests in the Texas coastal wet prairie ecosystem. They showed that species richness and diversity were lower in ephemeral ponds of tallow forests, and that these ponds contained fewer shredders than the grassland ponds. Shredders have a critical ecological function in aquatic and terrestrial habitats and are primarily responsible for initiating decomposition of whole leaf organic matter in ephemeral ponds and the forest floor. The high tannin content in Chinese tallow foliage may inhibit feeding by reducers, either by binding to protein molecules and rendering them unusable ("tanning") or by preventing microbial growth on leaves. Tallow tree leaf litter cannot be utilized by reducers until tannins are leached by seasonal flooding and its physical structure is subsequently altered by microbial action.

Fluctuating levels of resources is thought to play a pivotal role in facilitating the invasion process of pestiferous plant species (Dukes and Mooney, 1999; Davis et al., 2000). Rapid decomposition of Chinese tallow litter often results in temporally pulsed releases of nitrogen. In areas of expansive tallow tree invasion, such as Gulf coastal Texas and Louisiana prairies, nutrient feedbacks may facilitate Chinese tallow invasion. Cameron and Spencer (1989) examined the rate of Chinese tallow leaf decomposition and the quantity and rate of nutrient inputs from decomposing leaves in a tallow tree forest. They determined that approximately 24% of biomass in Chinese tallow leaves was lost within the first week; 50% of biomass was lost after four months, and total reduction occurred in approximately seven months. By comparison, some temperate deciduous trees take an average of 3.9 years to achieve total decay (Swift et al., 1979). Soil analysis revealed that concentrations of P, K, NO3-, Zn, Mn, and Fe were significantly higher in soils subtending tallow tree forests than from prairie plots, whereas concentrations of Na and Mg were significantly lower. Levels of Ca and S did not vary significantly between sites. These results suggest that established populations of Chinese tallow appear to significantly alter nutrient distribution in subtending soils, and may contribute to enhanced productivity of invaded habitats.

Response to Waterlogging and Salinity

Chinese tallow can tolerate a wide spectrum of soil conditions. In the Gulf coast, where the species has exhibited rapid growth and range expansion over the past 40 years, soils typically range from moderately acidic at the epigeal surface and becomes progressively alkaline with increasing depth (Crenweldge et al., 1988; Bruce, 1993). Jones and Sharitz (1990) demonstrated that Chinese tallow seedlings are comparable to water tupelo (*Nyssa aquatica*) in their response to flooding and oxygen stress avoidance, such as hypertrophied lenticels and adventitious root formation. Conner and Askew (1993) demonstrated that Chinese tallow tree seedlings exhibited significantly higher survivorship when subjected to short-term inundation by saltwater (20-27 ppt) than either red maple (*Acer rubrum*) or redbay (*Pursea borbonia*). Similarly, Conner et al.

(1997) found that Chinese tallow seedling survivorship was three times higher than that of baldcypress (*Taxodium distichum*), water tupelo (*N. aquatica*) and green ash (*Fraxinus pennsylvanicum*) under conditions of prolonged flooding with slightly saline water (10 ppm). Additionally, they demonstrated that Chinese tallow fully recovered from simulated storm surge events with 32 ppt saltwater, whereas all three native species experienced complete seedling mortality.

Butterfield et al. (2004) demonstrated that under a four-treatment water gradient ranging from permanently flooded to pulsed drought, Chinese tallow seedlings were able to thrive at any point along the water regime continuum, significantly outperforming loblolly pine (*P. taeda*), water tupelo (*N. aquatica*) and black gum (*N. sylvatica*). A single native species, sweetgum (*Liqudambar stryaciflua*), exhibited higher growth rate than Chinese tallow in drier treatments. Barrilleaux and Grace (2000) found significant effects of soil type and electrical conductivity (an indicator of soil salinity) on tallow tree seedling mortality in a Texas coastal prairie. In field trials, Chinese tallow suffered 73% mortality when grown on western soils (high sand/high conductivity), whereas tallow grown in central (clay/moderate conductivity) and eastern soils (silt-loamy/low conductivity) experienced only 3% and 0% mortality, respectively. Consequently, Chinese tallow appears to be able to tolerate short, infrequent pulses of saltwater flooding and may have a competitive advantage in coastal areas that may be subject to gradual or infrequent saltwater intrusion in the future and becoming a dominant species of southern coastal forests.

Growth Under Various Light Conditions

Chinese tallow is tolerant of a wide range of light conditions, and has growth rates comparable to or greater than, shade-tolerant and shade-intolerant species in both deep shade and full sun (Bruce, 1993). When compared to seedlings of American sycamore (*Platanus occidentalis*) and cherrybark oak (*Quercus falcata* var. *pagodifolia*) tallow tree seedlings attained greater height and biomass in deep shade (5% sun) than either of the natives, and equaled the growth of American sycamore in full sun (Jones and McLeod, 1989). In another study comparing Chinese tallow to green ash (*F. pennsylvanicum*), Jones and McLeod (1990) found that tallow had equal or greater growth rates (height and biomass) over a wide spectrum of light regimes relative to native ash (5-100% full sun) over a 100-day growing period. Furthermore, they estimate that a single, 15-year old tallow tree can reduce ambient light to 7%, and cast 80% or greater shade over a 30-m^2 area (Jones and McLeod, 1989; 1990).

Data by Rogers et al. (2000) showed that tallow tree seedlings exhibited a strong positive response to increased nutrients (specifically nitrogen) by increasing water-use efficiency (through reduction of stomatal conductance), and increasing leaf area, leaf number, leaf mass, and petiole length. Their data also support the results of previous studies by Jones and McLeod (1989; 1990) and suggest that Chinese tallow possesses significant physiological plasticity and can thrive under a wide range of natural light conditions. Under conditions of deep shade, Chinese tallow maintains high water-use efficiency and produces “shade leaves” by increasing leaf surface area (but not necessarily leaf mass) (Jones and McLeod, 1990). Furthermore, Chinese tallow maintains a high level of physiological activity in full sun (Rogers et al., 2000). The broad amplitude of light conditions in which tallow is able to thrive undoubtedly contributes to its success in a number of habitats.

Competitive Interactions

There are abundant data to suggest that invasive plant species may expand their range as a result of competitive superiority (Grace and Tilman, 1990; Gaudet and Keddy, 1988; Callaway and Aschehoug, 2000). However, recent studies (Clark et al., 1998; Hubbell et al. 1999) suggest that in some cases recruitment limitation may be more important than local competitive differences in determining the species composition of a given local patch. Consequently, observation that an invasive plant species is locally abundant does not necessarily indicate that it is competitively superior to native species in that patch. Rather, it may indicate high seed input by the non-native species (i.e., propagule pressure), such as when a small habitat is surrounded by habitats favoring the establishment of the non-native species (Smith and Knapp, 2001; Siemann and Rogers, 2003d). To investigate this hypothesis, Siemann and Rogers (2003d) added Chinese tallow seed to mesic and floodplain forests, and coastal prairie habitats, with and without soil disturbance. They predicted that (1) if low seed input limits local abundance, then experimentally added Chinese tallow and hackberry seed will readily germinate, grow, and survive, thereby increasing seedling abundance, and; (2) if a scarcity of suitable microsites limits invasion, then seed added on disturbed sites should grow and survive, thereby increasing seedling abundance (Siemann and Rogers, 2003d). They found relatively higher germination of hackberry vs. Chinese tallow at all three sites, but that Chinese tallow had overall higher survivorship in prairie and floodplain forest. Interestingly, tallow experienced moderate germination success in the mesic forest habitat, followed by 100% seedling mortality within approximately 1.5 years (~ 600 days) after planting. Soil disturbance had no effect on the germination rates of Chinese tallow, but increased germination success of hackberry seeds.

Jones (1993) examined the effects of soil temperature on intra- and interspecific root competition of Chinese tallow, sweetgum (*L. styraciflua*) and red maple (*A. rubrum*). He found that increasing soil temperatures resulted in significantly higher root biomass in tallow tree seedlings relative to that of natives when planted together, whereas below-ground competition was relatively less when Chinese tallow seedlings were planted with conspecifics. His results suggest that Chinese tallow may exhibit superior competitive ability in terms of resource acquisition in warmer temperatures relative to native species.

Rogers and Siemann (2004) tested the competitive ability of invasive (Texas) and native (China) tallow tree seedlings against annual ryegrass (*Lolium multiflorum*) under conditions of increased soil fertilization. Chinese tallow seedlings were grown to four weeks, at which time 1.5 grams of *Lolium* seed was added to a 7.65 liter pot containing individual Chinese tallow seedlings of either genotype; the pots were treated with a 15:10:5 fertilizer. Data show that competition for soil resources increased the stem height growth of Chinese genotypes, but did not affect shoot or root mass. Competition did not significantly affect any measurable growth of Texas genotypes, suggesting that invasive the invasive genotype is less effective in competition than the native genotype (Rogers and Siemann, 2004).

Microbial Interactions

The role of soil microbes and unique mycorrhizal associations in facilitating non-indigenous pest plant invasions is an area of ecology that, though sorely neglected, may offer critical insight into the more subtle mechanism(s) that act as catalysts for plant invasions. Nijjer et al. (2004) examined the effects of mycorrhizal inoculation, fungicide application, and fertilization on the growth of Chinese tallow and five native species (sweetgum, *L. styraciflua*, water tupelo, *N. sylvatica*, loblolly pine, *P. taeda*, white oak, *Quercus alba*, and water oak, *Q. nigra*). They found a significant, positive growth response (65%) of Chinese tallow seedlings in response to mycorrhizal inoculation, whereas growth response in native species ranged from negative (*Q. alba* = 1% reduction), negligible (*Q. nigra* = 6%), minor (*P. taeda* = 17%, *L. styraciflua* = 24%), to large (*N. aquatica* = 46%). Unless a species is able to exploit mycorrhizal associations in an innovative fashion, it is unlikely that generalist mycorrhizae associations with low host fidelity would be the sole mechanism of invasion. Although a number of generalist fungal pathogens have been known to associate with Chinese tallow (Table 2), clearly, there are many knowledge gaps that exist in understanding the role of soil microbes and mycorrhizal associations in Chinese tallow invasions.

Table 2. Generalist fungal pathogens associated with Chinese tallow.

Group	Genus	Common Name	Location	Reference
Oomycete	*Pythium* spp.	Root Rot		Alfieri et al., 1994
Basiliomycete	*Armillaria mellea*	Oak Root Rot	CA	Raabe, 1967
Basiliomycete	*Armillaria tabescens*	Root Rot	FL	Alfieri et al., 1994
Hyphamycete	*Alternaria* spp.	Leaf Spot	FL	Alfieri et al., 1994
Hyphamycete	*Phymatotrichopsis omnivora*	Root Rot	TX	Alfieri et al., 1994
Hyphamycete	*Pseudocercospora stillingiae*	Leaf Spot	FL, LA	Alfieri et al., 1994
Coelomycete	*Diploidia* spp.	Dieback	FL	Alfieri et al., 1994
Coelomycete	*Phomesis* spp.	Leaf Tip Necrosis	FL	Alfieri et al., 1994
Coelomycete	*Phyllosticta stillingiae*	Leaf Spot	FL, AL	Alfieri et al., 1994

Herbivory

In its introduced range, Chinese tallow stands are noticeably depauperate in terms of specialist herbivore loads (Harcombe et al., 1993; Bruce et al., 1997). Perhaps not surprisingly, Liu et al. (1988) report that one of the biologically active compounds from tallow foliage [(-)-loliolide] is a potent ant repellent. The absence of an appreciable herbivore load on plants is usually attributed to foliage and other plant tissues being highly defended (unpalatable) or of nutritionally marginal quality (Price, 1997). However, the relative abundance and species richness of non-herbivorous generalist arthropods in tallow tree stands were previously unpublished. Arthropods perform a number of ecosystem services, such as pollination, propagule diserspal, and nutrient cycling (Wilson, 1992; Jones et al., 1994; Price, 1997). Consequently, they may be sensitive indicators of changes to vegetation structure, function, and diversity.   Hartley et al. (2004) quantified arthropod communities in a Chinese tallow stand in coastal southeastern Texas and found that, of 811 individuals sampled, the orders Dipterans (flies), Acari (mites), and Araneida (spiders) comprised 78% of total species abundances. They concluded that Chinese tallow supports an unusual assemblage of arthropods of mostly predators and detritivores, with very few herbivores.

One of the prevailing theories explaining the success of invasive plant species is the Evolution of Increased Competitive Ability (EICA), proposed by Blossey and Nötzhold (1995). The EICA postulates that, in response to the absence of specialist herbivores (including pathogen loads), invasive plants evolve increased competitive ability (relative to native species) by shifting resources from defense to growth.

Siemann and Rogers (2003b) tested the EICA hypothesis by comparing growth and herbivory levels in tallow trees cultivated from native (Asian) and invasive (Texas and Hawaii) seed grown in competitive common gardens in Texas and Hawaii. Their results show that in the Texas garden, Asian genotypes were significantly smaller than North American genotypes, and both genotypes suffered very low levels of insect damage. However, in the Hawaiian garden, the situation was reversed. North American genotypes were significantly smaller than Asian genotypes. Additionally, North American genotypes experienced significantly more insect damage than Asian genotypes in the Hawaiian garden. The herbivore responsible for most foliar damage was *Adoretus sinicus* Burmsiter (Coleoptera: Scarabaeidae), a generalist chewing herbivore known to feed on more than 250 plant species in Hawaii (Habeck, 1963; Siemann and Rogers, 2003b). The study demonstrates that invasive species liberated from herbivory may evolve greater competitive ability, allowing them to expand their ranges. However, in the presence of an abundant generalist herbivore from the native range, this did not occur.

In an experiment testing generalist herbivore choice between Chinese tallow and native sugar hackberry (*Celtis laevigata*), Siemann and Rogers (2003d) planted tallow tree and hackberry seedlings in three habitats (mesic forest, coastal prairie, and floodplain forest). Each test plot was treated with insecticide and fungicide to reduce insect herbivores and foliage fungus. As predicted by the Enemies Release Hypothesis (Keane and Crawley, 2002), Siemann and Rogers (2003d) hypothesized that, in absence of insecticide and fungicide application, hackberry seedlings will experience greater insect herbivory and fungal damage than Chinese tallow seedlings. Furthermore, in plots treated with insecticide and fungicide, hackberry seedlings would experience greater survival and growth rate than Chinese tallow, as a result of being liberated from specialist herbivores and fungal pathogens. Their results show that insect damage was lower on untreated Chinese tallow seedlings than untreated hackberry seedlings, as predicted. However, eliminating herbivores increased survivorship of Chinese tallow seedlings only, and fungicide application had no effect on survivorship of either species. They conclude that lower chronic herbivory on tallow compared to native plants is not responsible for Chinese tallow's success in Texas.

The role of subterranean herbivores in plant population dynamics and community structure has received considerably less attention than their above-ground phyllophagous counterparts (Andersen, 1987, Mortimer et al., 1999). In a second test of the EICA hypothesis as it relates to root tissue, Rogers and Siemann (2004) assessed the effects of mechanical root damage and soil fertility on two Chinese tallow genotypes-invasive (seeds from Texas) and native (seeds from China), in a factorial experimental design. Herbivore damage was simulated by mechanically severing the entire root system of Chinese tallow seedlings five centimeters below the soil surface, after which a 15-5-10 fertilizer was applied to each treatment. Several tallow tree seedlings abscised all of their leaves during the week following root damage, but all had added new leaves by the termination of the 150-day experiment. Consistent with the EICA hypothesis, Chinese genotypes were negatively impacted by simulated root damage, whereas the Texas genotypes were able to completely compensate for root damage. Addition of fertilizer increased the growth of the Chinese genotypes, but not enough to compensate for root damage. Texas genotypes were not influenced by fertilization treatments (Rogers and Siemann, 2004).

Numerous studies show that plant species may enhance their growth and fitness by developing extrafloral nectaries (EFN) to attract pugnacious insects (e.g., predacious ants and parasitoid wasps) that discourage herbivores (Bentley, 1977; Tilman, 1978; Moya-Raygoza and Larsen, 2001). Despite the benefits gained from enhanced protection against herbivores, the production of EFN, the effluent of which is primarily composed of carbohydrates and amino acids (Baker et al., 1978), may be detrimental to plants, particularly in the absence of a well-developed community of specialist herbivores (Bentley, 1997). In the absence of ants, the uncollected sugary secretions support black sooty mold that can be harmful. In the absence of herbivores, such as on some islands, selection reduces the gland structure and function. Chinese tallow plants have a pair of swollen, glandular stipules at the leaf-petiole junction (Correll and

Johnson, 1970; Urbatsch, 2000). However, the potential function of these EFN glands and conditions that stimulate their activity remains unknown. Rogers et al. (2003) tested the production of EFN on Chinese tallow seedlings in response to simulated foliar herbivory and nutrient enrichment. They hypothesized that tallow tree seedlings subject to simulated herbivory and those receiving nutrient (NPK) enrichment would have a greater number of active EFN than undamaged, unfertilized seedlings. They also predicted that Chinese genotypes would have significantly higher EFN production than Texas genotypes, as a consequence of higher specialist herbivore loads. They found that nutrient enrichment did not appear to stimulate EFN activity. Both invasive (Texas) and native (China) genotypes increased EFN activity following simulated herbivory, but there were no statistically significant differences between the two genotypes (Rogers et al., 2003). The function and activity of EFN in tallow remain elusive. Further studies should be conducted to determine differences in quality (i.e., sugar/amino acid concentrations) and quantity in EFN effluent in Chinese tallow's native and introduced range.

Invasive plant species normally support diverse insect communities within 300 years of introduction (Strong, 1974). Until that time, potential herbivores may be behaviorally constrained because they do not recognize an invasive species as a potential food source under natural conditions, despite the fact that the host plant may be palatable. This is referred to as the Behavioral Constraint Hypothesis (Feeny, 1975; Abrahamson and Weis, 1997). The time lag may also be explained by the fact that introduced plant species may possess novel secondary compounds to which native herbivores are not physiologically adapted (the Novel Weapons Hypothesis) (Callaway and Ridenour, 2004). Both of these constraints require an evolutionary response from native insect fauna in order for generalist herbivores to utilize invasive plant species. These hypotheses were tested by Lankau et al. (2004) to determine whether feeding behavior is plastic or fixed by evolutionary constraints. They conditioned two species of acridid grasshoppers (*Melanoplus angustipennis* and *Orphullela pelidna*), an abundant and important herbivore of prairie ecosystems, with either Chinese tallow or sugar hackberry (*C. laevigata*) seedlings, and then released them into a prairie ecosystem enclosure containing a single tallow tree seedling of either introduced (Texas) or native (China) genotype. They determined that grasshoppers consumed similar amounts of both genotypes, suggesting that Chinese tallow may have been a palatable host plant since its introduction, but that fixed behavioral avoidance by generalist herbivores may contribute to Chinese tallow's low herbivore load in its introduced range (Lankau et al., 2004). In a similar experiment, Siemann and Rogers (2003a) conducted feeding trials whereby *M. angustipennis* grasshoppers were caged with a choice between Chinese tallow seedlings from Texas and China. Their data demonstrate that grasshoppers removed more foliage from introduced (Texas) foliage. They also found higher growth rates for the China seedlings compared to Texas seedlings, suggesting genetic variation in herbivore defense and growth responses (Siemann and Rogers, 2003b).

It is interesting to note that Johnson and Allain (1998) report observing "large concentrations of adult and juvenile leaf-footed bugs (*Leptoglossus zonatus*, Hemiptera: Coreidae) on Chinese tallow fruits at Brazoria National Wildlife Refuge (Texas). Densities of *L. zonatus* on fruits averaged approximately two individuals per fruit and approximately six individuals per fruit cluster." *L. zonatus* is known to feed on a wide range of native host plants; perhaps this species is in the initial stages of adapting, both behaviorally and physiologically, to feed on tallow tree seeds.

Rogers et al. (2000) examined growth and physiological responses of Chinese tallow foliage to various treatments of nitrogen, shade, and simulated herbivory. Contrary to their prediction that, under high levels of herbivory, Chinese tallow would show significant decreases in leave tissue growth and physiological activity, they found that tallow is extremely tolerant of foliar tissue damage and is capable of expedient morphological and physiological compensation to herbivore damage. These data concur with a later study by Rogers and Siemann (2003), who found that Chinese tallow seedlings were remarkably tolerant to both low-intensity, chronic defoliation and high-intensity acute foliation. Neither treatment negatively impacted tallow tree seedlings. Studies of simulated herbivory are often criticized because certain aspects of insect chewing cannot be accurately imitated by manual tearing or hole-punching foliage (Hendrix, 1988). Furthermore, many phytophagous insects release chemicals during chewing that elicit specialized responses from plants. Nevertheless, if performed carefully, it is assumed that simulated foliar herbivory provides an adequate representation of decreased leaf area and biomass experienced by insect herbivores (Hendrix, 1988; Rogers et al., 2000). Studies investigating herbivore-plant interactions may reveal mechanisms by which pernicious pest plant species escape density-dependent regulation and provide insight into possible control and management.

Allelopathy

The lack of significant top-down regulation (i.e., herbivory, predation, pathogens) on aggressive non-indigenous plant species suggest that other mechanisms must be involved to contribute to the success of these species in their host range. One such mechanism is allelopathy, whereby non-indigenous plants release novel chemical compounds that have deleterious effects on neighboring native species. Chinese tallow is known to possess a suite of toxic secondary metabolites in every part of the plant, so it is possible that this species does in fact gain a competitive advantage through chemical mediation, either by suppressing the growth and fitness of neighboring plants or facilitating its own growth.

Keay et al. (2000) hypothesized that Chinese tallow invasion in coastal herbaceous grasslands may be mediated in part by chemical inhibition. They applied aqueous extracts of leaf tissue to seeds of little bluestem (*Schizachyrium scoparium*) sown in cups filled with potting soil. Results show that germination of *Schizachyrium* was neither reduced nor slowed. These results were corroborated by experiments by Conway and Smith (2002), who tested potential allelopathic effects of Chinese tallow on native black willow (*Salix nigra*) and baldcypress (*Taxodium distichum*) seeds, as well as seeds of Chinese tallow. They applied aqueous extracts derived from tallow litter, woodland soil subtending tallow stands, and fresh tallow tree leaves, to seeds sown in petri dishes.

Results show that aqueous extracts did not inhibit germination and seedling root mass and length of native species when compared to seeds treated with distilled water (control). However, germination rates and all seedling measurements of tallow were higher for seedlings receiving aqueous extracts than for controls. These patterns suggest that Chinese tallow may facilitate and perpetuate its own growth and survival rather than inhibit establishment and survivorship of native species.

Adaptive Management Approach

An effective management strategy for long-term control Chinese tallow requires an integrated pest management (IPM) plan, which involves the application of biological, chemical, mechanical, and physical control techniques. A description of each these management strategies may be found in the "Management Techniques" section of this document. Prior to implementing an IPM plan, stewards of natural areas are encouraged to consider using an adaptive management approach, which requires establishing clear management goals, developing control programs based on those goals, and modifying the goals based on the outcome of post-treatment assessment (Randall, 1996).

Prior to implementing a Chinese tallow control program, vegetation managers should 1) establish management goals and objectives for their natural areas; 2) determine which populations threaten the most sensitive habitats and/or species, or have the potential to do so and assign priorities for control based on anticipated impacts; 3) determine what control methods are available and, if necessary, re-assign management priorities based on this information; 4) develop and implement an integrated management plan based on the aforementioned criteria; 5) monitor population dynamics and treatment efficacy in terms of originally stated goals and objectives, and; 6) re-evaluate, modify, or otherwise enhance the plan, as needed.

When establishing goals for a site-specific control plan, the following ecological, economic, social, and managerial factors should be considered (Thayer, 1997):

1) **Spatial Distribution**: The aerial extent of the invasion, plant density, and dispersion (i.e., clumped, random, uniform) of the species to be managed, as well other plant communities in the vicinity of treatment sites.

2) **Topography and Soil Types**: What is the spatial distribution of soils subtending target populations? Is there a relationship between soil type and elevation? What are the soil characteristics (e.g., marl, sand, loam, etc.)?

3) **Hydrology**: Has the site been altered by hydrologic features, such as remnant agriculture, canals, impoundments or wells that modify natural hydrologic regimes?

4) **Control Techniques**: Which treatment or combination of treatments will most likely be effective for the natural area being treated, based on available literature and practical experience? What is the most effective timing of treatments and what factors significantly influence treatment success?

5) **Economic Considerations**: What is the anticipated cost associated with initial treatment of sites, as well as re-treatment and monitoring? What time period will be required before the site reaches a "maintenance level" of population growth?

6) **Public Outreach**: Will the control program create negative public perception? Although difficult to communicate, it is critical that the public recognizes that "not all plants are necessarily good." Will a public awareness campaign increase awareness and foster support of control programs?

7. **Work Plan**: In order to plan for annual budgeting needs, labor, equipment, and logistics, establish a realistic schedule as an objective for initial treatment and follow-up/maintenance control.

<u>Management Techniques</u>

A successful control program for Chinese tallow will require an IPM approach - the integration of all available control techniques, including biological, mechanical, physical, and herbicidal methods. The current state of tallow control in Florida is not truly integrated, because biological control agents are not yet available. Furthermore, physical control methods, such as prescribed burning and hydrologic manipulation, remain either poorly understood or untenable to implement on large scale. Mechanical control typically involves felling trees and hand-pulling seedlings and saplings. Herbicide control presently offers the only pragmatic and cost-effective means of controlling range expansion of Chinese tallow into natural areas.

Biological Control

One hypothesis seeking to explain the success of invasive species in their host ranges is the "enemy release hypothesis" (ERH). First proposed by Darwin (1859) and later by Williams (1954), Elton (1958) and Gillett (1962), the underlying assumption of the ERH is that plants are suppressed in their native range by co-evolved, specialist natural enemies (herbivores and pathogens), and that release from these enemies provides a mechanism by which invasive populations expand and spread rapidly in ecosystems into which they are introduced (Maron and Vilà, 2001). Classical biological control involves the introduction, establishment, and dispersal of host-specific natural enemies in an attempt to suppress the population density of a pest species.

Successful biological control agents reduce pest species density and attenuate the rate of expansion into new habitats. Biological control cannot completely eradicate a pest species, and is usually used in conjunction with other management techniques, such as mechanical, physical, and herbicide applications (IPM). The National Academy of Sciences (1987) advocates the use of biological control agents as the primary pest control method in the United States. Unfortunately, the current forecast for the effective use of biological control agents for mitigating the spread of Chinese tallow in Florida appears bleak. Indeed, Chinese tallow would seem to be a prime candidate for biological control efforts. Its closest congeners have limited distribution outside of the conterminous United States, and it has no significant economic value, honey production notwithstanding. Furthermore, there is evidence to suggest that, in its native range, particularly in the Zhejiang Province, there are "numerous problems with insects" (Scheld, 1983; Zhang and Lin, 1994). The most significant of these pests are observed to be root-feeding grubs, moths (identified colloquially as the "poisonous caterpillar"), bagworms, and red spider mites (Scheld, 1983). During a visit to the Zhehiang Province Science Study Institute to study large-scale seed production of Chinese ttallow, Scheld (1983) states, "there is a small larva(e)… either caterpillar or perhaps a beetle, which attacks and does considerable damage to the (seed) pods themselves. In the orchards observed this was apparently responsible for at least 10% loss in yield." Two bagworm species of the genus *Eumeta* (*E. japonica* and *E. mimuscula*), both native to Japan, are well-known pests of Chinese tallow (Nishida, 1983). These personal observations confirm the presence of a community of generalist and specialist herbivores, at least a few of which may be suitable candidates feeding trials. A list of insect herbivores known to feed on various tissues of Chinese tallow is provided in Appendix Two of this document.

Paradoxically, the USDA reports that no efforts have been initiated with regard to identification of biological control agents of Chinese tallow, primarily as a result of focusing resources on higher priority species, such as Old World climbing fern (*Lygodium microphyllum*

(Cav.) R. Br.) and Brazilian pepper (*Schinus terebinthifolius* Raddi) or individual lack of research interest (B. Pemberton, *pers. communication*). Even under the "best case" scenario whereby Chinese tallow became an immediate high-priority candidate species for biological control efforts, the process of foreign exploration, quarantine, mass culture, and release/colonization typically takes no less than a decade.

Mechanical Control

Mechanical removal involves the use of bulldozers and similar heavy equipment to remove vegetation. Mechanical control is usually ineffective when employed as the sole treatment of aggressive invasive plants, because soil disturbance may create conditions for regeneration from the (exposed) soil seed bank and from root fragments, and well as the possibility of invasion by pioneer exotic species. Additionally, mechanical removal is usually not appropriate in natural areas due to intense soil disturbance and damage to non-target vegetation caused by heavy equipment.

Mechanical control of Chinese tallow has proven to be ineffective and impractical at best, and in some cases may worsen invasion. The Northwest Florida Water Management District (NWFWMD) reports that efforts to manage Chinese tallow in Lake Jackson using mechanical methods have proven "impractical, and even counterproductive, as cutting results in the immediate production of multiple small, independent shoots" (Thorpe, 1996; Jubinsky, 1993). Efforts to control Chinese tallow infestations along canals at the Savannah National Wildlife Refuge (SNWR) using heavy equipment to sheer trees at a height of 1 meter above ground has also proven ineffective. Cut trees rapidly produced vegetative shoots and "runners" and exhibited phenotypic plasticity by assuming an extremely dense "shrub-like" growth form, with more branches to contribute to prolific seed production and significantly more leaf area for photosynthesis (McCormick, *pers. observation*).

Physical Control

Woody vegetation can be physiologically stressed or sometimes killed by hydrologic manipulation or fire. Constraints, such as liability involved with burning, and effects on desired vegetation, often will limit the usefulness of these methods. Grace (1998) concluded that the use of fire to control Chinese tallow in coastal Louisiana prairies is ineffective at best, and may in fact exacerbate infestations. This is attributed, in part, to a number of morphological and physiological adaptations to fire exhibited by Chinese tallow, including the following:

- As tree diameter increases, thickening of the bark protects the cambium layer from damage to secondary growth. Above some minimum size, Chinese tallow appears resistant to top-kill (i.e., death of the above-ground portion of the plant) by fire.

- For smaller trees or trees subjected to extremely hot fires, response to top-kill is vigorous resprouting with the potential to produce up to 2 meters of regrowth within a single growing season. Consequently, tallow recovers from fire very quickly.

- As a consequence of damage by fire or mechanical cutting, Chinese tallow responds by root sprouting at some distance from the original plant, resulting in clonal spread for distances typically greater than 5 meters.

- Only the hottest fires are expected to ignite Chinese tallow, and trees typically neither carry nor transmit fire through the canopy, unlike many trees and shrubs.

- Chinese tallow stands are characterized by "low flammability" because it competitively excludes pyrogenic species that drive fire. Grace (1998) states, "it is common to watch a prescribed fire burn right up to the edge of a tallow stand and simply go out because of a lack of fuel." As a consequence, fire-regulated prairie communities invaded by tallow shift from being fire-regulated to tallow-regulated.

Herbicide Control

Large areas: Make basal bark application, according to label instructions, of triclopyr ester-containing herbicide such as Garlon 4™ or Pathfinder II™ or cut stump application of triclopyr ester or triclopyr amine containing herbicide such as Garlon 3A™. Use at least 20% dilution in oil for basal bark application and at least 10% dilution (water for triclopyr amine) for cut stump application. For cut stump application, apply herbicide solution immediately after cutting. Coppicing may be reduced by addition of imazapyr-containing herbicide (e.g., 3% Stalker™ or Arsenal™). Seedlings and saplings can be can controlled using foliar application (July to

October) of imazapyr-containing herbicide (1% water-solution of Arsenal™ or Habitat™), fosamine-containing herbicide (30% water solution of Krenite S™), or triclopyr ester-containing herbicide (2% water-solution of Garlon 4™). For trees growing in water, aquatic labeled herbicides such as Habitat™ (imazapyr) or Renovate™ (triclopyr ester) must be used.

Private Property: Homeowners with one or a few trees should use Brush-B-Gon™ or Brush Killer™ herbicide. These diluted herbicide products (8.0% and 8.8% triclopyr amine, respectively) are available in quart-size containers from retail nursery supply stores. Property owners with larger stands of trees can use the more concentrated Garlon 3A™ or Garlon 4™ (44.4% triclopyr amine and 61.6% triclopyr ester, respectively), available in 2.5-gallon or larger containers from farm supply stores. If the dead trees will remain standing, Garlon 4™ can be diluted at a rate of one part herbicide to five parts oil (i.e., 20%) and applied to the bark at the base of trees with stems less than 6 inches in diameter. Oil manufactured for this purpose is available from farm supply stores (Table 3). All herbicides are required to be clearly labeled with instructions regarding safe and accurate application of herbicides. If trees are treated during seed production, plant material should be disposed of in such a way that that seeds will not be dispersed to nearby habitats where they may germinate and produce new trees. Seedlings should be continually hand pulled before they reach seed-producing age.

Table 3. Herbicides for preventing sprouting of felled Chinese tallow trees (adapted from Langeland, 2002).

Herbicide	Application Method	Dilution	Availability
Brush-B-Gon™	Cut Stump	Undiluted	Retail Stores
Brush Killer™	Cut Stump	Undiluted	Retail Stores
Garlon 3A™	Cut Stump	1 Herbicide: 10 Water	Farm Supply Stores
Garlon 4™	Cut Stump	1 Herbicide: 5 Water	Farm Supply Store
Garlon 4™	Basal Bark	1 Herbicide: 5 Oil	Farm Supply Store

Physiological Considerations for Timing of Management

Conway et al. (1999) suggest applying foliar herbicides to Chinese tallow during its root replenishment period during leaf abscission, when root total non-structural carbohydrate (TNC) is highest and translocation of herbicides will be assimilated into perennating buds and organs, resulting in plant mortality.   Root TNC levels are highest during seed maturation until leaf abscission. Contrary to herbicide application, where treatment should coincide with highest root TNC levels, mechanical treatments should be timed to coincide with lowest root TNC concentration (Conway et al., 1999). Consequently, if mechanical treatment is implemented during tallow's seed formation stage (i.e., a period of lowest root TNC levels), a higher percentage of stand mortality should be achieved than at other times of the year (Conway et al., 1999) (Table 4).

Table 4. Chinese tallow root TNC levels from roots collected from trees in Texas (Adapted from Conway et al. (1999).

Phenological Stage	Date	Overall Root TNC Levels
Dormancy	Nov 1995-Jan 1996	47.94%
Bud Break	February 1996	47.30%
Leaf Development	Mar-April 1996	41.11%
Seed Formation	**May-June 1996**	**36.71%**
Seed Maturation	July-Aug 1996	51.69%
Leaf Abscission	**Sept-Oct 1996**	**60.72%**

Mapping Chinese Tallow

Best management practices of non-indigenous invasive plant species requires spatially detailed assessments of species distribution and numbers, acquired at regular intervals (Turner et al., 2003). Such information can be prohibitively expensive and/or logistically impossible to collect directly in the field. Measuring the distribution and status of invasive species indirectly through remotely sensed data offers rapid data acquisition with relatively expedient generation of map products and spatial statistics at costs that are usually lower than direct field survey methods.

Determining spectrally unique responses from individual species in various phenological stages of a plant's life history is critical in detecting populations of invasive species among a mosaic of vegetation communities (McCormick, 1999). Ground reflectance measurements indicate that tallow is characterized by higher-than-average reflectance in the red portion (0.63-0.69μm) of the visible electromagnetic spectrum during autumn months when tallow tree foliage turns crimson prior to abscission. Everitt et al. (2000) evaluated the efficacy of large-scale color infrared and conventional ("true color") films to detect tallow among coastal prairie and marsh habitats in coastal Texas. They report that, although Chinese tallow could be distinguished on both film types, it was more accurately delineated on true color film. Their results concur with those of Ramsey et al. (2002), who used scanned 1:12,000-scale color infrared (CIR) aerial photographs acquired during leaf senescence to detect tallow in transition habitats of the Texas-Louisiana border. They conclude that high spatial (less than one meter) but low spectral resolution remote sensing data was most useful in detecting and mapping Chinese tallow to greater than 90% accuracy. They speculate that higher accuracy might be obtained by using true color photographs, as a consequence of Chinese tallow's asynchronous and highly variable autumnal foliage. Ramsey and Nelson (2005) successfully applied an atmospheric correlation algorithm to hyperspectral image data to maximize the spectral uniqueness of tallow occurring within a mosaic of native upland and wetland vegetation forest communities (e.g., cypress-tupelo) and at low/scattered density. In a pilot study assessing the efficacy of coupling hyperspectral imagery with "precision farming" techniques, Mason (*pers. communication*) is mapping the distribution of Chinese tallow on lands owned by the St. John's River Water Management District, and using the resulting spatial data to determine specific herbicide treatment sites and quantities for District vegetation managers. Using canopy reflectance data sampled from 35 tallow trees, a "training set" was developed for spectral signature detection across 11 bands. Subsequent distribution maps were developed based on data in this "spectral library". Ground truth data based on 100 sample points estimate accuracy of thematic map products at 85% or better. This novel mapping service is currently being marketed by UAP Timberland and will assist vegetation managers in developing accurate annual management budgets and facilitate the coordination of labor, logistics, and treatment schedules.

In addition to generating map products and spatial statistics, remotely sensed data can also used as a basis for developing predictive models regarding species distributions. Albright et al. (2004) are developing a cooperative agreement between the U.S. Geological Survey (USGS) and the Chinese State Bureau of Surveying and Mapping to document the current distribution of Chinese tallow in both its native and host ranges and determining the physiographic and biological parameters that facilitate or limit its distribution within these habitats. They are planning to utilize these data to develop predictive spatial models describing the potential future distribution of Chinese tallow if allowed to spread under current and various climate and land use change scenarios.

Case Studies

Eglin Air Force Base (Niceville, Okaloosa County, Florida)

Eglin Air Force Base is one of the largest forested military reservations in the world, spanning some 464,000 acres in northwest Florida. The Eglin landscape contains almost half of the 83 natural community types recognized in Florida, providing habitat for more than 50 species on Florida's endangered species list and 12 federally listed species. In addition to containing one of the last major stands of long-leaf pine (*Pinus palustris*) on the Gulf coast, Eglin also contains sandhill pine, xeric hammock, upland hardwood and slope forest communities, as well as baygall, floodplain forest, wet prairie, and hydric hammock habitats.

On Eglin, the invasive species of greatest concern are Chinese tallow, cogon grass (*Imperata cylindrica*), torpedo grass (*Panicum repens*), and Japanese climbing fern (*Lygodium microphyllum*). Since its inception in 1995, the Eglin Invasive Non-native Species Control Program has removed more than 100,000 Chinese tallow trees from Air Force property. Additionally, all Chinese tallow trees planted decades ago in the base housing area and Eglin industrial areas for ornamental purposes have been removed.

Invasive species surveys are conducted by the Florida Natural Areas Inventory targeting at-risk high quality natural areas, as well as areas known to contain invasive non-native species. Survey information, maps, and GPS coordinates of these species can be provided to herbicide contractors, allowing rapid response and comprehensive treatment of large areas. Re-treatments are scheduled after two years or on an as required basis.

Santa Rosa Barrier Island

Chinese tallow was first documented in natural areas in the interdunal coastal swales (approximately five contiguous acres and scattered seedlings in surrounding areas) of Santa Rosa barrier island in 1995, after Hurricane Opal struck the Panhandle. The storm surge resulted in high mortality of mature slash pines and other native woody species due to saltwater inundation. Shortly after the water receded, thousands of tallow seeds germinated from the soil seed bank. Staff ecologist Dennis Teague believes that these seeds likely came from undocumented seed producing trees in the area that were killed along with the slash pines and other woody natives.

Initially, contractors attempted to hand-pull the rapidly emerging seedlings, but were quickly overwhelmed by their “carpet-like” density.

By 1999, the area was characterized by dense coverage of immature tallow trees (4-10’), which were treated that same year with a basal bark application with 18-20% Garlon 4™ and the adjuvant JLB™ Oil Plus Improved (or an equivalent oil carrier). Low-pressure sprays were applied with back-pack applicators to minimize drift and non-target mortality. Hand pulling small seedlings continued as necessary. Throughout 2000-2003, spot treatments were conducted to prevent sprouting, and on 21 December 2001, a restoration prescribed burn was conducted on three acres of the area with the dual objectives of removing dead woody debris and stimulating native plant growth. As of 2005, areas once infested with Chinese tallow have replaced by native groundcover. Spot treatments will be continue as required, in order to eliminate sprouting and regrowth. In 2002 and 2003, the entire area comprising Santa Rosa Island was treated for Chinese tallow and other woody invasive plant species. It is hoped that the Choctawatchee Bay will serve as a significant barrier to the continued dispersal of tallow seeds by avifauna from the mainland to Santa Rosa Island.

Eglin Main Base Property

The largest and most problematic infestation of Chinese tallow is located on the Main Base – a 50 acre site containing 15-20 year old trees of moderate to high density, surrounded by pine flatwoods. Vegetation surveys in 1999 revealed there was virtually no non-tallow species present in the herbacous layer. Thirty acres of the site had been cleared a number of years ago, but the project was abandoned and site was allowed to return to a semi-natural condition. Dennis Teague suspects that, once cleared, the site became vulnerable to tallow invasion from seed originating from landscape debris.

In 1999 and 2000 the area was treated with 18-20% Garlon 4™ and the adjuvant JLB™ Oil Plus Improved (or an equivalent oil carrier) using cut stump and basal bark application methods. High density seedings were hand-pulled when available labor permitted. Low-pressure sprays were used to minimize drift and non-target mortality and marking dye was used in solution to indicate treated plants. Follow up treatments were conducted in 2002 and 2004. In winter 2003, a 20-acre parcel was subjected to a prescribed burn to reduce fuel loading, facilitate access for re-treatments, kill seedlings, and stimulate native plant recovery. In 2003, the previously cleared area was mechanically treated with a brown tree cutter, which removes dense native vegetation (e.g., vines/scrub) that emerges following elimination of the tallow overstory and seriously limits access of sites for re-treatment. Treatment of this area is considered a success and will be monitored for post-treatment changes to vegetation succession and ecosystem processes. Additionally, it is expected that long-term spot-treatments will be required due to the existence of a large soil seed bank that had developed prior to initial treatment.

Staff biologist Dennis Teague attributes the program's success in controlling Chinese tallow on Eglin AFB with focusing attention on seed-producing trees, and prioritizing management areas such that sensitive habitats are treated first. "It may take a few years before you notice any success. After a while, though, treatments become quicker and cheaper and the areas recover with native species. The problem of dormant seeds in the soil still remains a challenge to long-term management." The annual budget for controlling exotic invasive species on Eglin AFB is approximately $55,000.

Payne's Prairie Preserve State Park (Micanopy, Alachua County)

Payne's Prairie Preserve State Park is a 21,000 acre designated Wilderness State Park in Micanopy, located approximately 13 miles south of Gainesville. Payne's Prairie is characterized by a mosaic of habitats, including marsh, wet prairie, ponds, open water, grassy fields, pine flatwoods, and hardwood hammocks. Since it was first documented in Payne's Prairie in 1996, Chinese tallow has become the most problematic invasive species in the Preserve, infesting approximately 5,000 acres of seasonally flooded wet prairie and marsh habitats. The buoyant seed is thought to have been dispersed via stormwater drainage from nearby Gainesville, where it has been extensively planted as an ornamental throughout the Historic District of the City.

Management efforts began in 1998, and are based on a combination of chemical, mechanical and physical control. Infested sites are first cleared and delineated using a bulldozer. Herbicide control is achieved with a basal bark or cut-stump application of Garlon 4™, with an 18% basal oil concentration. Depending on their density, seedlings are either hand-pulled, or treated with a foliar application of 1% Garlon 3A™. Following treatment of tallow, woody biomass, such as wax myrtle, salt bush, and box elder is chopped and crushed to prepare the site for a regular cycle of prescribed burning. Clearing infested sites in this manner makes Chinese tallow more conspicuous on the landscape, increasing re-treatment efficiency, and encourages the establishment of a diverse native herbaceous species composition. Although water levels are not directly manipulated in the Preserve, Chinese tallow trees are killed or at least physiologically stressed by prolonged flooding, depending on water depth (Jim Weimer, *pers. communication*). When funds and staff allow, treatment sites are revisited annually in November, when tallow trees are most conspicuous due to autumnal foliage. Control efforts are especially problematic in flooded sites because, although Chinese tallow thrives in these habitats, basal bark treatments cannot be applied in standing water, and field crew access to infestations are stymied.

Since FY 00-01, almost $300,000 has been budgeted for Chinese tallow control in Payne's Prairie, approximately one half of which is comprised of DEP-BIPM contracts. Despite removing an estimated 227,000 stems since the onset of their control program, there is currently more acreage invaded by Chinese tallow than in 1998. Although cost-sharing programs and DEP-BIPM-administered grants has been credited with much of the success of managing invasive plant species on state lands, greater results may be achieved by increasing funding for re-treatment programs, which ultimately dictate the long-term success of a invasive species control program. When asked if he considered the Chinese tallow control program a success, Payne's Prairie staff biologist Jim Weimer states, "The bottom line is… we're losing the battle."

St. John's River Water Management District

The St. John's River Water Management District (SJRWMD) jurisdiction covers approximately half a million acres, which is divided into conservation/restoration areas. While some of these areas contain no non-indigenous invasive plant species, most of them contain at least one problematic species – usually Chinese tallow, water hyacinth (*Eichornia crassipes*) or hydrilla (*Hydrilla verticillata*). The largest areas of tallow invasion are in Thomas Creek (Duval County) and Lake Jesup (Seminole County). The District's policy with regard to exotic species states that "… *established populations and isolated occurrences of plant and animal species not native to Florida will be monitored and either controlled, utilized, or eliminated*" (SJRWMD, 1990). Funding for and staffing of invasive species control programs are provided completely in-house. District Invasive Plant Manager Johnny Drew believes that the tallow on District lands was first introduced from surrounding nurseries, as well as from trees on private property serving as food sources for birds, which in turn disperse the seeds into adjacent natural areas.

Thomas Creek Conservation Area (Jacksonville, Duvall County)

Purchased by the District in 2001, the 6,000-acre Thomas Creek Conservation Area forms the boundary between Duvall and Nassau counties. Traveling east, the vegetation communities along the creek transition from a freshwater ecosystem of wax myrtle scrub, bald cypress swamps, loblolly pine flats and oak hammocks, to open expanses of salt marsh as the creek approaches the Nassau River. District vegetation mangers estimate that Chinese tallow current occupies 80% of Thomas Creek, much of it occurring as moderate density scattered individuals.

Herbicide control efforts began in 2003, consisting primarily of basal bark treatments of 25% Garlon 4™ (75% Bark Oil). If the site is inundated, field crews apply a cut-stump treatment of Arsenal™ and an oil-based surfactant with an SLN label ("Special Local Needs", a 24-C). When treating dense tallow "islands" on higher elevations, field crews access sites using ATVs and apply a foliar treatment over the crowns of trees. Since the majority of tallow is comprised of moderate density individuals, the District refrains from using aerial foliar treatments with high non-target impacts. Tallow saplings, if present in low density (defined as less than 50 individuals per acre) are hand-pulled. In persistently flooded areas, seedling survivorship is generally low. Therefore, seedlings are neither treated nor hand-pulled in these areas. Invaded areas are prioritized for treatment and follow-up by seasonal hydrologic regimes as well as weather. For example, tallow foliage is usually vulnerable to frost in the northern portion of the District, whereas the growing season in the southern portion of the District (i.e., Seminole County) is year-round. In those areas where frost damage occurs, field crews treat tallow infestations at the onset of the spring flush of foliage and continue until the winter months, when they shift their attention to tallow populations in the southern portion of the District.

Johnny Drew states that although he is confident that the District will meet its goal of achieving "manageable population levels" in Thomas Creek, total eradication of Chinese tallow is likely to be an unrealistic goal due to long-term soil seed bank recruitment, dispersal from surrounding seed sources, and difficulty in detecting outlying individuals.

Lake Jesup Conservation Areas (Sanford, Seminole County)

The Lake Jesup Conservation Area is a 5,257 acre floodplain along the eastern shore of Lake Monroe, providing flood protection, enhancing water quality, and protecting fish and wildlife habitat. Vegetation communities primarily include seasonally inundated prairie marshes and wooded hammocks. Chinese tallow is scattered throughout one-third of the site, much of it occurring as discrete, bell-shaped tree islands with numerous seed-bearing trees in persistently wet, low elevations areas (e.g., swales) and lower density saplings and seedlings colonizing the surrounding area.

Tallow treatment began in 1998-1999 and is confounded by persistent high water and difficulty of access by conventional means. To address this problem, the District employs an amphibious vehicle called a “marshmaster, equipped with an herbicide spray unit, to access tallow stands directly. Crews encircle tallow stands, and apply a foliar treatment of Arsenal™ with an oil surfactant to the canopy. Additional treatments and follow-up applications are performed in the same manner as the Thomas Creek site. According to Johnny Drew, he and his crew of nine field technicians have devoted a significant amount of resources to decreasing tallow populations to “manageable levels” in the Lake Jesup Conservation Area, and have successfully met their objective within two years of initial treatment. Assessment and monitoring of tallow population growth and range expansion on District property is carried out by visual observations made at regular intervals along a surveyed grid. Additionally, the District is participating in a pilot project involving the use of hyperspectral remote sensing data to quantify tallow distribution (described in the “Mapping” section of this document). A summary of expenditures, stems and area treated, and labor hours associated with controlling Chinese tallow within the Thomas Creek and Lake Jesup Conservation Areas are provided (Table 4).

Table 4. Summary of Chinese tallow management efforts in Lake Jesup and Thomas Creek, (1998-2004). Data provided courtesy of St. John’s River Water Management District.

Fiscal Year	**Herbicide Cost ($)**	**Agency Labor (hours)**	**# stems treated**	**Area Treated (acres)**
98-99	9,356	758	23,057	2,417
99-00	938	68	6,357	985
00-01	6,350	362	12,350	1,789
01-02	1,618	36	11,360	1,235
02-03	13,885	320	20,234	2,400
03-04	8,876	492	22,856	2,239
Total	41,023	2,036	96,214	11,065

St. Mark's National Wildlife Refuge (St. Marks, Wakulla, Jefferson, and Taylor Counties)

The St. Mark's National Wildlife Refuge was established in 1931 to provide wintering habitat for migratory birds, and is one of the oldest refuges in the National Wildlife Refuge System. It encompasses 68,000 acres spanning Wakulla, Jefferson, and Taylor counties along the Gulf Coast of northwest Florida. The Refuge contains expansive coastal marshes, key islands, tidal creeks and estuaries of seven north Florida rivers, and supports numerous species of flora and fauna, including seven federally-listed endangered species of birds, mammals, and reptiles.

In accordance with its mandate to conserve, protect, and enhance native fish, wildlife, and their habitats, the U.S. Fish and Wildlife Service is obligated to take "all necessary measures to reduce and control biological threats to native plant and animal communities, including invasive species." Chinese tallow is recognized as the most aggressive woody invader within St. Mark's NWR.

The main infestation of Chinese tallow is a 12.5 acre portion of the former "Mounds Field", which was abandoned from seasonal millet cultivation in 1981. Tallow is present in Mounds Field as medium density seed-producing trees and saplings. Staff biologists noted that this population had expanded exponentially over the previous five years, and appeared to have potential to further expand its range if not immediately eradicated. Additionally, because the infestation was located immediately adjacent to the congressionally-designated St. Mark's Wilderness Area, it was ranked as a high priority for control efforts.

There are no accounts of when tallow first colonized the site, but it was likely sometime after 1981. The site is now being actively managed by the FWS as pasture for migratory geese. The closest known significant infestation off-refuge is found on private lands and state road rights-of-way near Wakulla Station (S.R. 363). Infestations in that area persist despite recent land clearing for residential development. Since FY 2001, the St. Mark's NWR no longer receives annual federal funding specifically dedicated to exotics control, but continues to form productive inter-agency partnerships with the State of Florida Panhandle Uplands Invasive Working Group and the Florida Department of Environmental Protection-Bureau of Invasive Plant Management (DEP-BIPM).

In November 1998, the Mounds Field site was "walked down" with a D4 tractor, which crushes above-ground biomass without uprooting vegetation. At that time, the site was an "impenetrable tangle" of wax myrtle, tallow, palmetto, and smilax. The site is now primarily native herbaceous native high marsh vegetation (*Spartina patens*, *Spartina bakerii*, *Andropogon* spp., *Myrica cerifera*, etc.) with occasional Chinese tallow less than 6' in height. Herbicide treatments (Garlon 4™, 20-25% basal bark application) and prescribe burning have been conducted at the site each year since 1999.

Refuge biologist Michael Keys reports that, with a regular burning regime, native ground cover species are re-colonizing sites formerly occupied by monospecific tallow. Keys credits the DEP-BIPM as being a critical component to success in keeping tallow in St. Mark's NWR, and reports that "the worst of the Chinese tallow infestation is just about under control."

Public Campaign: Tallow Tree Replacement Program (Gainesville, Alachua County)

A successful plan to address the issue of non-indigenous invasive plant species relies upon public support and the recognition that all sectors of society have a stake in protecting Florida's natural areas (National Invasive Species Council, 2001). However, informing the general public that not all trees are beneficial can be difficult. Putz et al. (1999) coordinated a Chinese tallow tree replacement campaign in the City of Gainesville, Florida on Arbor Day, 1997, the goal of which was to garner public support for tallow control programs and increase awareness that individual horticultural choices may have environmental adverse consequences in neighboring natural areas (Figure 4). A number of stakeholders, including local, county, state, and federal governments, the University of Florida, garden clubs and native plant societies, and local commercial nursery growers, supported the efforts. Arbor Day ceremonies, which were attended by approximately 100 people, included presentations by Greg Jubinsky, a representative of FLEPPC and Jim Weimer, a biologist at Payne's Prairie Preserve. Events culminated in the felling of a Chinese tallow tree, followed by a cut stump treatment with herbicide. Three additional media events that highlighted the problem of tallow invasion were held, resulting in two articles in *The Gainesville Sun* (circulation 150,000) and coverage from local radio and television stations.

As an incentive for removing a tallow tree their property, several Gainesville nurseries offered homeowners a 30% discount on replacement native species. Overall, the program was regarded as a success, and an estimated 75 seed-bearing tallow trees were felled and treated throughout Gainesville from January-March 1997.

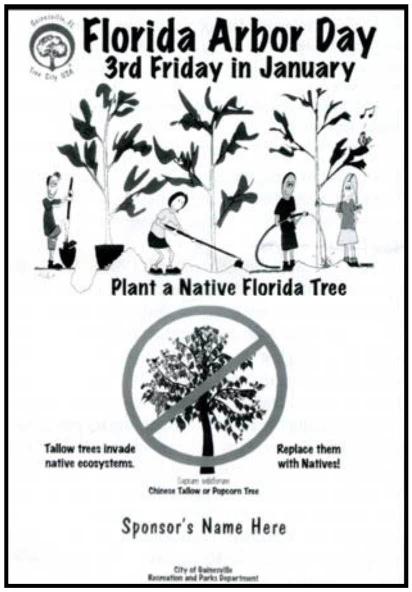

Figure 4. Promotional poster used for the Arbor Day Chinese tallow tree replacement program (from Putz et al., 1999).

The Arbor Day campaign elicited considerable public attention in the days following the event, including at least two "Letters to the Editor" of the *Sun* which were critical of the campaign, the city arborist, and those who cut tallow trees. The more vocal critics questioned the right of individuals to "kill" a tree, regardless of its ecological impact, while others complained that Arbor Day was an inappropriate day for a tree removal program (Figure 5).

Wrong Tool For Arbor Day

"I was quite disappointed to see the city arborist's decision to celebrate Arbor Day with a chain saw (guest column, Jan. 16). I certainly support the effort to replace tallow trees with native trees. However, the marking of a day dedicated to that important symbol of life and beauty – trees – by a tree-killing binge strikes me as way off the mark. It has been my understanding that Arbor Day celebrates the positive role trees play in nature and the community. There certainly is the understanding that some trees can become predators and dominate an ecosystem; therefore, it is good to remove them and replace them with more integrated species. Let us continue as long as there is replanting – not just removal. Nonetheless, I think it is objectionable of the arborist to celebrate Arbor Day with a chain saw."

Figure 5. Duplication of a "Letter to the Editor" published in *The Gainesville Sun* on January 20, 1997 (author name withheld).

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Glossary:

Aerial Seed Bank: Seeds stored in the canopy of a tree or shrub.

Acuminate: Tapering and drawn out into a narrow point.

Acute: Evenly narrowed into a point at an angle of less than 90 degrees.

Adventitious: Arising in an irregular or unusual position, such as roots along a stem or from leaves.

Alien Species: Any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem.

Allelochemicals: Compounds that have an allelopathic effect.

Allelopathy: The influence or effect of one living plant upon another; refers to biochemical interaction between all types of plants and its effect depends on a chemical compound being added to the environment.

Androgynous: Refers to an inflorescence composed of both staminate (male) and pistillate (female) flowers.

Arcuate: Curved or arched, fairly strongly.

Aril: Additional covering that forms on some seeds after fertilization, and developing from the stalk of the ovule.

Biological Control: The use of natural enemies, such as herbivores and pathogens, to reduce the damage caused by a pest population.

Caducous: Shed at an early age, ie caducous leaves.

Calyx: The outer series of leaf-like segments of the flower which is usually green in color, it may be large and colorful, present or absent. It encloses the flower while it is still a bud.

Cambium: The layer of tissue between the bark and wood in woody plants, from which new wood and bark develops.

Carpel: A simple pistil, regarded as a modified leaf; also, any of the two or more carpels that unite to form a compound pistil; the unit of structure of the female portion of a flower.

Control: As, as appropriate, eradicating, suppressing, reducing, or managing invasive species populations, preventing spread of invasive species from areas where they are present, and taking steps such as restoration of native species and habitats to reduce the effects of invasive species and to prevent further invasions.

Coppice: Woody biomass which has been regenerated from shoots formed at the stumps of the previous crop trees, root suckers, or both, i.e., by vegetative means. Normally grown on a short rotation for small material, but sometimes, e.g. some eucalyptus species, to a substantial size.

Dehiscence: Opening and shedding contents; said of stamens and fruits.

Denticulate: Having a small tooth (as in a leaf margin).

Dichogamous: Production of male and female reproductive elements at different times by a hermaphroditic organism in order to ensure allogamy.

Dormancy: A state in which seeds are prevented from germinating even under environmental conditions normally favorable for germination. These conditions are a complex combination of water, light, temperature, gasses, mechanical restrictions, seed coats, and hormone structures.

Ecosystem: Refers to the complex of a community of organisms and its environment.

Endangered Species: A species under threat of *imminent* extinction.

Endosperm: The food reserves within a seed.

Entire: With a smooth, even margin, lacking teeth or other indentations.

Epigeal: Living or occurring on or near the surface of the ground.

Eradication: Removal of every individual and propagule of an invasive species such that only reintroduction could allow its return

Exotic Species: A species introduced, purposefully or accidentally, from a native range.

Extinct: The *complete* global disappearance of a species from existence.

Extirpate: The local disappearance of a species, as opposed to extinction, which is global disappearance.

Fruit: The developed ovary of the flower containing ripe seeds, whether fleshy or dry, often used to include other associated parts such as a fleshy receptacle, then called a false fruit.

Genotype: The genetic constitution of an individual.

Glabrous: Naked, lacking hairs or scales.

Globose: Globe-shaped.

Habitat: The locality or external environment in which a plant lives.

Hypertrophy: An abnormal increase in the size of cells of a tissue. A morphological adaptation to physiological stress, such as the formation of lenticels on the bark of trees under water stress.

Imbibition: Absorption of fluid by a solid or colloid that results in swelling.

Indigenous: Native; originating or occurring naturally in the place specified.

Inflorescence: A flower or putting forth blossoms; the mode of development and arrangement of flowers on an axis; a flowering branch.

Integrated Pest Management (IPM): A pest control strategy that uses an array of complementary methods: natural predators and parasites, pest-resistant varieties, cultural practices, biological controls, various physical techniques, and pesticides as a last resort. It is an ecological approach that can significantly reduce or eliminate the use of pesticides.

Intraspecific Competition: A type of competition whereby an individual plant competes with one or more members of the same species for nutrients, space, light, etc.

Interspecific Competition: **C**ompetition between species for nutrients, space, light, etc.

Introduction: Refers to the intentional or unintentional escape, release, dissemination, or placement of a species into an ecosystem as a result of human activity.

Introduced Species: Species whose existence in a given region is due to human action or activity; this activity has led to its dispersal across natural geographic barriers, and/or has produced conditions favorable to its growth and spread.

Invasive Species: An alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health.

Latex: A milky exudate, drying rubber-like.

Lenticel: Corky spots on young bark, arising in relation to epidermal stomates.

Locule: A compartment of an anther or an ovary.

Monoecious: A plant species in which male and female organs are found on the same plant but in different flowers.

Native Species: With respect to a particular ecosystem, a species that, other than as a result of an introduction, historically occurred or currently occurs in that ecosystem.

Naturalize: To adapt to an environment not native; of foreign origin, but established and reproducing as though native.

Non-Indigenous Species: See "alien species."

Non-Native Species: See "alien species."

Orthodox Seed: **Seed** that can be dried and stored for long periods at reduced temperatures and under low humidity.

Persistent: Remaining attached after the normal function has been completed.

Petiole: Stalk of a leaf; hence petiolate.

Phenotype: The characters of an organism due to the interaction of genotype and environment, a group of individuals exhibiting the same phenotypic characters. The detectable expression of the interaction of genotype and environment constituting the visible characters of an organism.

Pistillate: Said of a flower bearing a pistil or pistils but not stamens, may refer also to a plant having only pistillate flowers.

Polyploid: a plant, or of a plant, with more than two sets (diploid) of the basic chromosome number (haploid) (cf. allopolyploid)

Precocious. Advanced in development; said of a species with a short period of juvenility. Flowers and bears fruit at a young age.

Propagule Pressure: Theory that predicts the greater the number and higher the rate of introduction, the better the chance of successful introduction.

Protogynous: A hermaphroditic organism that assumes a functional female condition first before changing to a functional male state. In plants, the stigma (female part of the flower) becomes receptive before anthers (male organs).

Raceme: Inflorescence having a common axis and stalked flowers in acropetel succession.

Root: The part of a plant, usually below the ground, that holds the plant in position, draws water and nutrients from the soil, stores food, and is typically non-green.

Seed: The part of a flowering plant that contains the embryo and will develop into a new plant if sown; a fertilized and mature ovule.

Seed Dispersal: The method by which a plant scatters its offspring away from the parent plant to reduce competition and expand range.

Soil Seed Bank: The soil seed bank consists of all viable seeds in the soil that have the potential to survive to reproduce. Seed banks can have transient seeds that germinate within a year of dispersal and persistent seeds that remain in the soil more that a year.

Species: A group of interbreeding individuals, not interbreeding with another such group, being a taxonomic unit including two names in binomial nomenclature, the generic name and specific epithet, similar and related species being grouped into a genus.

Spiciform: Spike-shaped.

Staminate: Producing or consisting of stamens; flowers with stamens but not pistils.

Stipule: One of a pair of leaf-derived organs inserted at or near the base of a petiole; hence stipulate.

Subulate: Awl-shaped, narrow and gradually tapering to a fine point

Threatened Species: Any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

Vector: A mechanism of transmission from one host to another. In terms of invasive species, a vector is a path, or method, of invasion. For example, a major vector in Zebra mussel invasion is ballast water.

Weed: Common-language term for a plant judged to be a nuisance.

Woody: Of or containing wood or wood fibers; consisting mainly of hard lignified tissues.

Appendix 1. Suggested native tree species for replacing Chinese tallow (from, Langeland, 2002).

Native Species	**Florida Hardiness Zones**
American Hornbeam (*Carpinus caroliniana*)	North, Central
Blackgum (*Nyssa sylvactica* var. *sylvatica*)	North, Central
Cedar Elm (*Ulmus crassfolia*)	North, Central
Eastern Hophornbeam (*Ostrya virginiana*)	North, Central
Eastern Redbud (*Cercis canadensis*)	North, Central
Flatwoods Plum (*Prunus umbellata*)	North, Central
Florida Maple (*Acer saccharum* spp. *floridanum*)	North, Central
Flowering Dogwood (*Cornus floridana*)	North, Central
Fringe Tree (*Chionanthus virginicus*)	North, Central
Geiger Tree (*Cordia sebestena*)	South
Paradise Tree (*Simarouba glauca*)	South
Red Bay (*Pursea borbonia*)	Throughout
Red Maple (*Acer rubrum*)	Throughout
Red Stopper (*Eugenia confusa*)	South
River Birch (*Betula nigra*)	North, Central
Satin Leaf (*Chrysophyllum oliviforme*)	South
Silverbell (*Halesia diptera*)	North, Central
Swamp Bay (*Persea palustris*)	Throughout
Turkey Oak (*Quercus laevis*)	North, Central
White Ash (*Fraxinus americana*)	North
Winged Elm (*Ulmus alata*)	North, Central
Non-Indigenous Species (but not invasive)	**Florida Hardiness Zones**
Crepe Myrtle (*Lagerstroemia indica*)	Throughout
Queens Crepe Myrtle (*Lagerstroemia speciosa*)	South
Trumpet Tree (*Tabebulia argentea*)	South

Appendix 2. Insect herbivores documented to consume Chinese tallow (Source: Zhang and Lin, 1994; translated from Chinese to English and provided courtesy of Dr. William E. Rogers, Texas A&M University, 2002).

Order	Family	Genus	Species	Distribution	Feeding Mode
Lepidoptera	Psychidae	*Acanthopsyche*			Bagworm
Lepidoptera	Saturniidae	*Actias*	*selene ningpoana*	China	Foliage
Coleoptera	Scarabaeidae	*Adoretus*	*tenuimaculatus*	Taiwan	Root/Leaf Eater
Lepidoptera	Noctuidae	*Agrostis*	*ypsilon*	Hawaii	Black Cutworm
Coleoptera	Scarabaeidae	*Anomala*	*corpulenta*	Paleoartic	Root/Leaf Eater
Coleoptera	Scarabaeidae	*Anomala*	*cupripes*	Paleoartic	Root/Leaf Eater
Coleoptera	Cerambycidae	*Batocera*	*horfieldi*	China/India	Stem Borer
Orthoptera	Gryllidae	*Brachytrupes*	*portentosus*	Taiwan	Foliage
Lepidoptera	Psychidae	*Chaliodes*	*kondonis*	China/Japan	Bagworm
Lepidoptera	Psychidae	*Clania*	*minuscula*	China	Bagworm
Lepidoptera	Psychidae	*Clania*	*variegata*	China	Bagworm
Lepidoptera	Limacodidae	*Cnidocampa*	*flavescens*	Indoaustralia	Foliage
Lepidoptera	Lymantidiidae	*Euproctis*	*bipunctapex*	China	Foliage
Lepidoptera	Eupterotidae	*Eupterote*	*saprivora*	China	Foliage
Coleoptera	Scarabaeidae	*Holotrichia*	*diomphalia*	Paleoartic	Root/Leaf Eater
Coleoptera	Scarabaeidae	*Madalera*	*orientalis*	Japan/Korea	Root/Leaf Eater
Coleoptera	Chrysomelidae	*Nodina*	*punctostriolata*	China	Foliage (AD)
Lepidoptera	Limacodidae	*Parasa*	*consocia*	Indoaustralia	Foliage
Lepidoptera	Hepialidae	*Phassus*	*excrescens*	China	Root Borer
Lepidoptera	Hepialidae	*Phassus*	*nodus*	China	Root Borer
Lepidoptera	Hepialidae	*Phassus*	*sinifer sinensis*	China	Root Borer
Lepidoptera	Saturniidae	*Philosamis*	*cynthia*	China	Foliage
Coleoptera	Scarabaeidae	*Popillia*	*mutans*	French Indochina	Root/Leaf Eater
Lepidoptera	Limacodidae	*Thosea*	*sinensis*	Indoaustralia	Foliage
Lepidoptera	Limacodidae	*Thosea*	*postornata*	Indoaustralia	Foliage
Heteroptera	Aphididae	*Toxoptera*	*odinae*	India/Taiwan	Foliage

UNIVERSITY OF FLORIDA

EXTENSION

Institute of Food and Agricultural Sciences

SS-AGR-45

NATURAL AREA WEEDS: Chinese Tallow (*Sapium sebiferum* L.)[1]

K. A. Langeland[2]

Introduction

Florida's natural areas--a great source of pride and enjoyment to its citizens--provide recreation, protect biodiversity and fresh water supplies, buffer the harmful effects of storms, and significantly contribute to the economic well-being of the state (Jue et al. 2001). Natural areas are protected in almost nine million acres (nonsubmerged) of state, federal, local and private managed conservation lands in Florida (Jue et al. 2001). Unfortunately, many of these natural areas can be adversely affected when they are invaded by nonnative invasive plant species. An estimated 25,000 plant species have been brought into Florida for use as agricultural crops or landscape plants. While only a small number of these have become invasive, those that do can adversely affect native plant communities by competing for space and resources, disrupting hydrologic and fire regimes, or hybridizing with native species. They must be managed for the protection of native communities in natural areas. Chinese tallow (*Sapium sebiferum* L.) is one of these invasive plant species.

How to Recognize Chinese Tallow

Chinese tallow is a deciduous tree with a milky sap that commonly grows to 30 ft tall. Leaves are simple, alternate, 1-2.5 inches wide, with broadly rounded bases and tapering to a slender point (Figure 1). Leaf stalks are 1-2 inches long. Small yellow flowers that are borne on spikes to 8 inches long occur in spring (Figure 2). The fruit is a 0.5 inch wide, 3-lobed capsule that turns brown at maturity to reveal 3 dull white seeds (Figure 1). The seeds, which often remain attached to the tree through the winter, resemble popcorn, suggesting the other common name of popcorn tree.

Distribution

The first record of Chinese tallow introduction into the United States is found in a letter from Benjamin Franklin written in 1772 to Dr. Noble Wimberly Jones of the Georgia colony. Franklin wrote: "I send also a few seeds of the Chinese Tallow Tree, which will I believe grow & thrive with you. 'Tis a most useful plant" (Bell 1966). As early as 1803, Chinese tallow was spreading into coastal

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Figure 1. Chinese tallow tree (*Sapium sebiferum* L.) can be identified by its simple, alternate leaves with broadly rounded bases that taper to a slender point and dull white seeds that remain attached after leaves have fallen.

Figure 2. In Spring, Chinese tallow tree displays spikes to 8 inches of small yellow flowers.

forests according to the noted French botanist Andre Michaux. Since Franklin's time, Chinese tallow has been introduced repeatedly to the United States as an ornamental and potential oil crop species. It is now naturalized in the outer coastal plain of South Carolina and adjacent North Carolina, south through Florida, and west to eastern Texas. Within Florida, Chinese tallow was naturalized in 57% of the counties in 1993 (Jubinsky and Anderson 1996) and found as far south as Dade County (Wunderlin et al. 1995).

Invasiveness

Chinese tallow has been recognized as a pest plant in the Carolinas since the 1970s (Langeland and Burks 1998). Within Florida, it has been reported from 46 natural areas (Florida Exotic Pest Plant Council Occurrence Database (http://www.fleppc.org)), and it is a target for removal from 12 natural areas in the Florida Department of Environmental Protection's Upland Invasive Exotic Plant Management Program (DEP Uplands Plant Control Summary, unpublished). Payne's Prairie State Preserve, south of Gainesville, Florida, once contained over 10,000 Chinese tallow trees (Jubinsky and Anderson 1996). Chinese tallow has been extensively used for ornamental planting and is a common plant on landscaped property. These trees present a constant source of seed for infestation of natural areas because the seeds are transported by birds such as pileated woodpeckers and grackles, as well as by water (Jubinsky and Anderson 1996). While the length of time needed to deplete the seedbank is unknown, indications are that seeds remain viable for many years (Jubinsky and Anderson 1966).

The Florida Exotic Pest Plant Council included Chinese tallow on its 1993 List of Florida's Most Invasive Species. **Chinese tallow was added to the Florida Department of Agriculture and Consumer Services Noxious Weed List (5b-57.007 FAC) in 1998. Plants on the Florida Noxious Weed List may not be introduced, possessed, moved, or released without a permit.**

Remove and Replace

Homeowners can help mitigate the problem of Chinese tallow trees in Florida's natural areas by removing them from their property. Mature trees should be felled with a chain saw by the property owner or a professional tree service. The final cut should be made as close to the ground as possible and as level as possible to facilitate application of a herbicide to prevent sprouting. Stumps that are not treated with a herbicide will sprout to form multiple-trunked trees (Figure 3).

Homeowners with only one or a few trees should use Brush-B-Gon or Brush Killer herbicide. These diluted herbicide products (8.0% and 8.8% triclopyr amine, respectively) are available in quart-size containers from retail nursery supply stores. Property owners with large numbers of trees can use the more concentrated Garlon 3A or Garlon 4 (44.4% triclopyr amine and 61.6% triclopyr ester, respectively), which are available only in 2.5-gallon or larger containers

Figure 3. Stumps of felled Chinese tallow trees that are not treated with a herbicide will sprout to form multiple-trunked trees.

from farm supply stores. If it is not objectionable for dead trees to be left standing, Garlon 4 can be diluted at a rate of 1 part herbicide to 5 parts oil and applied to the bark at the base of trees with stems less than 6 inches in diameter. Oil manufactured for this purpose is available from farm supply stores. The herbicide container will have a label with instructions for applying the herbicide. See Table 1.

If trees are cut at a time when seeds are attached, make sure that the material is disposed of in such a way the seeds will not be dispersed to new areas where they can germinate and produce new trees. Seedlings should be continually pulled by hand before they reach seed-bearing maturity.

Space in a landscape left after removal of Chinese tallow can be used to plant a new native or noninvasive non-native tree for shade, or some other landscape purpose. Tree species recommended in Table 2 are similar in size to Chinese tallow. Blackgum, maples, dogwood, and crepe myrtles provide fall color similar to Chinese tallow. Fact sheets that provide additional information on landscape plants can be viewed at http://hort.ifas.ufl.edu/trees/index.htm. For information on the availability of native landscape plant species contact the Association of Florida Native Nurseries (877/353-2366 or http://www.afnn.org). The Cooperative Extension Service Office in your county can help you identify plants appropriate to your property conditions, the ecosystems on and near your site, and your aesthetic preferences.

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Glossary

Natural area weeds: nonnative plant species that invade natural areas, usually adversely affecting native biodiversity and/or ecosystem functioning.

Natural areas: areas with native plant communities supporting native animal species, with relatively undisturbed soil systems, and hydrological and fire regimes relatively intact or under restoration.

Nonnative invasive plant species: Foreign plant species that produce reproductive offspring, often in very large numbers, at considerable distances from parent plants, and thus have the potential to spread over a considerable area.