

Florida's Brazilian Peppertree Management Plan



**Recommendations from the
Brazilian Peppertree Task Force
Florida Exotic Pest Plant Council**

*2nd Edition
April 2006*

Edited by J. P. Cuda, A. P. Ferriter, V. Manrique and J.C. Medal



**INTERAGENCY BRAZILIAN PEPPERTREE
(*Schinus terebinthifolius*) MANAGEMENT
PLAN FOR FLORIDA**

2ND EDITION

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J. P. Cuda¹, A. P. Ferriter², V. Manrique¹, and J.C. Medal¹, Editors

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The Brazilian Peppertree Management Plan was developed to provide criteria to make recommendations for the integrated management of Brazilian peppertree in Florida. This is the second edition of the Brazilian Peppertree management Plan for Florida. It should be periodically updated to reflect changes in management philosophies and operational advancements.

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I. EXECUTIVE SUMMARY

Brazilian peppertree, *Schinus terebinthifolius* Raddi (Anacardiaceae), is an aggressive, rapidly colonizing weed of disturbed habitats, natural communities and conservation areas in southern California, Hawaii, Texas, and peninsular Florida. In 1998, the U.S. Fish and Wildlife Service identified Brazilian peppertree as one of the most significant non-indigenous threats to federal listed endangered and threatened native plants throughout the Hawaiian Islands. This invasive shrub grows rapidly, tolerates a wide range of environmental conditions, and is a prolific seed producer. In Florida, Brazilian peppertree is a pioneer species of disturbed sites such as highways, canals, power line rights-of-way, fallow fields, and drained wetlands. Once established, it quickly displaces the native vegetation adjacent to the disturbance, often forming dense monocultures that reduce the biological diversity of plants and animals in the invaded area. Nearly 280,000 ha of all terrestrial ecosystems in central and south Florida are currently infested with Brazilian peppertree. As early as 1969, it was recognized as an important invader of the Everglades National Park. Today, vast monospecific stands of Brazilian peppertree pose a significant threat to restoration efforts in the Florida Everglades.

In the 1990s, the Florida Exotic Pest Plant Council's Brazilian Peppertree Task Force (BPTF), an interagency working committee of knowledgeable professionals, recognized that Brazilian peppertree represented one of the most serious threats to the ecology of Florida's natural areas, and was a high priority target for the development and implementation of a coordinated management plan. Although a broad array of control methods was available to manage existing stands of Brazilian peppertree, there was general agreement among public and private land managers that an ecologically-based integrated management plan was needed to provide an environmentally acceptable, cost effective, and permanent solution to this problem. This attitude was reflected in the first edition of the Brazilian Pepper Management Plan for Florida produced by the BPTF (Ferriter 1997). The initial Plan provided an overview of the problem and established criteria for making recommendations for a statewide management plan based on the best available knowledge.

This document is the first revision of the 1997 Brazilian Pepper Management Plan for Florida. It not only reviews the current literature on Brazilian peppertree but also incorporates recent advances in management philosophies and control methods as recommended in the original Plan. More importantly, this document describes for the first time site-specific integrated management strategies for Brazilian peppertree, and identifies the natural processes and mechanisms that can change the dynamics of plant communities in Florida currently dominated by this invasive weed. It also explains how ecological processes that are capable of having a selective and predictable population level impact on Brazilian peppertree can be manipulated using appropriate control technologies to permanently alter the plant's invasive characteristics.

II. INTRODUCTION

Problem Statement. Brazilian peppertree, *Schinus terebinthifolius* Raddi (Anacardiaceae), is an invasive weed that is threatening the biodiversity in Florida (Austin 1978, Loope and Dunevitz 1981a,b), California (Randall 2000) and Hawaii (Hight et al. 2003). This perennial shrub/tree that is native to Argentina, Brazil, and Paraguay (Barkley 1944, 1957) was most likely introduced into the U.S. prior to 1900 (Barkley 1944, Morton 1978, Mack 1991). According to Morton (1978), Brazilian peppertree was intentionally introduced into Florida by the USDA as an ornamental in 1898, presumably because of its attractive red berries that develop mostly from late October to December. However, there is other evidence to suggest that it was present 50 years earlier (Gogue et al. 1974, Schmitz et al. 1991), and that seeds were available in US trade as early as 1832 (Mack 1991). Although the plant was common in cultivation, it was a rare component of the flora in Florida until the late 1950s when Dr. Taylor Alexander discovered the first naturalized plants on Big Pine Key in Monroe County (Austin and Smith 1998).

In Florida, Brazilian peppertree is listed as a noxious weed (FLDACS 1999), a prohibited plant (FLDEP 1993), and a Category I invasive species by the Florida Exotic Pest Plant Council (FLEPPC 2005). In the early 1990s, it was estimated that > 280,000 ha (~1 million acres) mainly in the southern and central portions of the state were infested with Brazilian peppertree (Habeck 1995). Recent estimates based on aerial surveys indicate that approximately 3000 km² of all terrestrial ecosystems in central and south Florida have been invaded by this invasive weed (Ferriter 1997).

The invasiveness of Brazilian peppertree is attributed to its enormous reproductive potential. Large quantities of fruits, or drupes, are produced per plant, and wildlife disperses the seeds in their droppings (Morton 1978, Toops 1979). Brazilian peppertree outcompetes native plants because of its tolerance to conditions of extreme moisture (Ewe and Sternberg 2002, 2003) and salinity (Mytinger and Williamson 1987), its capacity to grow in shady environments (Ewel 1979), and possible allelopathic effects on neighboring plants (Gogue et al. 1974). In Florida, the plant readily invades disturbed sites (e.g., fallow farmlands) as well as natural communities such as pinelands, hardwood hammocks and mangrove forests, and is a major invader of the Everglades National Park (Ewel et al. 1982). Although the plant is still grown as an ornamental in California, Texas, and Arizona, Brazilian peppertree has been recognized as an invasive species in California (Randall 2000), and Texas (C. Chancellor, pers. comm.), and has become naturalized in over 20 countries worldwide (Ewel et al. 1982).

Goal. The overall goal of the BPTF is to develop and implement a strategic plan for protecting the integrity of Florida's natural ecosystems from further degradation caused by Brazilian peppertree. The goal of the BPTF can be achieved by shifting the successional dynamics of public and privately owned lands currently dominated by Brazilian peppertree towards more desirable plant communities where Brazilian peppertree is either eliminated or becomes a minor component of the flora.

Objectives. An overall reduction of Brazilian peppertree in Florida can be accomplished through the following objectives:

1. Develop and implement site-specific best management practices that will enhance the natural processes and mechanisms that direct vegetation change. By adopting an integrated management approach (see section IV), an economically feasible and environmentally sustainable solution to the Brazilian peppertree problem on Florida's public and privately owned lands can be achieved.
2. Implement an effective public information and awareness program that will provide basic information about the ecological impact of Brazilian peppertree in Florida's natural areas, and encourage the participation and support of the general public in issues related to the management of Brazilian peppertree.
3. Provide leadership in developing volunteer programs in different locations and provide training via demonstration projects in the latest techniques for controlling Brazilian peppertree on public lands and in urban areas.
4. Coordinate the support and resources from the Exotic Pest Plant Councils, Water Management Districts, federal and state agencies (e.g., Corps of Engineers, Department of Environmental Protection, Department of Transportation, Fish and Wildlife Conservation Commission, National Park Service, Nature Conservancy, and USDA) to leverage additional funding from the federal government for the management of Brazilian peppertree in Florida and elsewhere.

Recommendations. The following are priority recommendations as suggested by current and past members of the BPTF.

1. Maintain adequate funding for the continued discovery, evaluation and subsequent release of Brazilian peppertree biological control agents. The foundation of an effective management plan for an aggressive plant pest like Brazilian peppertree requires the successful introduction of host specific natural enemies from the weed's native range.
2. Encourage the adoption of IPM practices for Brazilian peppertree on all of Florida's public as well as privately owned lands.
3. Enhance existing control programs through coordinated efforts to seek partnerships with concerned citizen groups like the "Pepper Busters" and Master Naturalists.
4. Cooperate with state agencies and organizations such as Florida's Water Management Districts, Department of Environmental Protection, Cooperative Extension Service, Exotic Pest Plant Council, and Native Plant Society in the production and dissemination of training materials designed to educate the public about the problems associated with the introduction of invasive plants like Brazilian peppertree.

III. TECHNICAL BACKGROUND

Taxonomy

The taxonomy of Brazilian peppertree follows the higher classification scheme published by Mabberley (1997).

Kingdom Plantae
Division Magnoliophyta
Class Dicotyledonae (Magnoliopsida)
Subclass Rosidae
Order Sapindales
Family Anacardiaceae
IV. Rhoaeae
Genus *Schinus* L.
Subgenus *Euschinus*
Species *Schinus terebinthifolius* Raddi 1820

The order Sapindales, one of 18 orders within the subclass Rosidae, contains 15 families and about 5400 species. More than half of the species belong to only two families, the Sapindaceae and Rutaceae, each with nearly 1500 species. A well known but small family is the Anacardiaceae, consisting of 60-80 genera and about 600 species (Cronquist 1981, Fleig 1981). The family is distributed primarily pantropically, but some species occur in temperate regions.

Members of the Anacardiaceae are trees, shrubs, or woody vines that are characterized by the presence of well-developed resin ducts (or sometimes latex-channels) throughout most plant parts. Familiar examples of this plant family include sumac (*Rhus*), mango (*Mangifera*), pistachio (*Pistacia*), cashew (*Anacardium*) and poison ivy (*Toxicodendron*). These plants usually have alternate, pinnately compound or trifoliolate leaves, flowers that are most often unisexual, 5-merous, and with a 5-lobed nectary-disk, and typically drupaceous fruits (Cronquist 1981). Kartesz (1994) includes the additional genera *Comocladia*, *Cotinus*, *Lithrea*, *Malosma*, *Metopium*, and *Spondias* in his list of flora of the United States, Canada, and Greenland. The highly poisonous *Lithrea molleoides* (Vell.) Engl. from South America was planted in California as an ornamental (Bailey and Bailey 1976). *Comocladia* spp., originally from the Caribbean region and Central America, also have a very poisonous sap that causes swelling and blisters in the skin similar to poison ivy (Standley and Steyermark 1949).

Michaux's sumac or false poison sumac, *Rhus michauxii* Sarg., is currently listed as an endangered species by the U.S. Fish and Wildlife Service (USFWS 1989). This endangered sumac has a restricted distribution in the southeastern United States. Historically, Michaux's sumac occurred in Alachua County, Florida (Wunderlin and Hansen 2003), Georgia, North and South Carolina, and Virginia. There have been unconfirmed reports that a relict population of Michaux's sumac has been sighted in the Ocala National Forest, Marion County, Florida.

The plant family Anacardiaceae is represented in Florida by the following native species: poisonwood, *Metopium toxiferum* (L.) Krug and Urb.; poison ivy, *Toxicodendron radicans* (L.) Kuntz; poison oak, *Toxicodendron toxicarium*, (Salib.)

Gillis; poison sumac, *Toxicodendron vernix* (L.) Kuntze; and shining sumac, *Rhus copallinum* L. (Brizicky 1962, Wunderlin and Hansen 2003).

Poisonwood, *M. toxiferum*, is an important native pioneer species that coexists with Brazilian peppertree in south Florida's pine rockland community (Austin and Smith 1998). Its distribution is limited to southeastern Florida and the Keys. The fruits are considered an important food for the white-crowned pigeon, *Columba leucocephala* L., during the nesting season (Austin and Smith 1998). The white-crowned pigeon is considered a threatened species in Florida (FLFWCC 1997).

Other species of the plant family Anacardiaceae have been introduced into Florida and are currently cultivated for their edible fruits or seeds, including mango, *Mangifera indica* L., pistachio, *Pistacia* spp., and *Spondias* spp. The closely related plant family Rutaceae includes such fruit crops as orange, grapefruit, and lemon (*Citrus* spp.) that contribute significantly to Florida's economy, and whose distributions overlap with Brazilian peppertree.

The genus *Schinus* L. is native to South America and includes approximately 29 species (Barkley 1957). The genus name *Schinus* was established by the famous Swedish naturalist Carolus Linnaeus in 1753, and was derived from the word 'schinus', the Latin name for the Mastic tree (*Pistacia lentiscus* L.). Members of the genus have been introduced into other countries as ornamentals and for spice production (Morton 1978, Salamon 1981, Horta 1988). The center of distribution is northern Argentina (Barkley 1944, 1957). Four *Schinus* species have been introduced into the continental United States: *S. longifolius* (Lindl.) Speg. in Texas (Fig. 1), California peppertree *S. molle* L. (type species) in California, Texas, Florida, Hawaii and Puerto Rico (Fig. 2), *S. polygamus* (Cav.) Cabrera in California (Fig. 3), and Brazilian peppertree in California, Florida, Hawaii, Texas, Puerto Rico, and the Virgin Islands (Fig. 4).

Of the three *Schinus* spp. established in North America, only California peppertree (*S. molle*) is recognized as having ornamental value. This nonnative species from Peru was introduced into California almost 200 years ago as a shade tree. Although it is a popular ornamental, its potential to become invasive was first recognized 20 years ago (Nilsen and Muller 1980a,b). Recently, the California Invasive Plant Council listed California peppertree as an invasive species (Cal-IPC 2006).

Brazilian peppertree and its nonnative congener California peppertree belong to the subgenus *Euschinus*, which includes those species that have unarmed branches, compound leaves and paniculate inflorescences; *S. longifolius* and *S. polygamus* belong to the subgenus *Duvaua* that include species with spiny branches, simple leaves, and pseudoracemose inflorescences (Barkley 1944). It is noteworthy that California peppertree and Peruvian peppertree, *S. polygamus*, are exhibiting invasive characteristics in California similar to Brazilian peppertree in Florida and Hawaii (Morisawa 2000).

Brazilian peppertree (*S. terebinthifolius*) was first described in 1820 by the Italian botanist, Giuseppe Raddi (1770-1829). The specific epithet '*terebinthifolius*' is derived from the words 'terebinthus', the Latin name for the Terebinth tree (*Pistacia terebinthus* L.), and 'folium', or leaf, which refers to the resinous leaves that are similar to the Terebinth. Five varieties of *S. terebinthifolius* are recognized by Barkley (1944). Differences between the varieties are loosely based on several vegetative characters, including leaf length and also the number, shape and margins of the leaflets (Barkley 1944). Two varieties of Brazilian peppertree apparently were introduced into Florida

(see below). The synonymy of Brazilian peppertree is listed by Wunderlin and Hansen (2003) as follows: *Lithraea chichita* (Speg.) Speg., *Sarcotheca bahiensis* Turcz., *Schinus antiarthriticus* Mart. Ex Marchand (refers to the anti-arthritic action of its resin), *Schinus aroeira* Vell., *Schinus chichita* Speg., *Schinus mucronulata* Mart. (refers to the pointed leaf tip or mucro), *Schinus rhoifolius* Mart., *Schinus terebinthifolius* Raddi var. *acutifolius* Engl., *Schinus terebinthifolius* Raddi var. *aroeira* (Vell.) Marchand, *Schinus terebinthifolius* Raddi var. *pohlianus* Engl., *Schinus terebinthifolius* Raddi var. *glaziovianus* Engl., *Schinus terebinthifolius* Raddi var. *rhoifolius* (Mart.) Engl., *Schinus terebinthifolius* Raddi var. *selloanus* Engl., *Schinus terebinthifolius* Raddi var. *raddianus* Engl.

Brazilian peppertree is known by several common names depending upon the country where occurs. For instance, in the continental United States, Brazilian peppertree also is known as Brazilian pepper, pink pepper, and peppertree; in Brazil, aroeira, aroeira-vermelha, aroeira-da-praia; in Cuba, Copal; chichita in Argentina; pimienta de Brasil in Puerto Rico; warui in Fiji and faux poivrier in the French Riviera (Morton 1978, Fleig 1981). In Hawaii, the plant is called wilelaiki, nani-o-hilo, and Christmasberry due to its attractive green foliage and red fruits that ripen in December. Its shiny green leaves and bright red fruits that mature during the holiday season in Florida made it a popular substitute for holly. It quickly earned the name of Christmas pepper or “Florida Holly,” and was sold by the state’s wholesale and retail nursery industry until 1990 when it was banned for commercial use (Morton 1969, Austin and Smith 1998).

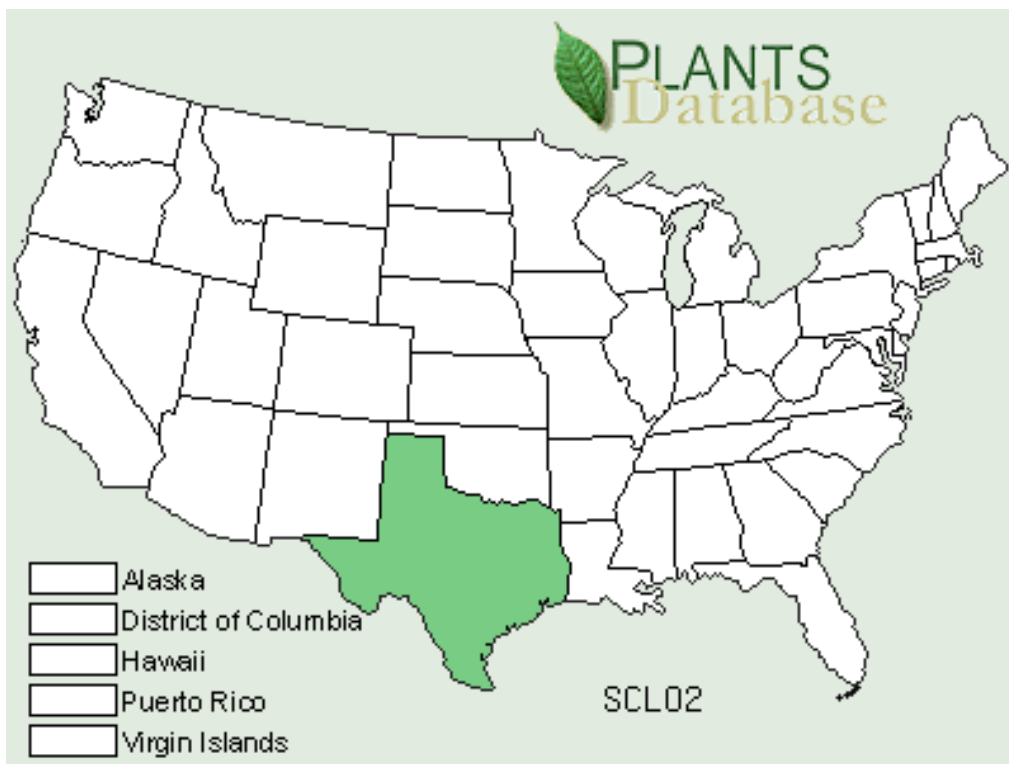


Figure 1. US distribution of *S. longifolius* (Source: USDA, NRCS 2006).

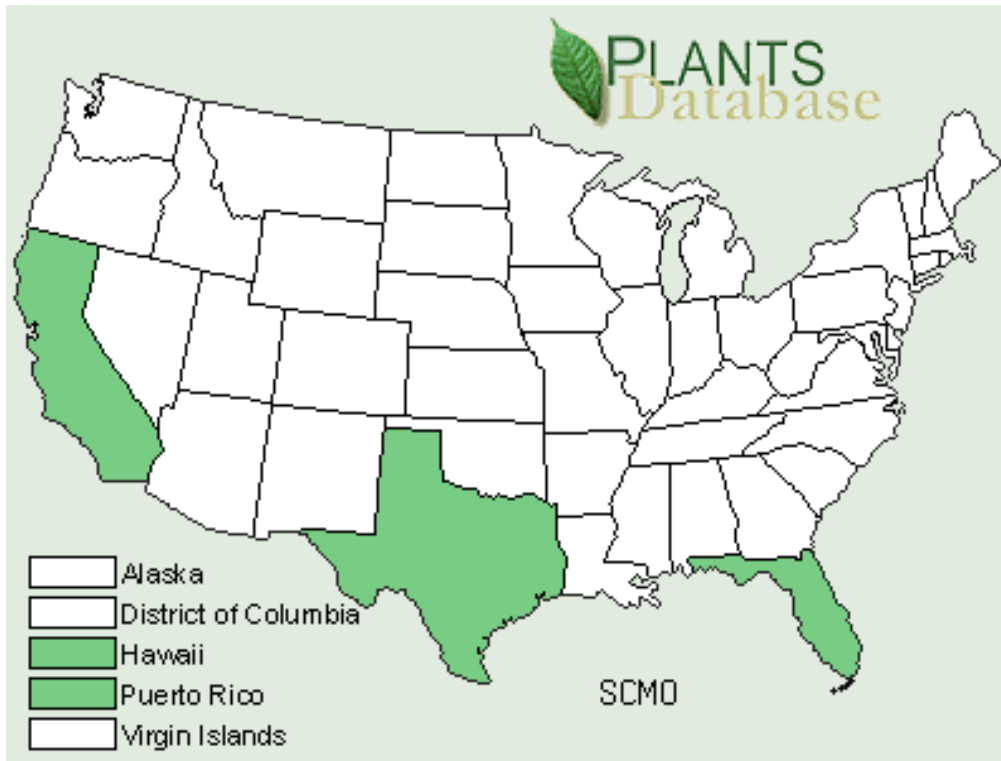


Figure 2. US distribution of *S. molle* (Source: USDA, NRCS 2006).

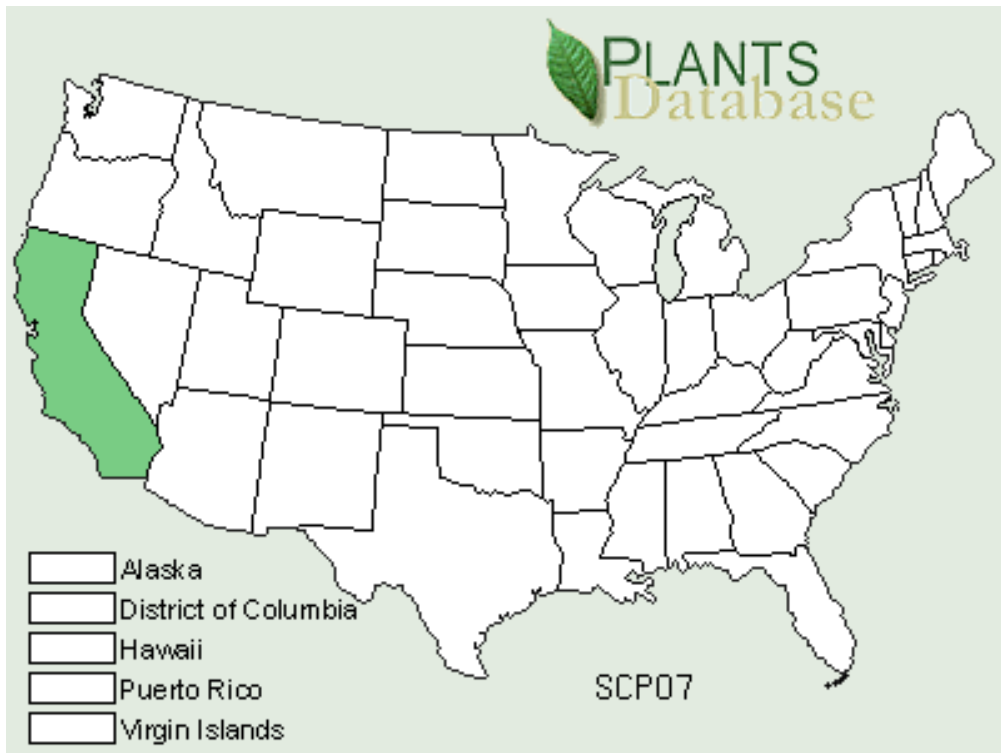


Figure 3. US distribution of *S. polygamus* (Source: USDA, NRCS 2006).

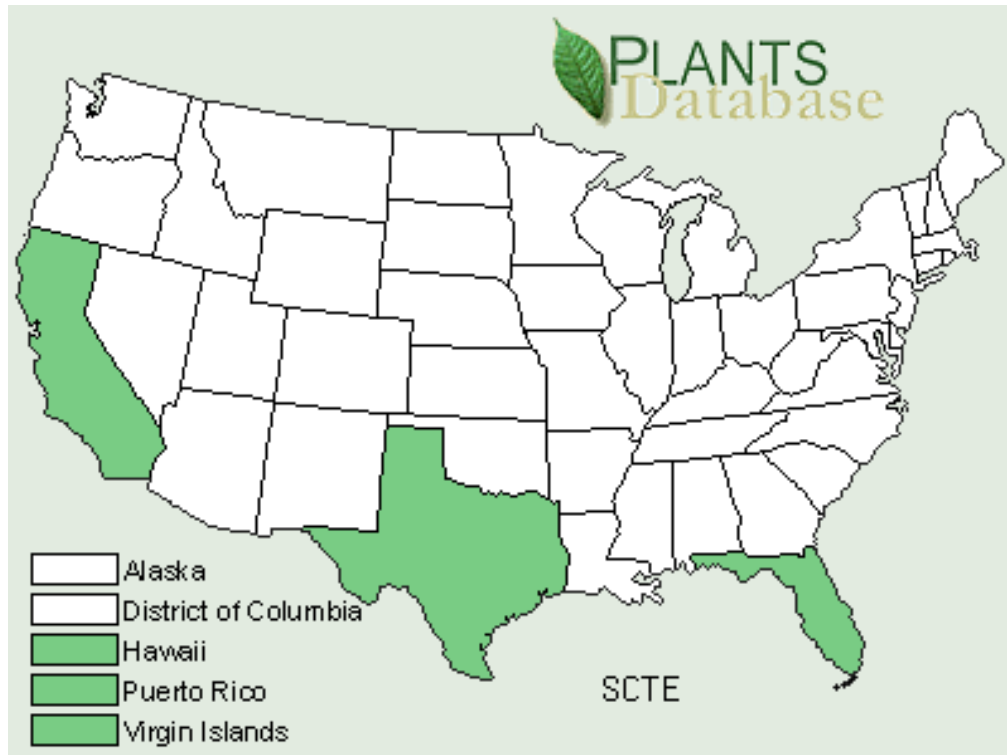


Figure 4. US distribution of *S. terebinthifolius* (Source: USDA, NRCS 2006).

Description. The following description of Brazilian peppertree was synthesized from several sources (Raddi 1820, Ewel et al. 1982, Tobe et al. 1998, Langeland and Burks 1998, and Randall 2000). Brazilian peppertree (Fig. 5) is a large evergreen shrub or small tree, height up to 7.5 m; branches multi-stemmed, arching and crossing to form a nearly impenetrable tangle to ground level; bark typically gray and smooth; leaves alternate, aromatic, evergreen, odd pinnately compound and generally opposite (8-20 cm including petiole) with shiny resinous coating; leaflets in opposite pairs and terminally single, 3-11 (usually 7-9) thin, sessile, oblong-elliptic to lanceolate (2-7 cm long by 1-3 cm wide), glabrous, margins entire, crenate or prominently toothed, upper surface dark green, lower surface paler, tips and bases usually blunt or rounded; inflorescence either axillary or terminal panicle; flowers unisexual on same plant (dioecious), greenish white with 5 petals (1.2-2.5 mm) and pedicel to 4 mm; fruit generally pink to bright red spherical drupe (4-7 mm diam.) containing a single seed and arranged in dense clusters.

Barkley (1944) described five varieties of Brazilian peppertree in South America based solely on morphological characters. Vegetative and reproductive morphological differences between varieties are noted below (Barkley 1944, 1957, Campbell et al. 1980):

- var. *terebinthifolius*: leaves 8-17 cm long; lateral leaflets 4-6, oblong-elliptic to obovate in shape, toothed to subentire margins, rounded to pointed tips; unwinged short petiole to 3 cm long. Inflorescences 2-11 cm long, triangular to lanceolate, leaf-like bracts with ciliate margins; pedicels 1 mm long; sepals triangular, ciliate margins; petals glabrous to ovate.

- var. *acutifolius*: leaves 7-22 cm long; leaflets 7-15, lanceolate in shape, margins obscurely toothed to smooth (entire), tips pointed, sessile; petiole to 4 cm long. Inflorescences 3-15 cm long, sparsely hairy, bracts ciliate; pedicels 1.5-2 mm long; sepals triangular-ovate, margins ciliate; petals lanceolate, mostly glabrous.
- var. *pohlianus*: leaves 7-19 cm long; leaflets 5-17, oval to obovate in shape; petiole 4 cm long; rachis broadly winged; stems and leaves velvety-hairy. Inflorescences 2-8 cm long, soft-hairy, bracts triangular; sepals triangular-ovate; petals lanceolate.
- var. *raddianus*: leaves 7-16 cm long; leaflets 3-9, obovate in shape, terminal leaflet larger than laterals, margins toothed to nearly entire, tips rounded. Inflorescence bracts triangular, sparsely glandular; sepals triangular-ovate; petals lanceolate.
- var. *rhoifolius*: leaves 5-17 cm long; leaflets 3-7, oval to obovate in shape, terminal leaflet larger than laterals, margins mostly entire, tips rounded. Inflorescences 1-9 cm long, bracts triangular; pedicels 1 mm long; sepals triangular-ovate; petals lanceolate to narrowly ovate.

Of the five recognized varieties of Brazilian peppertree, three have been introduced into the United States: *S. terebinthifolius* var. *acutifolius* Engl. in California; *S. terebinthifolius* var. *terebinthifolius* Raddi in California, Florida, Hawaii and Puerto Rico; and *S. terebinthifolius* var. *raddianus* Engl. in Florida and Puerto Rico (Barkley 1944). The remaining two varieties, *S. terebinthifolius* var. *pohlianus* Engl. and *S. terebinthifolius* var. *rhoifolius* (Mart.) Engl. presumably are not yet established in the United States (Barkley 1944).

Brazilian peppertree is largely a dioecious plant which means that the flowers are all unisexual, i.e., either male (staminate) or female (pistillate), and the sexes are physically separated, i.e., occur on male and female trees. Ewel et al. (1982), however, observed that a small number of trees in a population produce bisexual (“complete”) flowers or are monoecious, i.e., unisexual flowers occur on the same individual. The flowers are produced in showy, branched inflorescences (panicles), 2-11 cm long, which arise from the axils of leaves near the ends of stems (Fig. 5). In addition to flowers, the inflorescences also bear triangular to lanceolate, leaf-like bracts with ciliate margins. Both male and female flowers (Fig. 5) occur on stalks (pedicels) 1 mm long and essentially have the same structure: 5 small, green, triangular sepals with ciliate margins; 5 small, white, glabrous, ovate petals; 10 stamens concentrically arranged in 2 series of 5, the outer series being longer; a lobed disc at the base of the stamens; and a single-chambered (unilocular) ovary with 3 short styles. However, in male flowers, the ovary (pistillode) is non-functional, and in female flowers, the stamens (staminodes) are sterile. On female trees, flowering is followed by the production of bright red, fleshy, spherical drupes (“berries”), each 5-6 mm in diameter and containing a single seed (Fig. 5). The description above applies to typical Brazilian peppertree, var. *terebinthifolius*. There are a number of morphological differences between it and the other four recognized varieties, mainly in inflorescence and pedicel lengths, sepal, petal and fruit characters, and hairiness (pubescence).

Schinus terebinthifolius
Brazilian pepper-tree

illustration provided by:
IFAS, Center for Aquatic Plants
University of Florida, Gainesville, 1990



Figure 5. Brazilian peppertree, *Schinus terebinthifolius*. Shoot, flower and leaf morphology.

Campbell et al. (1980) noted that Brazilian peppertree is extremely variable in Brazil (and to a lesser degree in Florida), and that many exceptions to the general morphological descriptions can be expected. Due to difficulty in separating the varieties, e.g., morphological characters often overlap in the field, southern Florida populations have not been adequately characterized or classified to the varietal level. Because two varieties of Brazilian peppertree apparently were introduced into Florida (Barkley 1944), the possibility exists that hybridization has occurred between these two varieties (Campbell et al. 1980). Consequently, a project was initiated to survey and classify Florida populations of Brazilian peppertree to varietal level using DNA molecular markers developed by Williams et al. (2002). The use of molecular techniques has proven to be invaluable in reconstructing the history of invasions by exotic species and identifying their source populations (Davies et al. 1999, Novak and Mack 2001, Williams et al., in press). In order to uncover origins and patterns of introduction of Brazilian peppertree in Florida, Williams et al. (2004, 2005) collected plant samples from native and exotic ranges, and genotyped these individuals at nuclear and chloroplast loci. Two cpDNA haplotypes were found in Florida; haplotype A is more common on the west coast while haplotype B is more common on the east coast (Williams et al. 2005). Microsatellite data and cpDNA analyses suggested that two distinct genotypes of Brazilian peppertree were introduced separately on the east and west coasts of Florida (Williams et al. 2005). In addition, hybridization between these two introduced genotypes has resulted in genetic variation similar to that found within the plant's native range (Williams et al. 2005). The origin of haplotype A is southeastern Brazil (Williams et al. 2005); the origin of haplotype B is still unknown but preliminary evidence suggests it is somewhere along the coast of northeastern Brazil.

Distribution of Brazilian Peppertree. The genus *Schinus* is indigenous to Argentina, southern Brazil, Uruguay, Paraguay, Chile, Bolivia, and Peru (Barkley 1944, 1957). Brazilian peppertree is native to Argentina, Brazil, and Paraguay (Barkley 1944, 1957). The plant has been spread around the world as an ornamental beginning in the mid to late 1800s (Barkley 1944, Mack 1991). Naturalization of Brazilian peppertree has occurred in over 20 countries worldwide throughout subtropical regions located 40 degrees N and S of the equator (Fig. 6) (Ewel et al. 1982). The countries where Brazilian peppertree is considered adventive include American Samoa, Australia, Bermuda, Fiji, Island of Mauritius, Micronesia, New Caledonia, Reunion Island, South Africa, and Tahiti. In the United States and Caribbean region, the plant occurs in Hawaii, California, Arizona, Texas, Florida, the Bahamas, Commonwealth of Puerto Rico and US Virgin Islands (Habeck et al. 1994, USDA NRCS 2006).

Barkley (1944, 1957) lists the South American distribution of the five varieties that he recognized as follows: *S. terebinthifolius* var. *terebinthifolius* – from Venezuela to Argentina; *S. terebinthifolius* var. *acutifolius* – southern Brazil and Paraguay to Misiones, Argentina; *S. terebinthifolius* var. *pohlianus* (the most common variety of the species) – southern Brazil, Paraguay, and northern Argentina; *S. terebinthifolius* var. *raddianus* – south central Brazil; and *S. terebinthifolius* var. *rhoifolius* – south central Brazil. (Fig. 7)

Brazilian peppertree is recognized as one of the most widespread invasive plants in Florida. Although it occurs as far north as the coastal regions of Levy and St. Johns counties (Fig. 8), it is more widely naturalized in protected areas of central and south Florida due to its sensitivity to cold temperatures (Langeland 1998). Disturbed sites (e.g., fallow farmlands) as well as natural communities such as pinelands, hardwood hammocks and mangrove forests are vulnerable to invasion by Brazilian peppertree (Ewel et al. 1982). During the past 10 years, a dramatic increase in density of Brazilian peppertree has occurred on public lands managed by the South Florida Water Management District (Figs. 9-12).

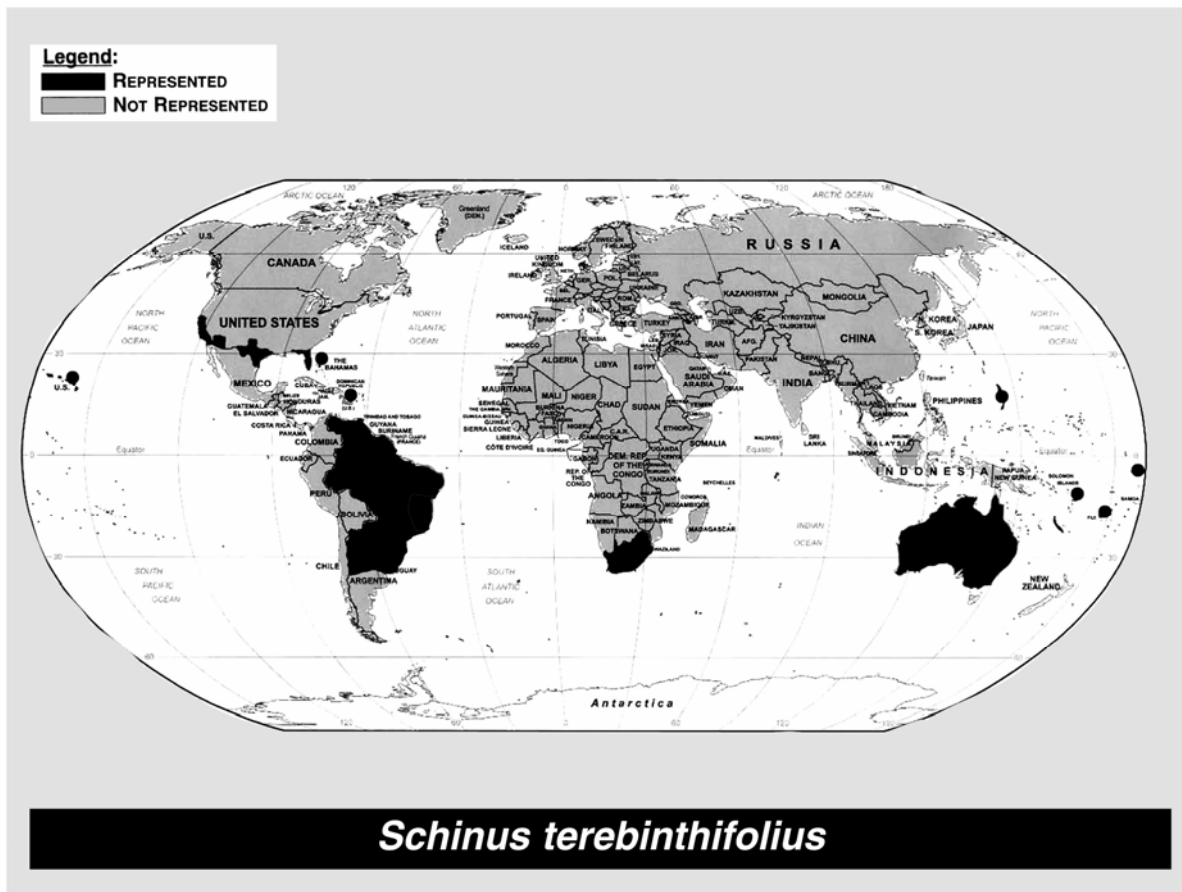


Figure 6. Worldwide distribution of *S. terebinthifolius* (Ewel et al. 1982, Habeck et al. 1994).



Figure 7. Distribution of *S. terebinthifolius sensu lato* in South America (Barkley, 1944, 1957).

Brazilian Pepper –1995

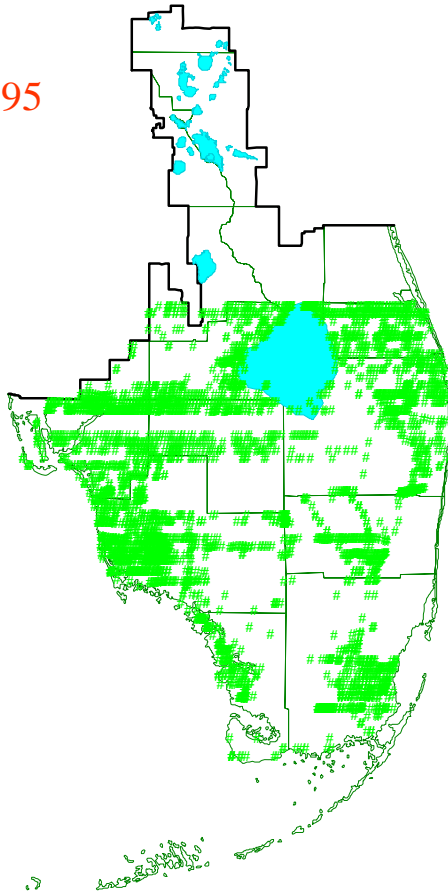


Figure 9. SFWMD aerial survey of Brazilian peppertree, 1995.

Brazilian Pepper –1999

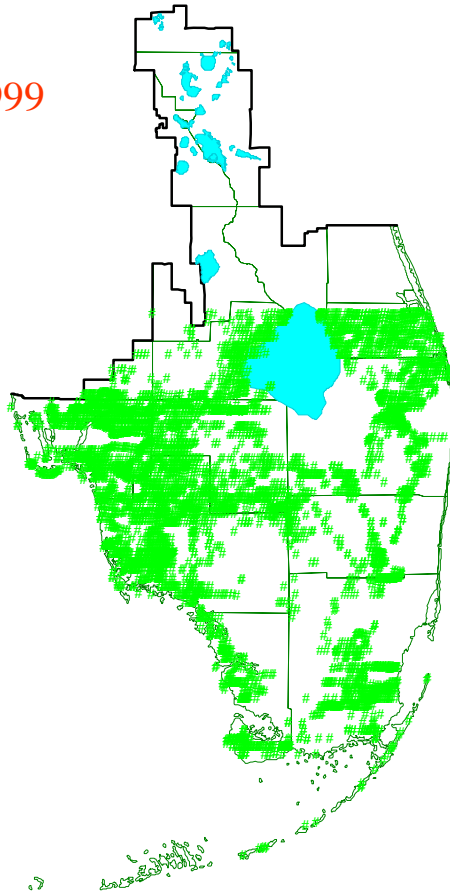


Figure 10. SFWMD aerial survey of Brazilian peppertree, 1999.

Brazilian Pepper –2001

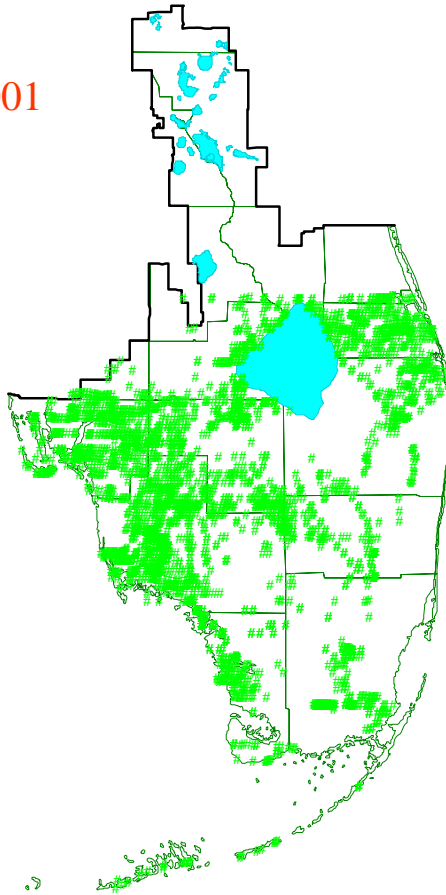


Figure 11. SFWMD aerial survey of Brazilian peppertree, 2001.

Brazilian Pepper –2003

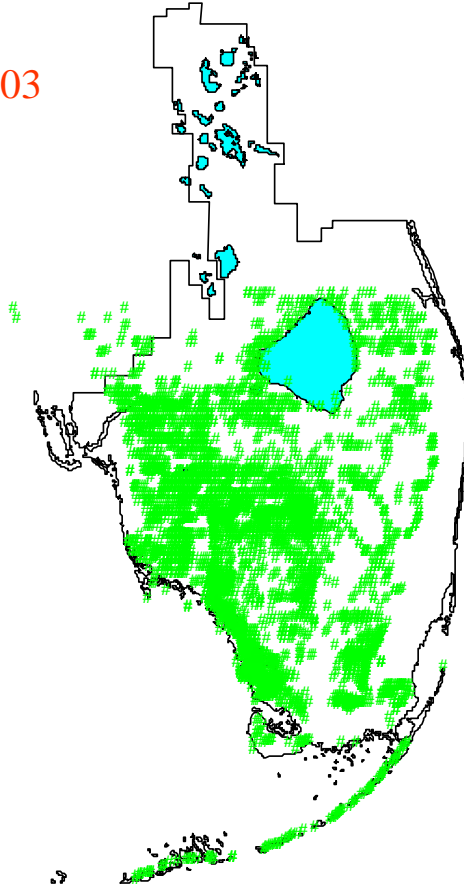


Figure 12. SFWMD aerial survey of Brazilian peppertree, 2003.

Remote sensing studies using geo-spatial enhancement of hyperspectral Landsat imagery (Lass and Prather 2003, Huang et al. 2004) and low altitude aerial digital imagery (Pearlstine et al. 2005) are being conducted to improve the detection of Brazilian peppertree at the landscape level. According to these studies, remote sensing data can accurately classify large and dense Brazilian peppertree infestations, but smaller infestations are difficult to detect and classify. Further research is needed to assess spatial enhancement methods in order to reduce commission errors and improve detection accuracy. Advances in this technology will allow researchers to track the distribution of Brazilian peppertree at the landscape level and detect changes in its distribution in Florida (and presumably other locations) over time in response to management.

Life History

Reproductive biology, phenology, and growth. Ewel (1979) summarized the many life history characteristics of Brazilian peppertree that make it the successful weedy species that it is, including: (1) fast growth, (2) prolific seed production, (3) near continuous shoot extension and leaf renewal, (4) vigorous resprouting, and (5) tolerance of a wide range of growing conditions. It is unique among weed species, however, in possessing a number of traits more typical of mature ecosystem species, including: (1) synchronous flowering and fruiting within a short time period, (2) male and female flowers produced on separate individuals, i.e., dioecious, (3) pollination by insects, (4) large, animal-dispersed seeds, (5) large cotyledons (important for seedling success), and (6) shade tolerant seedlings.

The reproductive potential of Brazilian peppertree is enormous with female trees producing thousands of seeds every year. Seed germination normally occurs from November to April (and sometimes as late as July!), but mainly January to February; seed viability ranges from 30-60% (Ewel et al. 1982). Seeds are generally not viable after 5 months following dispersal. However, Ewel (1979) reported seed germination in late fall under certain conditions. Seeds apparently retain their viability during the wet season floods, and germinate when water levels drop late in the year.

Ewel et al. (1982) discussed seedling survivorship in some detail and concluded that the tenacity and growth plasticity of Brazilian peppertree seedlings is unusual and makes this species especially difficult to manage. Seedlings grow very slowly, and can survive under the dense shade of mature stands, while exhibiting vigorous growth when the canopy is opened after a disturbance. For instance, in exposed open areas, such as young successional communities, seedling growth rates are among the highest, i.e., 0.3-0.5 m per year. Although seedlings are able to tolerate a broad range of extreme soil moisture conditions (Ewel 1979), prolonged submergence may increase seedling mortality (Ewel et al. 1982). Survival of established seedlings is high, ranging from 66-100% (Ewel et al. 1982).

Vegetative growth in Brazilian peppertree undergoes a cycle of dormancy in winter (October to December), when flowering occurs, followed by shoot renewal and extension growth (evidenced by the production of long, drooping branches); foliage production occurs more or less continuously most of the year (Tomlinson 1980, Ewel et al. 1982). The leaves are present on Brazilian peppertree plants year round. While there

is no general relationship between vegetative growth and reproductive development, i.e., inflorescence initiation and growth, branches can terminate all subsequent vegetative growth (in other words, become determinate) if flowering is prolific (Tomlinson 1980). Under optimal growing conditions, Brazilian peppertree is capable of reproducing 3 years after germination.

Brazilian peppertree is dioecious (separate male and female plants). Flower production is highly synchronous, and although it has been observed year-round in some areas of Florida, flowering normally begins in August or September (Ewel et al. 1982). The main flowering period of Brazilian peppertree in Florida occurs from September to October with a much-reduced bloom period from March to May. Numerous small, white flowers occur in dense axillary panicles near the end of branches. Flowers produce copious amounts of pollen and nectar, and are primarily insect pollinated. A diverse fauna of diurnal insects representing the orders Hymenoptera, Lepidoptera, Diptera, and Coleoptera has been found associated with the flowers of Brazilian peppertree in Florida (Ewel et al. 1982, Cassani 1986, Cassani et al. 1989).

Fruit development in Brazilian peppertree occurs soon after flowering. A massive number of bright red fruits are typically produced on the plants from November to February. Although most seed dispersal occurs shortly thereafter, some trees retain their fruits until July or August (Ewel et al. 1982). The fruits are eaten and dispersed primarily by mammals and birds although some dispersal occurs by gravity or water (Ewel et al. 1982). For example, raccoons (*Procyon lotor* L.) and opossums (*Didelphus virginianus* Kerr) consume fruits and no doubt contribute to seed dispersal (Ewel et al. 1982). Although catbirds (*Dumatilla carolinensis* (L.)) have been observed feeding on the fruits (Ewel 1986), robins (*Turdus migratorius* L.) are considered the most important avian seed dispersers; they consume large quantities of seed and spread them to habitats that Brazilian peppertree would never otherwise reach (Ewel et al. 1982). The fruits have a near obligate requirement for ingestion before the seeds can germinate; seeds within fruits that are not ingested have little chance of germinating before they lose viability (Panetta and McKee 1997). Seeds were found to remain viable in soil for less than 1 year; 6 months in Florida (Ewel et al. 1982) and 9 months in Australia (Panetta and McKee 1997). Mechanically removing the seed from the fruit, either by a machine or manually, is usually enough to promote seed germination. Germination rates do not differ between bird-ingested seeds or mechanically manipulated seeds (Panetta and McKee 1997). Water-soluble extracts from Brazilian peppertree fruits inhibited seed germination and it was postulated that the active components were phenolic acid compounds (Nilsen and Muller 1980a).

Like many hardwood species, Brazilian peppertree also is capable of resprouting from above-ground stems and crowns after damage from cutting, fire, or herbicide treatment. Resprouting also occurs from the roots with or without evidence of damage and often leads to the development of new daughter plants. Resprouting and suckering often is profuse and the growth rates of the sprouts are high, which contributes to the plant's habit of forming dense clumps (Woodall 1979). The clumping pattern often is seen during the early stages of invasion and can be explained by the suckering mechanism (Woodall 1979).

Ecophysiology. In general, plant species that are able to use available resources in the environment more efficiently are better competitors than other plant species (Ewe and

Sternberg 2002, 2003). Ewe and Sternberg (2002) found that Brazilian peppertree is less affected by seasonality and more tolerant to root flooding than native plant species growing in the Everglades. Specifically, Brazilian peppertree growing in disturbed and pineland communities in the Everglades showed no seasonal shift in water uptake and predawn water potentials remained constant. In contrast, native plants exhibited a decrease in water potentials during the wet season, which suggested the water potential response of the native plants could be caused by intolerance to root flooding. Furthermore, gas exchange patterns between Brazilian peppertree and native species growing in disturbed and pineland communities in Everglades were similar (Ewe and Sternberg 2003). However, during the wet season (e.g., the period of active growth) Brazilian peppertree had the highest mesophyll conductance, intrinsic water-use efficiency, and photosynthetic nitrogen-use efficiency than native species in the pineland community. Thus, certain gas exchange characteristics exhibited by Brazilian peppertree during the wet season could confer some physiological advantage over native species.

Li and Norland (2001) found that the phosphorus (P) content of Brazilian peppertree leaves and total and plant-available P in the soil were highly correlated. These results suggested that P enrichment in farmed soils facilitated the invasion of Brazilian peppertree in the Everglades. Moreover, Brazilian peppertree responded more favorably to the increased amount of nutrients and was able to outcompete the native sawgrass, *Cladium mariscus* (L.) Pohl ssp. *jamaicense* (Crantz) Kükenth., that previously dominated the area. Finally, Brazilian peppertree seedlings growing in Brazil showed a higher resistance to elevated pH conditions when compared with two other native plants (Bonnet et al. 2002). Taken together, these results demonstrate the ecological adaptability of Brazilian peppertree to grow vigorously under a wide range of environmental conditions.

Mycorrhizal Activity. Mycorrhizae are soil-inhabiting fungi that form obligate symbiotic associations with root tips of plants. They develop a mutualistic association with their hosts whereby the fungus provides the plant with inorganic nutrients, primarily P, in exchange for sugars derived from the photosynthate. Some mycorrhizae also provide N, water, and protection from harmful pathogenic fungi. More importantly, mycorrhizae have been shown to determine the direction that the vegetation succession of plant communities may take following disturbance (Aziz et al. 1995).

Ewel et al. (1982) observed that abandoned rock-plowed lands in the Everglades National Park were colonized and dominated by woody shrubs like Brazilian peppertree rather than herbaceous vegetation that occupied the sites prior to rock plowing. Apparently, rock plowing altered the substrate by creating better drained and aerated conditions that were conducive to mycorrhizal activity. Highly mycorrhizal-dependent plant species like Brazilian peppertree (Sequiera et al. 1998) were able to take advantage of the altered substrate by quickly colonizing an area where seasonal flooding had previously excluded the aerobic fungi.

Soil disturbance also influences arbuscular mycorrhizal (AM) activity (Reeves et al. 1979, MacGonigle et al. 1990, Aziz et al. 1995). According to Aziz et al. (1995), the total number of AM propagules and spores increased in plots where the soil was completely removed compared to partial soil removal plots over a two-year period. The increase of AM activity, correlated with changes in composition of AM fungi community, was associated with higher plant species richness in those plots. In contrast,

AM fungi activity remained unchanged in plots dominated by Brazilian peppertree while low levels of AM were found in mature glades. The authors concluded that soil removal eliminated dominant stands of Brazilian peppertree, and stimulated the increase of AM activity and growth of a diversity of plant species.

Chemistry and Toxicity. Phytochemical studies carried out during the 1960-70s revealed the presence of a number of diverse chemical compounds, including triterpene alcohols, ketones, acids, monoterpenes, and sesquiterpenes, in the bark, leaves and fruits of Brazilian pepper (Lloyd et al. 1977, Morton 1978). The high concentration of volatile (and aromatic) monoterpenes has been suggested to be a probable cause of the respiratory problems associated with crushed fruits. The fact that widespread respiratory ailments have occurred when the tree is in bloom suggests that these same volatile compounds may also be produced by the flowers (Lloyd et al. 1977). Morton (1969, 1978) reported that persons sitting or playing beneath Brazilian pepper trees exhibited flu-like symptoms, and sneezing, sinus congestion, chest pains and acute headache were among the possible inhalant effects. It is noteworthy that the pollen from the flowers appears not to be a significant source of irritation or allergies, as it is sticky and not easily carried by wind (Morton 1978). Campello and Marsaioli (1974) noted in a paper on triterpenes that the ingested fruits have a “paralyzing effect” on birds. The narcotic and toxic effects on birds and other wildlife also have been noted by others. For instance, Workman (1979) refers to the “hypnotic action” of fruit extracts, containing the triterpenes terebinthone and schinol, on chicks and mice. The AMA Handbook of Poisonous and Injurious Plants (Lampe and McCann 1985) reports that the tripterpenes found in the fruits can result in irritation of the throat, gastroenteritis, diarrhea, and vomiting in humans. Like most other members of the Anacardiaceae, Brazilian peppertree contains active alkenyl phenols, e.g., urushiol, cardol, which can cause contact dermatitis and inflammation in sensitive individuals (Lampe and Fagerstrom 1968, Tomlinson 1980). Contact with the “sap” from a cut or bruised tree can result in rash, lesions, oozing sores, severe itching, reddening and swelling (especially of the eyes), and welts (Morton 1978). Grazing animals, such as horses and cattle, also are susceptible to its toxic effects, and ingestion of leaves and/or fruits has been known to be fatal. Of taxonomic interest is the observation that the chemistry of Brazilian peppertree, specifically certain compounds extracted from the leaves and bark, is more similar to species of the related genus *Pistacia* than it is to other members of its own genus *Schinus* (Campello and Marsaioli 1975).

Economic Impacts.

Beneficial Uses. Brazilian peppertree is considered an important nectar and pollen source by the bee industry in Hawaii (Fig. 13) (Yoshioka and Markin 1991). In the continental United States, beekeepers in the northern latitudes often transport their colonies to Florida during the winter months, and have depended on Brazilian peppertree for colony maintenance (Sanford 1988). Honeybees foraging on the flowers produce a low-grade ‘peppery’ tasting honey that is marketed locally (Sanford 1988, 1995). However, conflicting interests between the migrant apiarists in Florida who consider Brazilian peppertree a valuable resource and land managers who want to remove this invasive species has been resolved by regulatory action (see below).



Figure 13. Brazilian peppertree honey (top) and peppercorns (bottom) sold in gourmet shops. (Photo credits: D.H. Habeck and R. Leavitt).

As its vernacular name suggests, the dried fruits of Brazilian pepper are used as a spice and are sold in gourmet shops the United States as “pink peppercorn” (Fig.13) (Morton 1978, Habeck et al. 1994). However, Bell and Taylor (1982) suggest that the use of the dried fruits as spice is inappropriate and possibly dangerous due to their toxic properties. In South America, all parts of the tree have been used in traditional herbal medicines since ancient times (Morton 1978). Some medicinal uses of Brazilian peppertree include treatment for ulcers, respiratory problems, wounds, rheumatism, gout, tumors, diarrhea, skin ailments, and arthritis (Campbell et al. 1980, Bennett and Habeck 1991). The juice of the macerated roots also has been used in an ointment for treating ganglionic tumors and contusions (Morton 1978). Recently, Queires et al. (2006) showed that polyphenols extracted from Brazilian peppertree induced autophagic cell death in human prostate carcinoma cell lines.

Brazilian peppertree has little commercial value as a source of lumber or pulpwood because of its relative low quality wood, small trunk size, poisonous resin byproducts, and difficulty of harvesting due to the multiple, low stems, and clumped plant structure (Morton 1978). However, fence posts, wood stakes and toothpicks are examples of some wood products that have been made from Brazilian peppertree (Morton 1978, Bennett and Habeck 1991). The resinous extracts of Brazilian peppertree have a high tannin content, and have been used by native South American to preserve fishing nets.

Organic mulches, derived from plant material that has been mechanically removed and then chipped, will decompose over time and enrich and improve the soil. Mulch is usually spread uniformly on the surface of the soil at the base of ornamental species used in landscaping mainly to prevent weed growth. However, it is not recommended to mulch Brazilian peppertree for use in landscapes unless the tree is male or not producing fruits.

A number of economic uses are reported for other members of the genus as well. The fruits of California pepper, or Peruvian mastic, *Schinus molle* L., said to contain an essential oil, are pulverized and used to make refreshing drinks known as “horchatas” or “atoles,” while gum from the trunk is reportedly used in varnishes and medicines, and for chewing (Uphof 1968, Williams 1981). Altschul (1973) reported that this species is used in the treatment of rheumatism in Mexico. In Peru, *S. molle* is used in the preparation of a mildly alcoholic drink (Rehm and Espig 1991). Like Brazilian peppertree, the dried fruits are exported from Peru and Ecuador to the United States, where are used as a substitute for black pepper; the essential oils from its leaves and fruits are used as an aromatic (Rehm and Espig 1991). The bark is used for tanning animal skins (Graf 1982), and when powdered, it serves as a purgative for domestic animals (Uphof 1968). A wine is reportedly made from the small twigs of *S. molle* (Hedrick 1972). Mabberley (1987) noted that *S. molle* is used as a fertility control agent in Uruguay. Another species, *S. polygamus* (Cav.) Cabrera (= *S. dependens* Orteg.), is used in Chile to treat rheumatism, and a red wine is prepared from its ‘berries’. The fruits of *S. latifolius* (Gillies) Engl. are used by native Chileans to make an intoxicating liquor (Uphof 1968, Hedrick 1972).

Social and Recreational Uses. Brazilian peppertree is grown as a roadside ornamental in Brazil. Although it was widely planted along city streets and home gardens before becoming invasive in Florida (Morton 1969), and Hawaii, Brazilian peppertree is no longer recommended as an ornamental in these two states because of its

invasive characteristics. Under certain circumstances, it could still be propagated as in indoor plant (Graf 1982). In Hawaii, the bright red berries have been used to make leis and Christmas wreaths (Morton 1978, Yoshioka and Markin 1991).

Economic Losses, Including Direct Control Costs. Because Brazilian peppertree has long been recognized as a threat to Florida's native plant and animal diversity (Workman 1979), successful but costly attempts have been made to mechanically clear small parcels of land of this invasive species. One of the most ambitious restoration projects was undertaken on a small portion of previously farmed land in the Everglades National Park referred to as the Hole-in-the-Doughnut (Doren et al. 1990). In this pilot study that was completed at a cost \$640,000, bulldozing and burning the existing Brazilian peppertree on a 24.4 ha site followed by complete removal of the rock plowed substrate was effective in preventing reinvasion of the site by the weed (Doren et al. 1990). However, they calculated that it would cost \$20 million (\$37,000 per ha) and take 20 years to restore the entire 2000 ha parcel.

The Florida Department of Environmental Protection's Upland Invasive Plant Control Program has allocated almost \$0.5 million specifically for controlling Brazilian peppertree with approved herbicides on approximately 1000 ha of selected state lands in the Suncoast Region of Florida during FY 2002-2003. When cost sharing by local participating agencies is included, the total cost for chemical control of Brazilian peppertree is approximately \$600/ha (FLDEP 2002).

The uncontrolled growth of Brazilian peppertree coupled with its allergenic properties also could negatively affect the multi-billion dollar a year tourist industry in Florida (Smith and Brown 1994). According to a recent report (UF/IFAS 1999), resident and non-resident wildlife-associated recreation in 1996 generated \$5.5 billion in revenue. Highly sensitive ecotourists may decide to vacation elsewhere rather than risk exposure to Florida's Brazilian peppertree-infested landscapes.

Health Effects. The foliage and fruits of Brazilian peppertree produce a pungent turpentine-like odor. This plant volatile apparently is produced only by female trees (Campbell et al. 1980), although Ewel et al. (1982) were unable to experimentally confirm this observation. Brazilian peppertree also displays allergen-causing properties similar to those induced by poison ivy, poison oak, and poison sumac. While not affecting as many people as some of the more familiar members of the Anacardiaceae, the plant sap can cause dermatitis and edema in sensitive people (Morton 1978, Perkins and Payne 1978). Exposure to the volatile flower secretions or the sap of Brazilian peppertree can produce a variety of allergic reactions. Susceptible individuals often experience respiratory problems such as chest pains, acute headaches, eye irritation, and flu-like symptoms when in close proximity to the plants. Direct contact with the plant sap or resin may result in a rash followed by intense itching in at risk people. Ingesting the bark, leaves, and fruits can be toxic to humans, mammals, and birds (Morton 1978).

Even though extracts of Brazilian peppertree are widely used in Brazil as a topical anti-inflammatory agent and to sterilize wounds, a recent study suggested that the indiscriminate use of Brazilian peppertree extract might present a health risk to humans (Ribeiro Dantas de Carvalho et al. 2003). Specifically, results from this study showed that Brazilian peppertree stem bark extract causes DNA damage and mutations in bacteria, and that oxidative damage may be responsible for the observed genotoxicity.

Environmental Impacts.

Impact on Threatened and Endangered Species. The invasion of Florida's natural shoreline habitats and saline communities of the Everglades National Park by Brazilian peppertree (Mytinger and Williamson 1987) threatens rare federal and/or state listed native plants such as the Beach Jacquemontia, *Jacquemontia reclinata* House (Solanales: Convolvulaceae) and the Beach Star, *Remirea maritima* (Cyperales: Cyperaceae) Aubl. (Coile 1998, D.F. Austin, pers. comm. in Langeland and Burks 1998). In the Everglades National Park, the nesting habitat of the gopher tortoise (*Gopherus polyphemus* Daudin), a threatened species in Florida, is being encroached upon by Brazilian peppertree (Doren and Jones 1997). In Hawaii, Brazilian peppertree also is negatively impacting several threatened and endangered plant species, including the Haleakala silverword, *Argyroxiphium sandwicense* DC. ssp. *macrocephalum* (Gray) Mérat (Asteraceae); liliwai, *Acaena exigua* Gray (Rosaceae); and the mahoe tree, *Alectryon macrococcus* Radlk. (Sapindaceae) (Hight et al. 2002).

Interaction with Native Animal and Plant Populations. Brazilian peppertree is displacing native vegetation not only in Florida but also in California (Randall 2000), Hawaii (Hight et al. 2002), Bermuda, the Bahamas, and Australia (Habeck et al. 1994). The plant also is capable of disrupting critical tritrophic level interactions. For example, shading caused by dense stands of Brazilian peppertree in Florida Panther National Wildlife Reserve has been shown to kill food plants used by the white-tailed deer (*Odocoileus virginianus* (Zimmerman)), which in turn is an important prey item of the endangered Florida panther (*Felis concolor coryi* (Bangs)) (Maffei 1997).

This invasive weed also is poisonous to some mammals and birds because of the presence of the highly toxic resin in the bark, leaves, and fruits (Lloyd et al. 1977, Morton 1978). Ingestion of the leaves and fruits can be fatal to grazing animals such as cattle and horses (Morton 1978). Excessive fruit feeding by birds also can lead to digestive problems and even death (Morton 1978). Intoxication of migratory robins, one of the principal avian disseminators of Brazilian peppertree, is not uncommon (Blassingame 1955). Species diversity and density of native bird populations declines in mature Brazilian peppertree stands when compared to native pinelands and forest-edge habitats (Curnutt 1989).

According to Clouse (1999), leaf-litter under Brazilian peppertree plants growing in the Hole-in-the-Donut area of Florida Everglades serves as a safe refuge for exotic insects (e.g., ants) that would otherwise not have gained such a strong foothold in this native habitat. This study shows the important role of Brazilian peppertree in determining the establishment of whole new assemblages of exotic species.

Wax myrtle, *Myrica cerifera* (L.) Small (Myricaceae), is an evergreen shrub or small tree native to the southeastern United States. It is found throughout Florida, including the Everglades National Park (Craighead 1971). Chemicals released from the foliage and roots of wax myrtle have been shown to inhibit germination and growth of Brazilian peppertree (Dunevitz and Ewel 1981). Thus, the reduced vigor exhibited by Brazilian peppertree plants growing in close proximity to wax myrtle will likely reduce its competitiveness, lower its reproductive potential, and increase its susceptibility to herbivores and diseases (Dunevitz and Ewel 1981, W. A. Overholt, unpubl. data).

Burch (1992, 1994) reported that love vine, *Cassytha filiformis* L. (Lauraceae), a native parasitic plant, has been observed attacking Brazilian peppertree plants in south Florida. According to Burch (1992, 1994), parasitism of Brazilian peppertree by love vine appears to significantly affect the growth and reproduction of the invasive weed in some areas. The aforementioned studies on wax myrtle and love vine demonstrate the potential for exploiting the interactions between some native plants and Brazilian peppertree when developing a management plan for this invasive species.

Brazilian peppertree also causes maintenance and safety problems for the Florida Department of Transportation. Excessive growth of the plant along and through highway rights-of-way fences actually lifts them clear of the ground, allowing wildlife onto high-speed limited access highways (Caster 1994).

Impact of Weed Control on Nontarget Plants. Coastal mangrove forests are especially vulnerable to invasion by Brazilian peppertree following damage to the mangrove communities by human activities or natural catastrophes such as hurricanes (Armentano et al. 1995) or periodic freezes (Doren and Jones 1997). According to Doren and Jones (1997), selective removal of Brazil peppertree from mangrove ecosystems is difficult. For instance, mechanical removal of Brazilian peppertree disturbs the substrate and favors its reestablishment. Mangroves also are highly vulnerable to widespread application of foliar herbicides. A combination of hand removal and direct injection of herbicides is effective in selectively eliminating Brazilian peppertree on a small scale, but is not cost effective on large mixed stands of mangroves and Brazilian peppertrees (Doren and Jones 1997).

Effects on Ecosystem Functions and Ecological Relationships. Brazilian peppertree forms dense monocultures of tangled woody stems that completely shade out and displace the native vegetation in parks and wildlife areas, reducing the biological diversity of the plants and animals (Ewel et al. 1982, Bennett and Habeck 1991). The widespread infestation of parks and abandoned farmlands has been attributed mainly to seed dispersal by frugivorous birds and mammals (Haeger 1978, Ewel 1986).

The plant also is successful in colonizing many undisturbed natural environments and native plant communities (Woodall 1982), including saw-grass marshes, muhly prairies, subtropical slash pine forests, tropical hardwood hammocks, salt marsh-mangrove forests, palmetto prairies, cypress savannas, and sand pine scrub oak (Loope and Dunevitz 1981a, Ewel et al. 1982, Woodall 1982, Doren and Jones 1997). The invasion of natural areas by this aggressive, woody plant poses a serious threat to biodiversity in many of Florida's ecosystems, and is eliminating many indigenous food sources for wildlife (Morton 1978).

The invasion of native plant communities by Brazilian peppertree and subsequent displacement of associated wildlife can be attributed to certain biological traits exhibited by the plant. Attributes of Brazilian peppertree that contribute to its invasiveness include a large number of fruits produced per female plant, an effective mechanism of dispersal by birds (Panetta and McKee 1997), tolerance to both shade (Ewel 1979), fire (Doren et al. 1991), salinity (Mytinger and Williamson 1987), moisture extremes (Nilsen and Muller 1980b, Ewe and Sternberg 2002), and an apparent allelopathic effect on neighboring plants (Gogue et al. 1974, Nilsen and Muller 1980a,b, Morgan and Overholt 2005).

Plant species that become community dominants like Brazilian peppertree are capable of changing environmental conditions and resource availability over large areas that have been invaded, or will create a new community structure (Gordon 1998). For example, Brazilian peppertree appears to increase soil development and elevation in shallow soil systems (Gordon 1998). In colonized hardwood hammocks, Brazilian peppertree plants taller than 1m are significantly more fire tolerant than other woody species (Loope and Dunevitz 1981b). Moreover, once Brazilian peppertree forms dense stands, the high moisture retained by its litter and low fuel levels in the understory may reduce the fire frequency in pyric pine rocklands (Wade et al. 1980).

According to Bond (1993), plant invaders that suppress the seedlings of other species are called “keystone weeds”. This description aptly applies to Brazilian peppertree because the plant’s documented allelopathic and shading effects reduce establishment of native species (Gogue et al. 1974, Ewel et al. 1982, Morgan and Overholt 2005). In addition, Brazilian peppertree dominates the understory of unburned pine rockland by growing more rapidly and shading the competing native shrubs and herbs. Pine rocklands dominated by Brazilian peppertree contain ~ 50% of the species richness of uninvaded sites (Loope and Dunevitz 1981b). In portions of the Everglades where fires have been suppressed, this species was found to comprise 40% of the trees that reached at least 2 m in height, and 66% of the trees reaching 5 m or more (Loope and Dunevitz 1981b).

Management Options.

To date, management efforts in Florida to control Brazilian peppertree have focused on prohibiting the sale of the plants by the nursery trade, mechanical or physical removal, and chemical control. Mechanical or physical methods (e.g., cutting, burning and flooding) and herbicide applications are routinely used for controlling existing Brazilian peppertree stands often in combination (Gioeli and Langeland 1997, Langeland 2001). These chemical and mechanical control measures have been used with some success in spite of plant’s ability to recover from the effects of these conventional control practices (Koepp 1978a, Pierce 1978, Woodall 1978). Maintenance programs often are required to prevent regrowth due to the plant’s regenerative capacity, but can be expensive especially for large infestations of Brazilian peppertree because multiple treatments are needed for long term control. Chemical and mechanical controls, however, are unsuitable for some natural areas (e.g., mangrove forests) because they may have negative side effects on non-target species and the environment (Doren and Jones 1997). In order to maintain the integrity of Florida’s fragile ecosystems and natural resources, effective control of Brazilian peppertree will require the integration of all the following management options (see Section IV).

1. *Biological control.* Biological control should be the basis for an integrated approach for the management of Brazilian peppertree in Florida (Cuda et al. 1999, Cuda et al. 2004). If it is successful, biological control will preserve Florida’s fragile environment by reducing our reliance on non-selective mechanical control methods and herbicides. The introduction into Florida of natural enemies from the native range that feed and reproduce only on Brazilian peppertree plants (classical biological control)

could reduce the competitiveness of this naturalized weed, and contribute to an environmentally acceptable and sustainable solution to the Brazilian peppertree problem in Florida (Scoles et al. 2005).

1.1. *Adventive biological control.* The only insect currently causing some damage to Brazilian peppertree in Florida is the adventive Torymid wasp *Megastigmus transvaalensis* Hussey (Hymenoptera: Torymidae) (Fig. 14), which attacks the drupes or seeds (Habeck et al. 1989, Wheeler et al. 2001, Cuda et al. 2002a). In recent years, this insect has been expanding its range throughout the Brazilian peppertree infested area (Wheeler et al. 2001, Cuda et al. 2002a). *Megastigmus transvaalensis* was originally described from South Africa (Boucek 1978), and was probably introduced accidentally into the USA from Reunion or Mauritius via France in Brazilian peppertree seeds sold as spices in some food shops (Habeck et al. 1989). Recently, Wheeler et al. (2001) completed a detailed study on the distribution and effect of the drupe-feeding wasp *M. transvaalensis* on Brazilian peppertree in Florida. During this 2-year study, they observed that up to 31% of the drupes were damaged by the wasp during the major winter fruiting period and up to 76% during the minor spring fruiting phase. Seeds that are damaged by the developing wasps also fail to germinate. However, further studies are needed to determine why a higher incidence of wasp-damaged drupes was observed in plants occurring more inland rather than in coastal sites (Wheeler et al. 2001).



Figure 14. *Megastigmus transvaalensis*, an adventive torymid wasp attacking Brazilian peppertree fruits in Florida (Photo credit: D.H. Habeck).

1.2. *Augmentative biological control.* Fungal diseases are not uncommon and can be quite damaging to Brazilian peppertree. The fungus *Sphaeropsis tumefaciens* Hedges infects the plant by producing galls on the stems and branches that vary in size from small swellings to baseball-sized enlargements (Ridings and Marlatt 1976). The large galls are frequently associated with a proliferation of shoots and branches, a condition known as “witches broom” (Fig. 15). During a 1995 survey of Florida plants, a foliar disease was observed on several Brazilian peppertree plants in Palm Beach County (Semer and Charudattan 1997). Disease symptoms consisted of dark, reddish-purple necrotic lesions randomly distributed over the leaf surface. Further testing identified the fungus as *Rhizoctonia solani* Kühn; this was the first report of *R. solani* causing a leaf lesion disease in Brazilian peppertree (Semer and Charudattan 1997). Two additional leaf spot fungi have been observed infecting Brazilian peppertrees in Florida. Charudattan (1996) tested the effectiveness of *Chondrostereum purpureum* (Pers.) as a bioherbicide for selectively controlling Brazilian peppertree along highway rights-of-way in Hillsborough Co, FL. Also, a species of the genus *Pseudocercospora* was discovered infecting the leaves of Brazilian peppertree in the Everglades (R. W. Barreto, pers. observ.). Except for *C. purpureum*, the potential for using the aforementioned native fungi as bioherbicides of Brazilian peppertree remains to be examined.



Figure 15. Brazilian peppertree stem gall produced by the fungus *Sphaeropsis tumefaciens*. Notice the characteristic “witches broom”, a proliferation of shoots and branches from the diseased stem tissue . (Photo credit: D.H. Habeck).

1.3. *Classical biological control.* In its native range, Brazilian peppertree does not exhibit the characteristics of an invasive weed (Campbell et al. 1980). The rapid growth and spread of naturalized populations of this weed in Florida and Hawaii is thought to be due to the absence of competitive plant taxa, and/or natural enemies (DeFosse 1979, Bennett et al. 1990, Bennett and Habeck 1991, Habeck 1995, Hoshovsky and Randall 2000, Hight et al. 2002, Cuda et al. 2004).

A lack of natural enemies on Brazilian peppertree in Hawaii was the rationale for initiating a classical biological control program in the 1950s (Krauss 1963). Surveys in southern South America were conducted in 1954-55 to identify potential biological control agents. Insects screened and released in Hawaii were: *Episimus utilis* Zimmerman (Lepidoptera: Tortricidae) in 1954, *Lithraeus atronotatus* Pic (Coleoptera: Bruchidae) in 1960, and *Crasimorpha infuscata* Hodges (Lepidoptera: Gelechiidae) in 1961 (Julien and Griffiths 1998). Two of the insects established, but they apparently have had little effect on Brazilian peppertree populations in Hawaii (Yoshioka and Markin 1991, Julian and Griffiths 1998).

A classical biological control program was initiated in Florida during the mid 1980s following the completion of two domestic surveys of the insect fauna associated with Brazilian peppertree conducted between May 1979 and July 1980 at three sites in Lee County, Florida (Cassani 1986, Cassani et al. 1989). These surveys revealed 115 arthropod species associated with the plant. Of these, 40% (46 species) were phytophagous, 51% (59 species) predaceous, and 9% (10 species) miscellaneous. However, none of the phytophagous insects recorded on Brazilian peppertree in Florida were causing significant damage to the plant and some were pests of crop plants such as citrus. Recently, a survey of the acarofauna, or mites, associated with Brazilian peppertree in Florida was completed to assess the potential for negative effects by native predaceous mites on the eggs or larvae of small candidate arthropod natural enemies (Wiggers et al. 2005).

Exploratory surveys for promising natural enemies in the native range of Brazilian peppertree were initiated in 1987 in South America (Bennett et al. 1990). A large arthropod fauna (139 species) was found associated with the plant in Brazil. Further surveys conducted by researchers of the University of Florida and the Universidade Federal do Parana in Curitiba, Brazil, have increased the insect fauna to at least 200 species (Bennett et al. 1990; Bennett and Habeck, 1991).

Several insects were identified from exploratory surveys conducted in Brazil during the 1990s as potential biological control agents because they visibly damage the plant in its native range and seemed to be host specific (Habeck et al. 1994, Cuda et al. 2004). Three of the insects- a defoliating sawfly *Heteroperreyia hubrichi* Malaise (Hymenoptera: Pergidae), a shoot and flower attacking thrips *Pseudophilothrips ichini* Hood (Thysanoptera: Phlaeothripidae), and a defoliating tortricid moth *Episimus utilis* Zimmerman (Lepidoptera: Tortricidae) that was introduced into Hawaii for biological control of Brazilian peppertree in the 1950s, were studied in quarantine and appear to be sufficiently host specific to release in Florida (Medal et al. 1999, Cuda et al. 2002b, Hight et al. 2003, Cuda et al. 1999, 2005, Martin et al. 2004).

* See Appendix I for more information on biological control candidates.

2. *Chemical control.* The use of herbicides is the most common and cost-effective method employed to date for controlling Brazilian peppertree (Fig 16). Several herbicides are currently recommended for controlling Brazilian peppertree in California and Florida (Gioeli and Langeland 1997, Randall 2000, Langeland and Stocker 2001, Langeland 2002, BASF 2005). Optimal performance of these herbicides depends on the application method, the type of herbicide used, application rate and environmental conditions. Cut-stump treatments or basal bark applications of triclopyr will effectively control Brazilian peppertree (Langeland and Stocker 2001). Foliar applications of triclopyr, glyphosate or imazapyr also can be effective for suppressing uncontrolled growth of Brazilian peppertree. In Florida, Brazilian peppertrees growing in aquatic situations should be treated only with glyphosate or imazapyr products approved for aquatic use (Langeland and Stocker 2001).

Several herbicides and application techniques were evaluated to control Brazilian peppertree growing in Northeast Collier County, Florida (Laroche and Baker 1994). Foliar application of imazapyr or triclopyr resulted in greater than 90% control of Brazilian peppertree. However, non-target vegetation also was affected by all foliar treatments, except for wax myrtle that showed resistance to the imazapyr application. Recently, up to 98% control of Brazilian peppertree has been achieved with imazapyr using a technique referred to as “lacing”, which involves treating only half the foliage with a low volume back pack sprayer (Phil Waller, BASF, pers. comm.) Basal soil applications of both hexazinone and tebuthiuron also were effective against Brazilian peppertree resulting in 80 to 95% control (Laroche and Baker 1994). Other treatments such as basal bark application of a mixture of imazapyr and triclopyr are effective in an oil-based solution (BASF 2005). However, when treating dense stands of Brazilian peppertree it is difficult for applicators to spray around the circumference of multiple-stemmed trees while carrying a backpack sprayer.

Cutting the plants down with a machete or chain saw and treating the stumps with an approved herbicide also is effective in controlling Brazilian peppertree. Langeland (2002) evaluated the use of three glyphosate products for controlling adventitious sprouting of melaleuca, *Melaleuca quinquenervia* (Cav.) S.T. Blake (Myrtaceae), and Brazilian peppertree stumps. Results showed that all three formulations of glyphosate were effective in preventing resprouting, and similar results were obtained when using triclopyr. However, treating all the individual stumps of a multi-stemmed species like Brazilian peppertree is labor intensive.

Control of Brazilian peppertree also may be accomplished by matricide-selectively controlling reproductively mature female trees either chemically or mechanically. Using this approach, control efforts are focused on stopping the production of new seeds, thus preventing seed dispersal by birds that are primarily responsible for spreading the plant. In situations where time, funds and availability of herbicides are limiting factors, treating only female plants is recommended (Langeland and Stocker 2001).

Herbicides and application methods currently recommended for controlling Brazilian peppertree in Florida are shown in Table 1.



Figure 16. Chemical control of Brazilian peppertree; (top) foliar application of herbicide using ATV, and (bottom) observing the effects of basal bark application of triclopyr ester and oil mixture, UF/IFAS Southwest Florida REC, Immokalee, June 2005 (Photo credits: Ed Hanlon and Phil Stansly).

Table 1. Herbicides and application methods for Brazilian peppertree control in Florida (Source: Gioeli and Langeland 1999).

| Active Ingredient ¹ | Products | Application Methods | Comments |
|----------------------------------|----------------------------------------------------------------------------------------------------|-----------------------------------|--------------------------------------------------------------------------------------|
| Glyphosate (4 lb/gallon) | Rodeo, Aquamaster, Aquaneat, Eagle, Aquapro, Glypro, Glyphosate Herbicide, Accord | Cut stump Foliar | Available from agricultural suppliers. May be applied directly to water. |
| Glyphosate (3.7 lb/gallon) | Roundup Weed & Grass Killer Super Concentrate | Cut stump Foliar | Available from retail garden suppliers. May not be applied directly to water. |
| Glyphosate (3 lb/gallon) | Roundup Pro, Credit, Glyphos, Glypro Plus Rattler, Honcho, Glyphosate Herbicide VMF, Touchdown Pro | Cut stump Foliar | Available from agricultural suppliers. May not be applied directly to water. |
| Triclopyr amine (3 lb/gallon) | Garlon 3A, Renovate | Cut stump Foliar | Available from agricultural suppliers. May be applied directly to water. |
| Triclopyr amine (0.59 lb/gallon) | Enforcer Brush Killer | Cut stump Foliar | Available from retail garden suppliers. May not be applied directly to water. |
| Triclopyr amine (0.54 lb/gallon) | Ortho Brush-B-Gon | Cut stump Foliar | Available from retail garden suppliers. May not be applied directly to water. |
| Triclopyr ester (4 lb/gallon) | Garlon 4 | Cut stump Foliar Basal bark | Available from agricultural suppliers. May not be applied directly to water. |
| Triclopyr ester (0.75 lb/gallon) | Pathfinder II | Cut stump Basal bark | Available from agricultural suppliers. May not be applied directly to water. |
| | Vine-X | Cut stump Basal bark | Available from retail garden suppliers. May not be applied directly to water. |

¹Based on the acid.

* See Appendix II for more information about herbicide applications.

3. *Legal control.* A state law prohibiting the sale, cultivation and transportation of Brazilian peppertree was passed by the Florida legislature in 1990 (Florida Statutes 2005). Later, the Florida Administrative Code was amended in 1993 declaring Brazilian peppertree a prohibited species (FLDEP 1993). To date, twenty-five Florida

counties/municipalities have enacted local ordinances prohibiting the sale of Brazilian peppertree or require its removal (Fig. 17) (Burks 2000). Brazilian peppertree currently is listed as a noxious weed by the Florida Department of Agriculture and Consumer Services (FLDACS 1999), a prohibited plant by the Florida Department of Environmental Protection (FLDEP 1993), and Category I invasive species by the Florida Exotic Pest Plant Council (FLEPPC 2005).

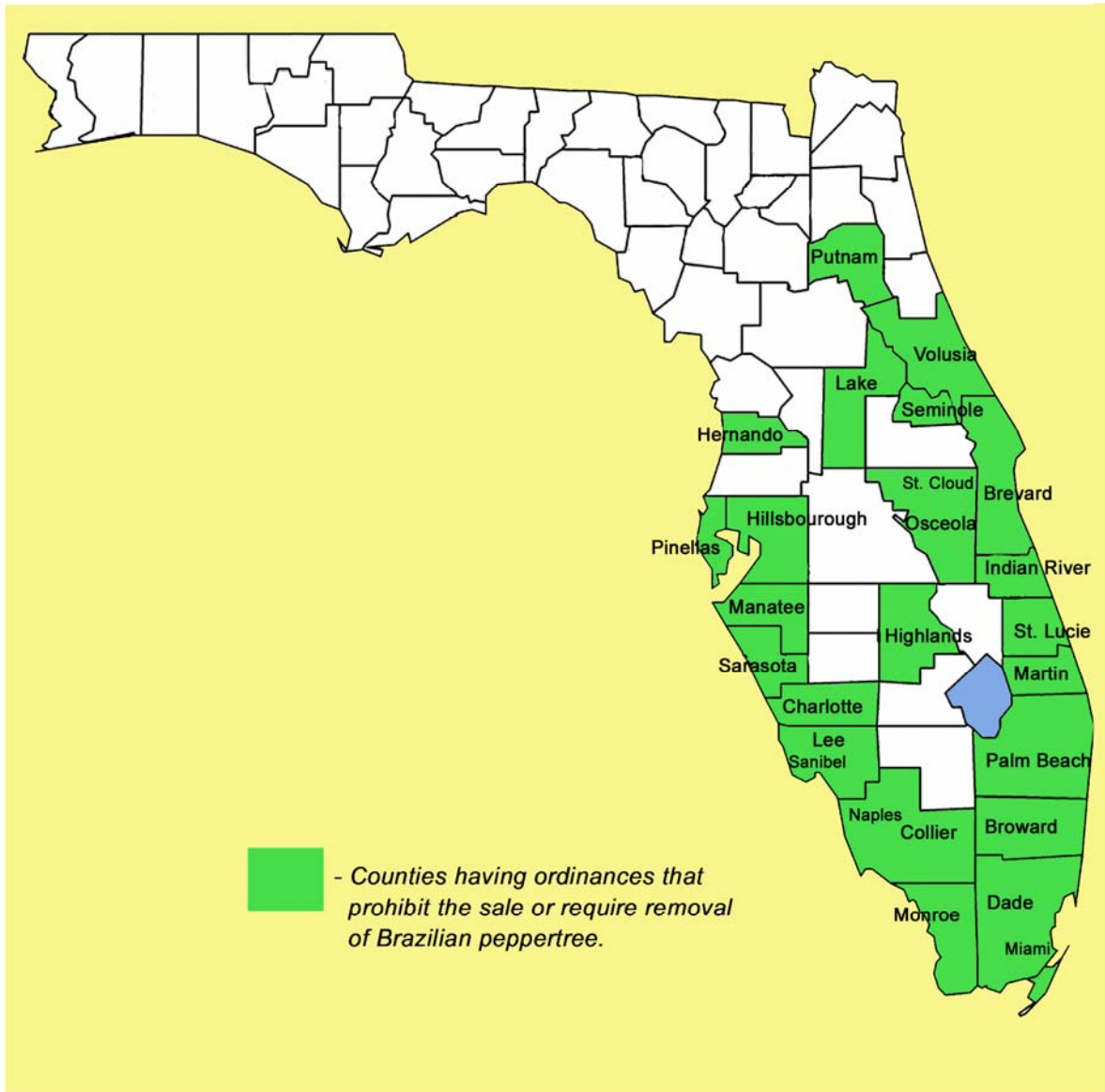


Figure 17. Florida counties/municipalities having specific ordinances prohibiting the sale or require removal of Brazilian peppertree after Ferriter (1997) (Figure credit: M. Sanford).

4. *Mechanical control.* Manual removal although time-consuming often is an effective method to control small stands of Brazilian peppertree in suitable areas. Although hand pulling can be effective for seedlings and small saplings, once the plant attains a height of several feet only heavy equipment is capable of removing the entire plant including the root system to prevent resprouting. Repeated-hand pulling must be followed up with other control methods.

Brazilian peppertree plants can be removed by the use of heavy equipment such as bulldozers, front end loaders, root rakes and other specialized equipment (Fig. 18). Other control methods must be implemented after the existing stands are removed because disturbance of the soil usually creates favorable conditions for regrowth from the seedbank, resprouting, and recolonization by long distance avian seed dispersal. However, the use of heavy equipment is not suitable in sensitive natural areas such as mangrove communities where alternative control measures are required.



Figure 18. Front end loader in Port St. Lucie fitted with cutting/grinding attachment for removal of Brazilian peppertrees along roadside rights-of-way (Photo credit: J. Dunton).

5. *Physical control.* The physical environment, such as water fluctuation, salinity, presence or absence of fires, etc, can stress plants or even kill them (Fig. 19). Physical techniques include soil removal, prescribed burning, and flooding (Randall 2000). As mentioned previously, soil removal can be effective for eliminating Brazilian peppertree and preventing its reestablishment but this method is labor intensive and costly. Prescribed burns have been used to control Brazilian peppertree with mixed results. The seeds fail to germinate following exposure to fire but the plants will readily resprout from the crown and roots (Randall 2000). Repeated fires at 3 to 7 year intervals were found to slow down the invasion rate of Brazilian peppertree but would not completely prevent its reestablishment (Doren et al. 1991). Thus, the use of fire as a management tool for controlling Brazilian peppertree is recommended only for removing existing stands and must be combined with other tactics as part of an integrated management plan.

Long periods of flooding may stress or even kill Brazilian peppertree plants. At the Everglades National Park, Brazilian peppertree is absent from marshes and prairies with hydroperiods exceeding 6 months (LaRosa et al. 1992). In addition, studies have shown that Brazilian peppertree seedlings are vulnerable to prolonged submergence (Ewel et al. 1982). The Sanibel Restoration Project (See Sanibel Island case study) illustrates the effects of flooding in managing Brazilian peppertree stands. However, once established, Brazilian peppertree is capable of surviving periods of prolonged flooding and exhibits some tolerance to salinity (Ewe 2004).



Figure 19. Brazilian peppertree on a ditch bank in Hillsborough County being killed by exposing the roots with a high pressure water hose technique referred to as hydrojecting (Photo credit: Heather Faessler).

Recent Case studies.

1. *Everglades National Park*. Farming in the Hole-in-the-Donut (HID) region in the Everglades National Park (ENP), Florida, between 1916 and 1975 altered approximately 4000 ha of natural vegetation, including short hydroperiod prairies and pinelands (Loope and Dunevitz 1981a, Krauss 1987). When farming practices ended in 1975, Brazilian peppertree aggressively colonized the more intensively farmed portions of the HID. Currently, Brazilian peppertree forms an almost impenetrable thicket over most of the former agricultural lands (Ewel et al. 1982, Krauss 1987, Doren et al. 1990). Hydroperiod and substrate modifications, including nutrient enrichment of the farmed soils, facilitated the invasion of Brazilian peppertree in this area (Loope and Dunevitz 1981a, Li and Nordland 2001).

Dalrymple et al. (2003) performed a pilot test beginning in 1989 to examine whether it was necessary to remove all soil down to consolidated bedrock to inhibit re-colonization by Brazilian peppertree and permit wetland restoration in the HID. Two different soil treatments were established: 1) partial soil removal (PSR) consisted of all existing vegetation cover removed while a thin layer of rock-plowed substrate was left intact (6 ha), and 2) complete soil removal (CSR) with all the vegetative cover and underlying rock-plowed substrate removed down to bedrock (18 ha). The 8-year study showed that complete soil removal (CSR) of rock-plowed substrate produced by farming was necessary to prevent re-establishment of Brazilian peppertree and to promote natural re-colonization by native wetland plants. In contrast, the partial soil removal (PSR) treatment did not prevent the re-colonization and re-establishment of a canopy of Brazilian peppertree, and by 1996, the site was again dominated by a monoculture of this invasive weed. This study showed the difficulties associated with simply controlling existing stands of Brazilian peppertree in natural areas, and highlights the importance of seeking alternative and more ecologically sustainable methods to direct the process of plant succession in a predictable manner.

2. *Tampa Bay*. Brazilian peppertree is an important invader of mangrove forests surrounding Tampa Bay. Natural mangrove forests provide critical habitat for an abundance of fish species, arboreal arthropods, mammals, birds, reptiles, and aquatic invertebrates. Displacement of mangrove forest by a canopy of Brazilian peppertrees has deleterious effects on native species that depend directly on the structural diversity of the mangrove canopy to survive. Mangrove forests provide critical habitat for several species and subspecies of songbirds, and many estuarine birds. Although it is estimated that at least 37,000 ha (100,000+ acres) of Brazilian peppertree occur in the upper mangrove ecosystems of Everglades National Park, upper mangrove ecosystems in Pasco and Hillsborough Counties are likewise dominated by Brazilian peppertree (Beever 1994, Lewis et al. 1996).

Removal of Brazilian peppertree from mangrove ecosystems is extremely difficult because mechanical removal will destroy and disturb the mangrove community substrate. In addition, herbicides used to control Brazilian peppertree are detrimental to mangroves, causing high mortality (Beever 1994). Only removal by hand and injector herbicide systems was successful in eliminating Brazilian peppertrees from small areas (Beever 1994). Lewis et al. (1996) compared the effectiveness of the three most common

herbicides used to control Brazilian peppertree: glyphosate, triclopyr amine, and triclopyr ester. Herbicide treatments were applied to plots dominated by Brazilian peppertree and also containing mangrove species in Tampa Bay, Florida. Results showed that the basal bark application of triclopyr ester was the most cost-effective method, causing 100% mortality after 60 days post-treatment. However, further research is needed to determine the best means of selectively removing large infestations of Brazilian peppertree within mangrove ecosystems. [Note: Biological control would seem to be an appropriate tactic in this unique and sensitive environment; see Section IV. JPC].

3. *Fern Forest Nature Center (Pompano Beach)*. Fern Forest is a 102-ha designated urban wilderness park in the vicinity of Fort Lauderdale, Florida. This site is rich in botanical diversity, and lies in a depression in the Atlantic Coastal Ridge designated as Cypress Creek Slough (Pierce 1970). The area was drained in the early 1900s as a consequence of the construction of water management canals for flood abatement, agriculture uses, and development. During a habitat assessment of the park, remnants of the historical slough were discovered, including several small isolated wetlands, a deciduous hardwood swamp, a cypress swamp, and large tracts of desiccated marl limestone (Cowardin et al. 1979, Mitsch and Gosselink 1986, MacAdam 1992). These areas, which comprised 26 ha or approximately 25% of the park property, were no longer functioning wetlands. Draining the area made it vulnerable to invasion by undesirable vegetation, primarily Brazilian peppertree.

A restoration project was initiated in 1990 with the objective of restoring an area of South Florida forested wetlands to its pre-drainage condition (Weller 1995). Physically removing the Brazilian peppertrees and restoring the natural hydrology resulted in the re-establishment of several types of wetland communities at the Fern Forest Nature Center in the three-year project (Weller 1995). This example shows the importance of developing effective programs to successfully preserve natural areas in Florida. However, the manual removal of Brazilian peppertree that was accomplished in this pilot project is labor intensive, costly and impractical for larger tracts of land infested with the weed.

4. *Sanibel Island*. Since incorporation in 1974, the city of Sanibel has been recognized as a shining example of a “Sanctuary Island”. This is evident by the strict environmental standards that were established for guiding planning and zoning (by eight naturally occurring ecological zones), restricting development, and the fact that almost 70% of the island is held under public ownership for conservation purposes (Clark 1999). Invasive plant removal on the J.N. “Ding” Darling Refuge began in 1976. The city of Sanibel entered into a formal cooperative agreement in 1996 with the U.S. Fish and Wildlife Service, who manages J.N. “Ding” Darling National Wild-life Refuge, and the Sanibel-Captiva Conservation Foundation. An important component of this program was the adoption of local legislation, through public environmental education, aimed to regulate and ultimate eradicate invasive exotic plants including Brazilian peppertree. The restoration process entailed the removal of eight invasive exotic plant species, hydrological reconfiguration, and native plant recruitment and enhancement (Clark 1999). Physical control of Brazilian peppertree has been implemented since the development of an advanced surface water control program. A system of weirs, installed

in 1995 at a cost of \$4.5 million, maintains surface water at 3.2 ft NGVD. The system provides flood protection for residents while restoring interior fresh water wetlands. The return of the hydrology to historical levels has caused some Brazilian peppertree plants that invaded transitional areas between cordgrass/leather fern swales and tropical hardwood hammock ridges, to become stressed or die out due to lengthy periods of inundation. Also, the coordination and timing of fire and herbicide applications have been shown to be somewhat effective in controlling Brazilian peppertree (Clark 1999). In addition to implementing the control measures, two volunteer groups routinely surveyed city properties and maintained inventory records of wildlife and vegetation before, during, and after restoration. As a result of this program, melaleuca was eradicated from Sanibel island and Brazilian peppertree infestations have been either eliminated or dramatically reduced on some of the intensively managed properties.

**See Appendix III for previous case studies on Brazilian peppertree management.*

IV. INTEGRATED MANAGEMENT PLAN

Permanent suppression of Brazilian peppertree in Florida will require an ecologically-based, adaptive management plan (Ferriter 1997, Walker 1997). The purpose of this management plan will be to provide land managers with a predictable strategy for addressing the Brazilian peppertree problem. A basic tenant of the Brazilian peppertree management plan is that the invaded plant communities are dynamic and will require the application of various technologies (e.g., chemical, cultural, and mechanical controls, as necessary) to enhance the natural processes and mechanisms that direct vegetation change (Sheley and Pinella 2001, Sheley and Krueger-Mangold 2003). Where possible, natural controlling processes (e.g., biological control, plant competition, allelopathy) will be manipulated to increase their effectiveness.

Prior to implementing Brazilian peppertree control measures, the following factors must be considered and used in developing a site specific management plan:

1. Occurrence - extent of infestation, density, spatial distribution and other plant communities that are present.
2. Topography and soils - How does occurrence relate to elevation and soils? What are the characteristics of the soils - organic, sandy, hydric?
3. Hydrology - Has the site been impacted by drainage? Are there canals, agricultural fields, or wells nearby that may have caused a drawdown of the water table on the site?
4. Available management techniques - Which method of treatment or combination of methods is most suitable to the site being treated?
5. Economic factors - How much will it cost to exert initial control and then provide a long term follow up? What are sources of funding, grants, mitigation? Will the work be done by agency staff or by a contractor?
6. Public perception - Will public reaction cause bad publicity? What can be done to educate the public to avoid negative reaction?
7. Work schedule - Determine a reasonable time schedule as a goal for initial treatment and plan for routine maintenance control.

In order to implement a site-specific IPM plan for Brazilian peppertree, the critical ecological processes that direct plant community dynamics to the detriment of Brazilian peppertree in that particular ecosystem must be identified and manipulated. Those processes with the highest probability of causing change in the desired direction will be modified to produce predictable results (Sheley and Krueger-Mangold 2003). This approach, which is referred to as ‘successional weed management’, requires a basic understanding of the three general causes of plant succession: disturbance, colonization and species performance (Rosenberg and Freedman 1984). Sheley and Pinella (2001) noted that . . .”Within the limits of our knowledge about the conditions, mechanisms, and processes controlling plant community dynamics, these three components [disturbance, colonization and species performance] can be modified to allow predictable, successional transitions. We can design the disturbance regime and attempt to control colonization and species performance through management . . .” Three different management scenarios for Brazilian peppertree in Florida based on this model are illustrated below.

(1) In the first scenario, the Brazilian peppertree infestation is a virtual monoculture (Fig. 20). This situation is typical of most public and private lands that are currently dominated by Brazilian peppertree. Management objectives in this example are aimed at increasing the production of native plants at the expense of Brazilian peppertree. In south Florida, the seed input into successional communities is often 25 species (native and non-native) per month, and all Brazilian peppertree dominated forests contain seeds/seedlings of some native species (Ewel et al. 1982). Because this particular site consists mostly of Brazilian peppertree, appropriate chemical and mechanical control practices can be aggressively applied to remove the existing canopy with minimal impact on non-target native species. Once the standing biomass is removed, the appropriate Brazilian peppertree biological control agents (e.g., sawfly and thrips) will be released to attack the understory regrowth and seedlings. The establishment and effect of the biological control agents will be carefully monitored. An area-wide fire ant control program will be implemented during the biological control agent release phase to increase the likelihood of natural enemy establishment by minimizing ant predation. Because Brazilian peppertree produces most of its seeds in the fall and winter when seed production by native species declines (Ewel et al. 1982), a supplemental seeding program will be implemented. Seeds of competitive native species (see below) will either be broadcast or presented in strategically placed bird feeders for natural dispersal during the winter when Brazilian peppertree is exploiting a colonization time when there is little competition from native species (Ewel et al. 1982). Thus, the process of plant succession to the desired state will be controlled primarily by natural enemies and plant competition with an occasional herbicide retreatment, if necessary.

(2) The second scenario is typical of a plant community that consists of a mixed stand of Brazilian peppertree and several native plant species (Fig. 21). Desirable native species such as gallberry (*Ilex glabra* (L.) A. Gray), saw palmetto (*Serenoa repens* (W. Bartram) Small), sumacs (*Rhus* spp.) and wax myrtle are common in many habitats that have been invaded by Brazilian peppertree and represent the same functional group as the target weed, i.e., woody shrubs. Wax myrtle is one of the more valuable native species because of its allelopathic properties (Dunevitz and Ewel 1981). In this example,

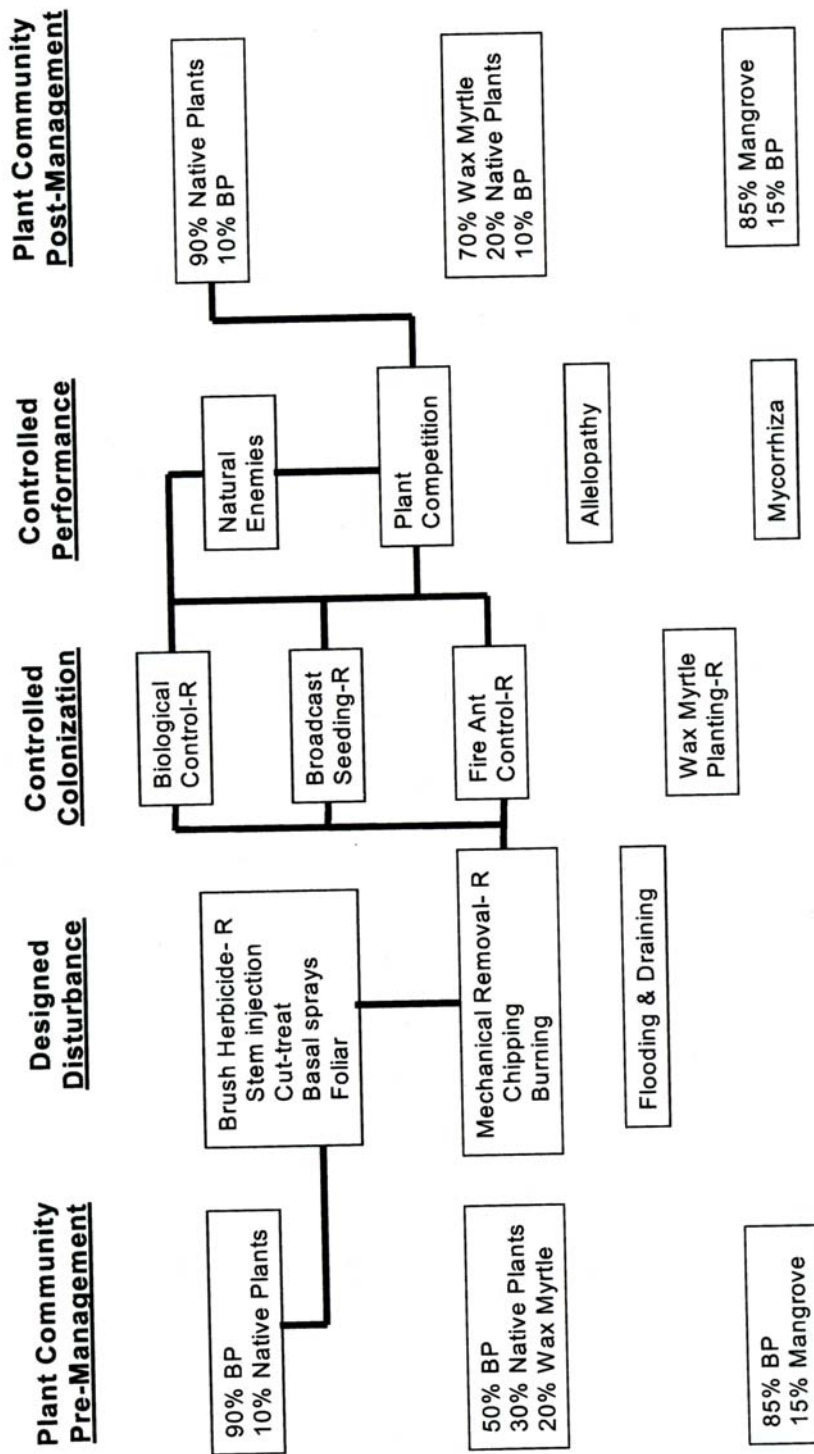


Figure 20. Successional management plan for a Brazilian Peppertree dominated ecosystem. R indicates that the technique is repeated (modified from Sheley and Pinella 2001).

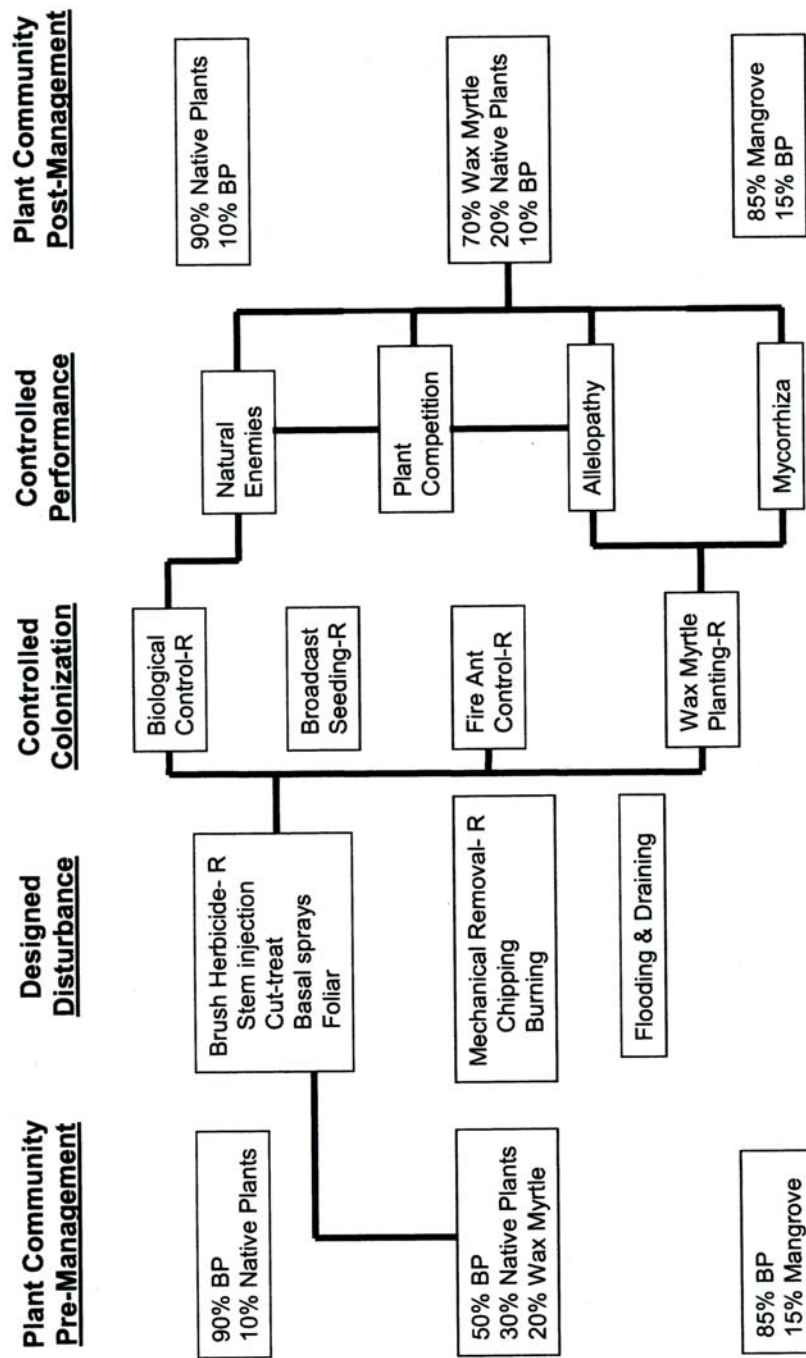


Figure 21. Successional management plan for a mixed stand of Brazilian Peppertree and wax myrtle. R indicates that the technique is repeated (modified from Sheley and Pinella 2001).

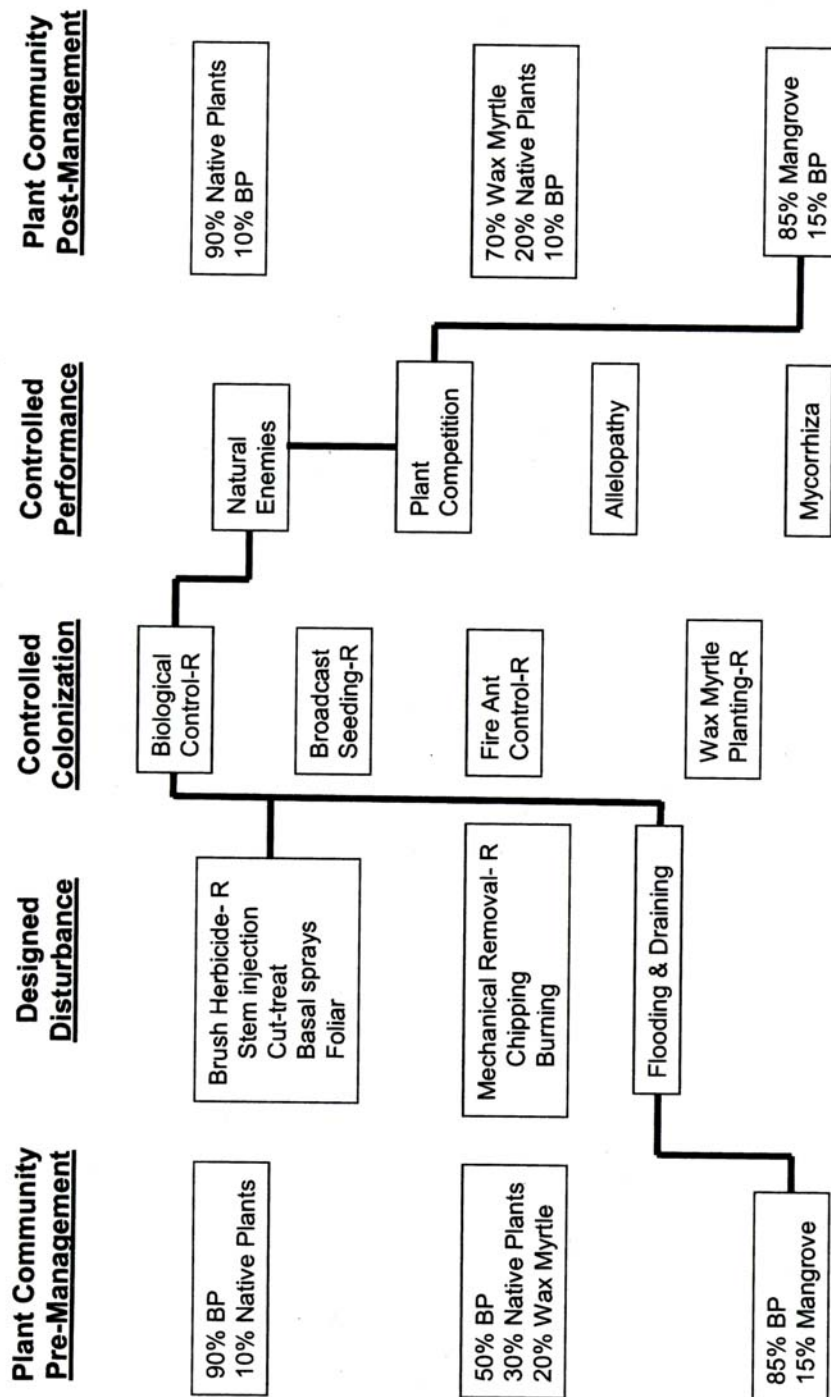


Figure 22. Successional management plan for a mangrove community invaded by Brazilian Peppertree. R indicates that the technique is repeated (modified from Sheley and Pinella 2001).

Like the goal is to selectively remove Brazilian peppertree without disturbing the native species. Preserving the native species during the designed disturbance phase will reduce the likelihood of immediate recolonization by Brazilian peppertree (Ewel et al. 1982). In order to minimize non-target impacts on the native shrubs, the designed disturbance phase is limited to selective application of herbicides currently labeled for Brazilian peppertree control (Langeland 2001, Langeland and Stocker 2001). The herbicide of choice would be imazapyr because it can provide good control of Brazilian peppertree yet wax myrtle has been shown to tolerate foliar applications of this herbicide (Laroche and Baker 1994). After selective removal of the Brazilian peppertree canopy, appropriate biological agents (e.g., sawfly and thrips in upland sites; leaflet roller and psyllid in extended hydroperiod sites) will be released to control the understory seedlings and any regrowth from chemically-treated canopy trees. A fire ant control program in the upland sites will be beneficial during the controlled colonization phase to increase the likelihood of biological control agent establishment. Growth of wax myrtle will be encouraged through natural seed dispersal via bird feeders, broadcast seeding of mechanically or chemically scarified seeds, or planting wax myrtle seedlings. The scarification process, which is accomplished in nature by dispersal agents such as tree swallows or other *Myrica* seed feeding birds, is essential for germination of wax myrtle seeds (Ewel et al. 1982). As in the previous example, the process of plant succession to the desired state will be controlled primarily by natural enemies and plant competition with an occasional herbicide retreatment, if necessary. The only difference is that the growth of wax myrtle will be specifically targeted because of its demonstrated allelopathic effects on Brazilian peppertree. Although the actual mechanism of allelopathy in wax myrtle is unknown, the allelochemicals that are produced may be disrupting the uptake process by damaging the root hairs of Brazilian peppertree, or possibly inhibiting the growth of the mycorrhizal fungi that are associated with the plant and are considered necessary for normal uptake functions.

(3) In the last scenario, Brazilian peppertree has invaded and become the dominant species in a coastal mangrove forest (Fig. 22). Mangrove forests typically dominate Florida's natural shoreline habitats and saline communities. However, the ability of Brazilian peppertrees to tolerate a wide range of site conditions and extended hydroperiods (Ewe and Sternberg 2002, Ewe 2004) makes this invasive shrub a formidable invader of mangrove forests. Ewel et al. (1982) observed that although established Brazilian peppertree plants tolerate a wide range of water levels and salinities, the seedlings were quite vulnerable to rapid changes in water depth. Seedling mortality was highly correlated with rapid flooding and drying events. Thus, the only designed disturbance option available for selectively managing large infestations of Brazilian peppertree within mangrove communities that are highly sensitive to mechanical and chemical control practices is manipulation of water regimes to reduce the number of seedlings. Further reduction of the surviving Brazilian peppertrees will be accomplished by matricide (selectively controlling reproductively mature female trees either chemically or mechanically) and releasing a suite of biological control agents that are adapted to these habitat conditions. For example, the leaflet rolling moth *Episimus utilis* Zimmerman and the leaflet-galling psyllid *Calophya terebinthifolii* Burckhardt & Basset typically are associated with Brazilian peppertrees inhabiting coastal environments in southeastern Brazil. In contrast, the defoliating sawfly *Heteroperreya hubrichi* Malaise

and the flower and stem thrips *Pseudophilothrips ichini* (Hood) have rarely, if ever, been observed attacking Brazilian peppertrees in these coastal mangrove communities. The high humidity associated with Florida's coastal marine environment also would be conducive to propagation of the native parasitic plant *Cassytha filiformis* L. (Lauraceae), which can weaken Brazilian peppertrees (Burch 1992, 1994) and the establishment of a host-specific fungal pathogen, possibly a *Septoria* sp. recently discovered in Brazil (Faria 2004). Thus, plant succession would be directed towards maintaining a healthy mangrove dominated forest using only low impact tactics such as prescribed flooding and natural controls.

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VII. APPENDICES

APPENDIX I. CLASSICAL BIOLOGICAL CONTROL AGENTS.

Several insects and at least one pathogen were identified from exploratory surveys conducted in northern Argentina, southeastern Brazil and recently Paraguay as potential biological control agents because they visibly damage the plant in its native range and seemed to be host specific (Habeck et al. 1994, Cuda et al. 1999, Cuda et al. 2004, Faria 2004). The following is a brief summary of the biology and impact of these natural enemies on Brazilian peppertree.

Heteroperreya hubrichi Malaise (Hymenoptera: Pergidae)

The defoliating sawfly *H. hubrichi* (Fig. 23) was initially selected as a candidate for further study because the larvae defoliate the plant in its native range, and the insect was collected only from Brazilian peppertree in South America. The biology, ecology and host range of the sawfly *H. hubrichi* were investigated in Brazil, Florida, and Hawaii (Vitorino et al. 2000, Medal et al. 1999, Hight et al. 2003, Cuda et al. 2005).

Heteroperreya hubrichi is a primitive non-stinging wasp native to northern Argentina, southeastern Brazil and eastern Paraguay. The larval stage of this insect is phytophagous (plant feeding). The adults are black with yellow legs, and the sexes can be separated on the basis of size (females are larger), the presence of the ovipositor in females, and also antennal morphology. Field data collected in Brazil indicate this species is bivoltine (2 generations per year). Sex ratio of the adults is approximately 1:1 (males to females) when reproduction is bisexual, but the sawfly also exhibits arrhenotoky. Arrhenotoky is a form of reproduction whereby mated or unmated females produce offspring; mated females produce females and unmated females produce only males. In Brazil, a pupal diapause period occurs in the summer (December to February) and winter (June to August).

Upon emergence from the pupal stage, females mate and/or oviposit in young woody branches that are adjacent to the more tender terminal shoots. This behavior enables the sawfly to avoid the toxic resin common in the Brazilian peppertree's terminal growth. The female uses her saw-like ovipositor to cut the stem tissue and insert her eggs between the thin bark and the phloem. The eggs are elliptical in shape, and are deposited side by side in long rows of variable length and number. Females exhibit maternal behavior by guarding the egg masses during the incubation period, but die as soon as the first larvae hatch.

The period of egg maturation is about 15 days. The number of eggs is directly linked to the size of egg mass. The average number of eggs per mass is ~ 100. Females prefer to oviposit on plants that are < 3 m in height, and select young branches with a diameter between 2.5 to 5 mm for oviposition. In Brazil, the majority of sawfly egg masses (76.5%) occurred on plants with hairy leaves (varieties *pohlianus* and *rhoifolius*). However, in laboratory and greenhouse studies, sawflies readily accepted var. *raddianus*, the smooth variety of Brazilian peppertree that commonly occurs in Florida.

The larvae are bright green with a black head capsule, and have red areas at the end of abdomen and adjacent to the head capsule in the last two instars. The larval stage

has seven instars in the females and six in the males. The duration of the larval stage (from emergence of the neonate larvae to pupation) is 45 days. The pre-pupal phase is characterized by the change in the size of the last instar larvae (25% smaller), and cessation of feeding. In this phase, the larvae burrow in the soil to a depth ranging from 3 to 4 cm to pupate. The pupation chamber acquires the color of the surrounding soil, and is ~ 1 cm in length, and ~ 0.5 cm in width. The pupal stage lasts from 1 to 5 months, with an average of 4 months.

The larva of *H. hubrichi* is the damaging stage. Developing larvae are voracious leaf feeders (Fig. 23), and can cause complete defoliation of Brazilian peppertrees depending on the size of the plant and quantity of larvae present. This type of feeding damage could severely injure or kill young plants and prevent older plants from reproducing, thereby reducing the competitive advantage that Brazilian peppertree currently holds over native vegetation. In Brazil, it is not uncommon to find Brazilian peppertree shrubs (and more rarely mature trees) completely defoliated by the sawfly. Larvae are gregarious in the early instars, and feed in groups on tender leaves mainly on new shoots. When the larvae reach the third instar, they disperse over the plant and attack leaves of all age classes.

Since the entire life cycle from adult to adult can be completed in less than 4 months under ideal conditions, this insect may be capable of producing two or three generations per year in central and south Florida where Brazilian peppertree is a severe problem. Simulated herbivory studies conducted under field conditions in south Florida over a two-year period have shown that growth and reproduction of Brazilian peppertrees are severely impacted when the plants are subjected to multiple defoliations within the same growing season (Treadwell and Cuda 2004).

The federal interagency Technical Advisory Group for the Introduction of Biological Weed Control Agents (TAG) recommended the release of the defoliating sawfly *H. hubrichi* in Florida. This biological control agent currently is undergoing risk assessment as required by the National Environmental Policy Act (NEPA) due to concerns raised about toxins produced by the larvae.

Pseudophilothrips ichini (Hood) (Thysanoptera: Phlaeothripidae)

Another promising natural enemy of Brazilian is the thrips *P. ichini* (Fig. 24). The biology and field host range of *P. ichini* were studied in southeastern Brazil (Garcia 1977), and its host range was investigated in Florida quarantine (Cuda et al. 2002b). *Pseudophilothrips ichini* has not been observed feeding on plants other than Brazilian peppertree in its native range (Garcia 1977, J. H. Pedrosa, pers. observ.). In Brazil, *P. ichini* usually is associated with the Brazilian peppertree varieties *pohlianus* and *raddianus*. Because this thrips was found attacking only Brazilian peppertree in field surveys, Garcia (1977) suggested that *P. ichini* might be a good candidate for biological control of Brazilian peppertree. More importantly, there are no native congeners of Brazilian peppertree in the United States that would be at risk from attack by *P. ichini*.

The life cycle of *P. ichini* begins when the female deposits her eggs on the leaves of the plant. After hatching, the immature thrips undergo two larval instars that are the active feeding stages. As soon as the larval feeding phase is completed on the host plant, the remainder of the life cycle occurs in or on the soil. Unlike other families of the

Thysanoptera that have only two pupal instars (the propupa and pupa), thrips belonging to the family Phlaeothripidae that includes *P. ichini* are unique in that they undergo three non-feeding pupal instars (the propupa, pupa I and pupa II) instead of two (Mound and Marullo 1996).

While these developmental phases are not true larvae or pupae, these terms are commonly used to describe the immature stages in a thrips life cycle. The immature stages vary in length, depending on climate and other factors. Like the sawfly, *P. ichini* is arrhenotokous; mating is not required to produce offspring. Unmated females of *P. ichini* deposit eggs that develop only into males whereas mated females produce eggs that develop into females (Mound and Marullo 1996).

Adults of *P. ichini* are relatively small (3-6 mm) but have a high reproductive rate. *Pseudophilothrips ichini* is polyvoltine; up to four generations per year have been observed in Curitiba, Brazil, and it is considered a common species in its native range (Garcia 1977). The adults are black and winged whereas the wingless larvae are mostly red but occasionally orange. Both the larval and adult stages damage the plant.

In Brazil, the adults overwinter on Brazilian peppertree. In early spring (September), females start laying eggs singly or in small groups on the leaflet pedicels and blades, or on the new tender shoot growth. The larvae hatch from the eggs in 7-8 days at 24 °C. The first and second instars last 6 days and 11-12 days, respectively. The two-nonfeeding prepupal and pupal stages require ~ 8 days to complete their development. After transformation to the adult stage, females undergo a 5 to 15 day preoviposition period, and can oviposit up to 220 eggs during their lifetime (45-78 days). Duration of the complete life cycle for *P. ichini* is temperature dependent. According to Garcia (1977), the life cycle from egg to egg was completed in 76 days at 18 °C, and 38 days at 24 °C. Under laboratory conditions, females lived an average of 78 days at 23.1 °C when maintained in vials provided with food.

The life cycle of the flower and stem thrips was studied more recently in Brazil in an attempt to develop a mass rearing procedure (Harmuch et al. 2001). The egg incubation period lasted 4 days. The durations of the first and second larval instars were 3 and 4 days, respectively. The prepupal stage, which is unique to the Phlaeothripidae (Mound and Marullo 1996) lasted 5 days and the first and second pupal stages were completed in 4 and 2 days, respectively. The adult stage lasted 20 days. The total (or cumulative) development time from the egg to adult stage of the Brazilian peppertree thrips was 42 days under ambient laboratory conditions.

Larvae of *P. ichini* usually are found clustered around the stem of a tender shoot (Fig. 24). They feed by rasping and sucking the plant sap, which frequently kills the growing tip. The adults are usually found on the new unfolding leaves where they feed, mate, and oviposit. Although they can be more randomly distributed on the plant, the adults usually are found aggregated with the developing larvae. Adults also will feed on the flowers, causing them to abort. This type of feeding damage can inhibit seed production in mature plants and growth rate of younger plants. In addition, there is anecdotal evidence suggesting that feeding damage by *P. ichini* promotes infection by plant pathogens that contributes to shoot death (R. Barreto, pers. comm.).

Natural enemies of *P. ichini* in Brazil include the following: *Macrotacheliella* sp. (Hemiptera: Anthocoridae), *Orius* sp. (Hemiptera: Anthocoridae), *Cardiastethus rugicollis* (Hemiptera: Anthocoridae), *Lestodiplosis* sp. (Diptera: Cecidomyiidae), an

unidentified thrips; and a parasitoid, *Tetrastichus gentilei* Guercio (Hymenoptera: Eulophidae) (Garcia 1977).

A petition to release *P. ichini* from quarantine was prepared and submitted to the TAG in November 1996. Request for release from quarantine was denied because the biological and host range testing data presented in the original petition did not adequately address the risk to native plant species and to the closely related California peppertree *S. molle*, a common introduced ornamental in southern California. A new petition to release the thrips *P. ichini* was prepared and resubmitted to the TAG in October 2002 (Cuda et al. 2002b). Although the revised petition addressed virtually all of the concerns raised by reviewers in the earlier petition, the TAG raised some new non-target issues. These concerns have been addressed, and an addendum to the 2002 petition will be submitted to the TAG in 2006. A permit to release the thrips *P. ichini* in Florida is anticipated once TAG recommends release of the insect and Environmental and Biological Assessments have been submitted to satisfy NEPA requirements.

Episimus utilis Zimmerman (Lepidoptera: Tortricidae)

Martin et al. (2004) investigated the biology of the leafrolling tortricid moth *E. utilis* in quarantine while establishing a laboratory colony for conducting host range tests. Adults (Fig. 25) are small, grayish brown moths with distinctive markings on the forewings (Zimmerman 1978). When at rest, the adults are cryptically colored, resembling either tree bark or bird droppings. Sexes can be readily separated without magnification by examining the wing pattern (Zimmerman 1978). Average life span for the adult moths is 8 to 9 days, and development from egg to adult stage occurs in about 42 days.

Females can deposit up to 172 eggs during their lives. Eggs are usually deposited singly but occasionally in groups of up to six eggs on the upper and lower surfaces of Brazilian peppertree leaflets. The eggs, which are glued to the leaflet, are compressed, ovoid, and light green in color with a smooth chorion when first deposited but darken as they develop. The thin, scale like shape and transparency of freshly deposited eggs probably afford them some protection from predation and possibly parasitism.

The caterpillar (or larval stage) of *E. utilis* attacks the foliage of Brazilian peppertree. Early instars are tan to light green in color but as they reach maturity, the larvae turn bright red before pupating and are approximately 15 mm long (Fig. 25). In general, the larval stage has 5 instars although a 6th instar may occur on occasion.

Feeding habits of the larvae vary depending upon their age. Newly hatched larvae and early instars feed by scraping the surface of the leaflets. Early instars are leaflet tiers, and normally feed between young and expanding leaflets that have been tied together with silk. The 1st to 3rd instars typically web together two or more adjacent leaflets flat against each other. Older larvae bind single leaflets into the characteristic cylindrical roll that is usually associated with *E. utilis* in nature. A cohort of approximately 35 larvae is capable of completely defoliating a 0.5 m tall Brazilian peppertree potted plant in less than 3 weeks (Martin et al. 2004).

Unlike the sawfly *H. hubrichi* that pupates in the soil and is vulnerable to flooding and possibly ant predation, mature larvae of *E. utilis* pupate in the tree canopy inside

rolled leaflets attached to the plant. Pupae are brown in color with the head, appendages and wings darker than the abdomen.

Parasitism plays a key role in regulating populations of *E. utilis* in southeastern Brazil and may explain why the insect is not more damaging in its native range. Krauss (1963) reported that *E. utilis* is attacked in Brazil by *Bracon* sp. as well as an undescribed species of *Apanteles*. According to Martin et al. (2004), larvae of *E. utilis* imported from Brazil often were parasitized by *Apanteles* sp. and *Cotesia* sp. (Hymenoptera: Braconidae) as well as *Pristomerus* sp. and *Xiphosomella* sp. (Hymenoptera: Ichneumonidae).

In Hawaii, where it was released in the 1950s, *E. utilis* is widely distributed on Brazilian peppertree, but the insect apparently is not sufficiently abundant to severely damage the plant (Goeden 1977, Yoshioka and Markin 1991, Julien and Griffiths 1998, J.P. Cuda 2002, personal observation). The ineffectiveness of *E. utilis* as a biological control agent in the Hawaiian Islands may be due in part to biotic mortality factors unique to that environment. For example, two wasps that were introduced into Hawaii for classical biological control of the sugar cane leafroller *Hedylepta* (= *Omiodes*) *accepta* (Butler) were discovered attacking *E. utilis* soon after it was released against Brazilian peppertree (Davis 1959, Krauss 1963).

Although satisfactory biological control of Brazilian peppertree by *E. utilis* was not achieved in the Hawaiian archipelago, this failure should not preclude the introduction of the insect into Florida. *Episimus utilis* could be a more effective biological control agent of Brazilian peppertree in Florida because it would be introduced into a new environment where the ecological conditions may be more favorable to the insect. For example, biotic mortality from introduced and native parasitoids and predators may be less severe in Florida compared to Hawaii.

Other Potential Biological Control Agents

Several new natural enemies are being investigated as candidates for biological control of Brazilian peppertree. One of these is leaflet galling psyllid *Calophya terebinthifolii* Burckhardt & Basset (Hemiptera: Psyllidae) (Burckhardt and Basset 2000). Preliminary studies on the biology, host range and dispersal capabilities of this insect have been completed in the state of Santa Catarina, Brazil (Barbieri 2004). The biology of this species probably is similar to that of *C. schini* Tuthill, a pest of California peppertree, *S. molle* (Downer et al. 1988). Adults and nymphs of *C. terebinthifolii* feed by inserting the stylets of their piercing-sucking mouthparts into the phloem tissue of Brazilian peppertree. Females deposit light colored eggs that darken just prior to hatching generally on the unexpanded leaves. Upon hatching, the nymphs create shallow pit galls in the leaflets, with up to several dozen pits per leaflet. There are four nymphal instars, and the adults emerge through the dorsum of the final instar. Reproduction probably occurs year-round in tropical species of the genus *Calophya* (Burckhardt and Basset 2000). Downer et al. (1988) observed that adults and eggs of *C. schini* were present year-round on California peppertree. Developing nymphs damage the plant by forming the pit galls and introducing toxins along with the saliva. The pitting and associated distortion of the leaflets can lead to extensive defoliation when psyllid populations are high. Also, the nymphs secrete wax and honeydew, which leads to the

formation of sooty mold.

Another potential biological control agent of Brazilian peppertree is the leafhopper *Typhlocyba karachiensis* Ahmed & Jabbar (Homoptera: Cicadellidae). Although Brazilian peppertree is native to South America, it was reported that this leafhopper attacks Brazilian peppertree in Pakistan (Ahmad and Jabbar 1971, R. Mahmood, CAB International Regional Bioscience Centre-Pakistan, pers. obs.). Apparently, Brazilian peppertree is commonly grown as a hedge plant in many localities in the city of Karachi. According to the Ahmad and Jabbar (1971), *T. karachiensis* attacks the plant from February to November, and can become quite abundant especially on older leaflets, which suffer severe damage. Eggs of the insect are imbedded in the leaflet tissue along the midrib. The life cycle of *T. karachiensis* is completed in 18-22 days during April to May, and there are five instars in the nymphal stage. During a recent survey conducted in Karachi in March 2004, R. Mahmood of CAB-IRBC, Pakistan, observed that Brazilian peppertree is not invasive in the region. He also noticed that the older leaflets were covered by black sooty mold and were dead or dying. No leafhoppers were present but numerous exuviae (cast skins) were discovered on the underside of the leaflets, suggesting that leafhopper attack had been high recently. Apparently, *T. karachiensis* damages the plant by sucking the sap from the leaflets and interfering with photosynthesis when the black sooty mold develops on the honey dew secreted by the insect as it feeds. This insect has not been collected in previous South American surveys of arthropods associated with Brazilian peppertree (Silva et al. 1968), which suggests that it may be a new associate of Brazilian peppertree in Pakistan or it may be an unreported adventive species from South America.

In March 2004, a survey trip to northern Argentina in was conducted in collaboration with scientists from the USDA-ARS South American Biological Control Laboratory located in Buenos Aires (Gandolfo et al. 2004). During this trip, several new insects were discovered attacking Brazilian peppertree, including two species of defoliating caterpillars, and three wood-boring beetles. One of these beetles is a weevil that was identified as *Apocnemidophorus blandus* (Pascoe) (Coleoptera: Curculionidae). The adults damage the leaflets by creating extensive feeding holes. Leaflets that are heavily damaged by the feeding weevils eventually abscise. Although the larval biology of the insect is unknown, most species in this weevil genus attack the twigs, stems, or branches of their host plants, feeding under the bark or in the cambium layer (C.W. O'Brien, pers. comm.). It is also possible the larvae of this species may attack the root crowns or even the roots of Brazilian peppertree.

Surveys for pathogenic fungi associated with Brazilian peppertree in the state of Minas Gerais in southeastern Brazil were carried out from 2001 to 2003 (Faria 2004). The purpose of these surveys was to discover pathogens of Brazilian peppertree with biological control potential. Several fungi were found during the surveys, including a *Septoria* sp. (Sphaeropsidales). Preliminary pathogenicity and host-specificity tests were performed with this plant pathogen that included only a limited number of local plants belonging to the Anacardiaceae. However, only Brazilian peppertree was infected by the *Septoria* sp. The significant defoliation that *Septoria* sp. caused both in the field as well as under controlled greenhouse conditions coupled with the indications that this fungus is host-specific based on the results of the initial host range tests indicate that this species may be a potential biological control agent for Brazilian peppertree. A related fungus, *S.*

passiflorae, has proven to be an effective biological control agent of the invasive banana poka, *Passiflora tripartita* (Juss.) Poir var. *tripartita* Holm-Nie. Jörg. & Law, in Hawaii (Trujillo et al. 2001).



Figure 23. *Heteroperreyia hubrichi*, a defoliating sawfly of Brazilian peppertree. Adult female guarding egg mass inserted into stem (left); gregarious larvae feeding on leaflet (right) (Photo credit: J.C. Medal).



Figure 24. *Pseudophilothrips ichini*, a thrips that kills the shoot tips of Brazilian peppertree. Adult female (left); larvae on young stem (right) (Photo credits: M.D. Vitorino and D.H. Habeck).



Figure 25. Adult (top) and mature larva (bottom) of *Episimus utilis*, a leafrolling moth introduced into Hawaii for biological control of Brazilian peppertree (Photo credits: D.H. Habeck and L. Buss).

APPENDIX II. RESULTS OF HERBICIDE TRIALS (Source: Ferriter 1997).

Table 1 Results of herbicide trials on Brazilian pepper conducted by Woodall (1982).

| Herbicide | Rate | Method | % Cont. | Summary |
|-----------|----------------------|----------------|---------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| AMMATE | .46kg a.i./Liter | Stump | 43% | Stump treatments are suitable only when tops are required to be removed from the site. They give temporary control and are labor intensive. |
| BANVEL | .06kg a.i./Liter | Stump | 90% | |
| DED-WEED | .06kg a.i./Liter | Stump | 92% | |
| VELPAR | 4.5 kg a.i./ha | Broadcast-soil | 95% | New seedling developed within 9 months, possibly originating from stored seeds as well as a new seed crop. |
| AMMATE | 65kg a.i./1000 L | Foliar | 0% | Due to the fact that foliar applications are a physiologically indirect means of killing root systems, the probability for long lasting success with this method is low –Brazilian Pepper is a vigorous, easily sprouting species. |
| BANVEL | 1.2kg a.i./1000 L | Foliar | 52% | |
| DED-WEED | 4.8kg a.i./1000 L | Foliar | 82% | |
| VELPAR | 4.8kg a.i./1000 L | Foliar | 75% | |
| VELPAR | 8ml/ 5cm s.b.d. | Basal-soil | 98% | For widely scattered bushes where access to the main stem is difficult, basal spot is easy, effective and selective. |
| HYVAR | 8ml/ 5cm s.b.d. | Basal-soil | 98% | |

Table 2 Results of herbicide trials on Brazilian pepper conducted by Ewell *et al.*, (1982)

| Herbicide | Rate | Method | % Cont. | Summary |
|-------------------|------------------|------------|---------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| BANVEL 720 Liq. | 5% | Foliar | 58% | Malformed epicormic and basal sprouts were observed after defoliation following application, but most of these sprouts later died |
| BANVEL 720 Liq. | 2.5% | Foliar | 77% | |
| BANVEL 720 Invert | 3.5% | Foliar | 73% | |
| BANVEL 720 Invert | 1.8% | Foliar | 62% | |
| BANVEL 5G | 48ml/m crown dm. | Soil | 18% | Results were not readily visible until at least 2 months after application. This treatment was not effective even after 9 months following application. |
| BANVEL 5G | 8ml/m crown dm. | Soil | 8% | |
| ROUNDUP | 1.7% | Foliar | 54% | Recommended for large numbers of small individuals, as in the understory of a stand. |
| ROUNDUP | .8% | Foliar | 100% | |
| VELPAR | 24 g/L water | Foliar | 100% | Killed >75% of the neighboring shrubs and vines, most of them were still dead 9 months post treatment. |
| VELPAR | 12g/L water | Foliar | 100% | |
| GARLON (M-4021) | .8% | Foliar | 92% | Recommended for large numbers of small individuals, as in the understory of a stand. |
| GARLON (M-4021) | .3% | Foliar | 77% | |
| GARLON (M-4021) | 1.5% | Basal-Bark | 100% | Had little long-term impact on understory plants. Recommended for killing large trees. |
| GARLON (M-4021) | .5% | Basal-Bark | 100% | |

Table 3 Results of herbicide trials on Brazilian pepper conducted by Doren and Whiteaker (1990).

| Herbicide | Rate | Method | % Cont. | Summary |
|-----------|------|------------|---------|-----------------------------------------------------------------------------------|
| GARLON 4 | 2% | Basal Bark | 94% | Very little difference in treatment effectiveness between the two concentrations. |
| GARLON 4 | 4% | Basal Bark | 96% | See above. |

Table 4 Results of herbicide trials on Brazilian pepper conducted by Laroche and Baker (1994).

| Method ¹ | Herbicide | Rate | % Control |
|---------------------|-----------|-----------------------------------|-----------|
| EZJECT | RODEO | 1 capsule @ 2" intervals | 0% |
| | RODEO | 1 capsule @ 4" intervals | 0% |
| | RODEO | 1 capsule @ 8" intervals | 0% |
| FISCAN | SPIKE | 1 capsule @ 3" intervals | 0% |
| | SPIKE | 1 capsule @ 6" intervals | 0% |
| | SPIKE | 1 capsule @ 12" intervals | 0% |
| | VELPAR | 1 capsule @ 3" intervals | 0% |
| | VELPAR | 1 capsule @ 6" intervals | 0% |
| | VELPAR | 1 capsule @ 12" intervals | 0% |
| Basal Soil | SPIKE | 0.25 ounces / 6" BSD ² | 98% |
| | SPIKE | 0.5 ounces / 6" BSD | 95% |
| | SPIKE | 1 ounce / 6" BSD | 97% |
| | VELPAR | 2 milliliters / every 2" BSD | 40% |
| | VELPAR | 4 milliliters / every 2" BSD | 84% |
| | VELPAR | 8 milliliters / every 2" BSD | 91% |
| Basal Bark | GARLON 4 | 1:4 oil @ 0.1 oz/ 1" BSD | 5% |
| | GARLON 4 | 1:4 oil @ 0.25 oz/ 1" BSD | 10% |
| | GARLON 4 | 1:4 oil @ 0.5 oz/ 1" BSD | 55% |
| Foliar | ARSENAL | 0.5% solution ³ | 95% |
| | ARSENAL | 1.0% solution | 98% |
| | GARLON 3A | 1.5% solution | 93% |
| | GARLON 3A | 3.0% solution | 97% |
| | RODEO | 0.5% solution | 0% |
| | RODEO | 1.5% solution | 55% |

APPENDIX III. PREVIOUS CASE STUDIES (Source: Ferriter 1997).

1. Big Cypress National Preserve

Brazilian peppertree is one of the most problematic exotic species in the Preserve. Brazilian pepper quickly invades disturbed, well-drained sites such as roadside soil banks, levees, oil well pads, old farm fields, and abandoned homesites, with the largest monotypic stands occurring on filled sites. In addition, scattered trees and small stands can be found in hardwood hammocks, as an understory plant in pinelands, and as an epiphyte on stumps and cypress knees. Brazilian peppertree control has been ongoing since the creation of the Preserve in 1974. Primary treatment methods have been basal treatments with 15% Garlon 4® using diesel fuel as a carrier or stump treatments using 100% Garlon 3A®. In 1994, a 150 gallon spray tank was purchased and a foliar spray program was initiated using Garlon 4® herbicide (2.5% solution) with water and Kinetic® added as a surfactant. This program was designed to reduce the seed source in an effort to minimize Brazilian peppertree recruitment into surrounding natural areas. Another facet of the National Park Service effort to eradicate Brazilian peppertree from the Preserve relies on the use of heavy equipment. Prior to federal acquisition, lands within the Preserve were often used for activities that resulted in disturbance to the natural landscape. These lands were subject to rock mining, homesteads, farming, and road and canal construction. These human-caused changes to the landscape often resulted in the filling of wetlands. These filled areas are almost always heavily infested with Brazilian peppertree. The strategy for eradicating Brazilian peppertree focused on its intolerance to extended inundation (Hilsenbeck 1972, as cited in Duever et al., 1986). Based on this premise, the plan for eradicating the plant from these areas focused on extending the hydroperiod by restoring the areas' elevations to predisturbance conditions. Brazilian peppertree was mechanically removed from the areas utilizing a bulldozer with a root rake. With the use of a track-hoe and bulldozer, the fill material was excavated and disposed of. The final elevations were determined by the presence of cap rock and/or the elevations of the surrounding areas. Monitoring of these sites has revealed no re-establishment by Brazilian peppertree. To date, over 250 acres of Brazilian peppertree have been removed.

2. Biscayne National Park

Brazilian peppertree is less problematic on the islands of Biscayne National Park than other invasive pest plants such as *Colubrina asiatica* (Lather leaf), *Thespesia populnea* (Seaside mahoe) and *Schaevola taccada*. However, on the mainland, especially around Convoy Point, Brazilian peppertree is becoming more widespread, particularly after Hurricane Andrew. A possible reason for this is the transport of copious seed material from the islands to the mainland by hurricane winds. The plant quickly colonized disturbed sites and, once established, spread to new areas. The aerial extent of Brazilian pepper coverage in Biscayne National Park today is unknown, and a mapping project is planned to provide this information. Since Hurricane Andrew, exotic plant control in Biscayne National Park has not been performed with any regularity. The resource managers are formulating an exotic plant management plan and hope to

implement a major initiative soon. Documentation of control efforts will be required under the new plan. The main method used for the treatment of Brazilian peppertree is cut and spray using Garlon 3A. Basal bark treatments using Garlon 4 are being planned. The latter treatment will be used on Brazilian peppertree in remote areas, while the cut and spray method will be applied on trees in high profile areas.

3. De Soto National Memorial

Brazilian peppertree is one of the most problematic exotic species in DESO Park. It is found in the Park's dense mangroves and in isolated areas adjacent to the Park. Mechanical removal has been used in appropriate areas. The herbicidal control program involves applying triclopyr (Garlon 3A) to fresh cut stumps 4" to 6" in length. It is applied with a hand pressure sprayer. Product use rate is applied at an undiluted or 1:1 mixture applied to the cambium. The DESO Brazilian peppertree control program was initiated in January 1994.

4. Everglades National Park

Brazilian peppertree was first reported growing in a farmed area of the Park known a Hole-in-the-Donut in 1959 (Alexander and Crook 1974) but probably became established there in the 1940's (Olmsted and Johnson 1983). It began to spread throughout this area as these farmlands were abandoned. In the early 1960's, Craighead reported that Brazilian pepper had advanced around Everglades City. In 1972, after Hurricane Donna, Hilsenbeck found that the plant had invaded Muhlenbergia prairie and the mangrove zone near West Lake. Brazilian peppertree distribution was mapped by Park resource management personnel in 1976 and found to have spread to parts of the pinelands, the Flamingo area, the coastal area around Madeira and Little Madeira Bays, and north of Park headquarters along the eastern Park boundary. An unpublished report by Koepp (1978b) on the occurrence of *Casuarina* in the southeastern corner of the Park indicated its presence there as well. A 1982 survey of Brazilian peppertree in mangrove areas found that plants were discontinuously distributed and occurred in patches with certain habitats; i.e., low mangrove areas, being more susceptible to invasion than others (Olmsted and Johnson 1983). The most recent information on Brazilian peppertree distribution in the Park is derived from a Park mapping project using 1987 aerial photographs. This distribution map reveals an aerial extent of Brazilian peppertree in excess of 105,000 acres, 95% of which lies in the mangrove zone along the west and northwest coasts. Details on the mapping procedure are found in Rose (1988). Recent, cursory surveys in the East Everglades indicate that a number of tree islands; e.g., bayheads in Shark Slough, particularly those disturbed by dry season wildfires and, more recently, by Hurricane Andrew, are supporting increasing numbers of Brazilian peppertree. The size and extent of Brazilian peppertree populations in the Park defy control methods by available resources. The majority of the control effort -- surveying, treatment, and monitoring, is carried out by rangers in the various districts of the Park. They are guided by annual "action plans" developed by district backcountry rangers in cooperation with Park resource managers. The control work carried out varies among the districts and is a reflection of differences in personnel, funding, and other work

assignments. Recent control efforts have concentrated on maintaining areas treated in past years. Flamingo District rangers have treated and maintained the area along the main Park road between West Lake and Mahogany Hammock and between East and Northwest Cape. Pine Island District rangers, with assistance from seasonal work crews, have maintained the Anhinga Trail at Royal Palm. Northwest District rangers (at Everglades City) have treated and maintained several backcountry campsites. The time devoted to Brazilian peppertree control is limited by the treatment of other Category I exotic pest plants including *Casuarina* spp. and *Colubrina asiatica* which have established populations on the islands and shores of Florida Bay and the Gulf Coast.

The herbicidal control of Brazilian peppertree in the Park is accomplished by applying trichlopyr (Garlon) as a basal bark or cut stump treatment. The basal bark formulation contains 4% - 8% mineral oil, while the cut stump formulation contains 50% water. Follow-up treatments are necessary to treat regrowth (sprouts). Small plants are pulled by hand or treated with a foliar application of Arsenal where the dilution and rate of application vary depending upon the formulation used. The mechanical removal of mature Brazilian peppertree from 3.5 acres on an upland site at Chekika Hammock in the East Everglades Acquisition Area was carried out in the fall of 1993 as part of a mitigation and restoration project. The Brazilian peppertrees were uprooted using heavy equipment, piled into heaps, and mechanically mulched. The mulch was laced around the bases of native trees left standing in the cleared area; i.e., *Bursera simaruba* and *Ficus aurea*, creating a series of low maintenance beds 18 - 24 inches deep. Brazilian pepper recruitment in these beds is easily controlled by hand pulling. The cleared area, however, consisting of three zones with varying elevational and hydroperiod patterns, necessitated that a different Brazilian peppertree management strategy be used for each zone. One zone (shallow soil on higher ground) is managed to control the re-establishment of Brazilian pepper by regular mowing, thus hindering the establishment of woody vegetation. A second zone (long hydroperiod marsh) is revegetating naturally with typical wetland species; Brazilian peppertree is controlled by the hand pulling of seedlings. The third zone (intermediate in elevation and hydroperiod) was regarded as being most susceptible to Brazilian peppertree colonization and was covered with sod (St. Augustine grass) as a temporary ground cover and weed deterrent. Brazilian peppertree has not yet been found in this zone. This area will eventually be planted with subtropical hardwood species similar to those found in the adjacent hammock.

5. Hole-in-the-Donut Mitigation Project

Situated within the boundaries of Everglades National Park, the Hole-in-the-Donut (HID) comprises approximately 4,000 ha of previously farmed land. One-half of the area was rock-plowed, and, after its abandonment in the mid-1970s, the area has been invaded by Brazilian peppertree. The remaining 2,000 ha of non-rock plowed land, abandoned from 1930 through the early 1960s, has returned primarily to native vegetation with only a small portion dominated by Brazilian peppertree (Ewel et al. 1982). When the Park acquired the HID in 1975, farming ceased, and restoration of the area was addressed. Several studies were carried out in the Park to examine old field succession. (See Doren et al. 1990, for a summary.) However, the rapid spread and establishment of Brazilian peppertree in the area, estimated at increasing by as much as

twenty times its population density per year (Loope and Dunevitz 1981a), proved too overwhelming for successful restoration. During the late 1970's and 1980's, several methods were tested to eliminate Brazilian peppertree, including bulldozing, burning, mowing, and planting and seeding of native species, and all failed. However, one method, the complete removal of disturbed substrate, resulted in the recolonization of previously rock-plowed sites by native vegetation to the exclusion of Brazilian peppertree. This has been attributed to the removal of the effects of the disturbed substrate and subsequent increase in hydroperiod (Doren et al. 1990). In 1989, through an off-site, compensatory mitigation project, funding was provided for a pilot project involving the experimental removal of the disturbed substrate on approximately 24 ha of degraded (previously rock-plowed) wetlands within the HID. On 18 ha of the site, Brazilian pepper was mechanically removed and the soil removed to bedrock, while on the remaining 6 ha, part of the soil was left after Brazilian peppertree removal. Continuous monitoring has revealed that the larger site has successfully eliminated Brazilian peppertree (and other pest plants) and restored native wetland species, while *Schinus* has recolonized the entire area of partial soil removal. This study and data from several other sites in Dade County indicate that the restoration of Brazilian peppertree-dominated, rock-plowed wetlands are dependent upon the complete removal of the fundamental substrate; i.e., the artificially created substrate with concomitant hydrological improvements. Details of the pilot study are given in Doren et al. (1990). The apparent success of the pilot project has encouraged the Park to expand the work on a larger scale and reclaim all the remaining Brazilian peppertree-dominated, rock-plowed wetlands within the HID. The Park has applied for a Federal Clean Water Act, Section 404, dredge and fill permit and a State of Florida wetland regulatory permit to establish a regional mitigation bank. It is estimated that the mechanical removal of Brazilian peppertree (and subsequent substrate removal) from the entire 2,000 ha in the HID will take up to 20 years to complete.

6. Myakka River State Park

Opened to the public in 1942, Myakka River State Park encompasses 28,875 acres. Oak and cabbage palm hammocks, grassy marshes and sloughs surround both the upper and lower Myakka Lakes. Vast expanses of dry prairie and pine flatwoods help make Myakka River State Park one of the largest and most biologically diverse parks in the state. Its proximity to the coast and limited surrounding developments have helped to restrict the level of Brazilian peppertree infestation within the park. Following resource management guidelines set by the Florida park service and the unit management plan specifically outlined for the park, an average of 100 Brazilian peppertrees are reported and removed from the park each year. An aggressive monitoring program by park staff requires exotic species to be reported. Location information is logged, and the trees are slated for removal. Volunteers and various community organizations, including community service workers, are used to help park staff in Brazilian peppertree removal. Early detection allows workers to hand pull young seedlings and saplings. Larger trees (up to 3" diam.) are removed (including the root systems) by hand digging. When hand removal becomes impractical due to size or location, Garlon 4 (mixed with JLB oil) is applied as a basal bark treatment.

7. Sanibel Island - Sanibel-Captiva Conservation Foundation

Results from an experiment conducted by the Sanibel-Captiva Conservation Foundation (SCCF) on Sanibel Island, Florida (1990-1991), and the effects of a substantial rainfall in 1995 suggest that Brazilian peppertree can be stressed or killed by flooding. In both cases, Brazilian peppertree did not exhibit the adaptations generally found in wetland species of woody plants in response to flooding. These adaptations include adventitious rooting and lenticular enlargement (Kozlowski 1984), both of which were observed in buttonwood trees immediately adjacent to the stressed Brazilian peppertree. Inundation produced stress to varying degrees including leaf chlorosis, wilting and abscission. Trees that lost all of their leaves eventually died. Dead trees took approximately 1.5 years to decompose. The following are results of the SCCF 1990-1991 experiment that involved the artificial flooding by periodic pumping of a 4.5 acre Brazilian peppertree infested impoundment of varying grade elevations. The average water level in the impoundment for 77 days (September 19-December 4) was 3.2 feet NGVD, with a high of 3.9 feet NGVD. Trees flooded by an average of 9.5 to 15 inches of water showed varying degrees of stress; some lost all of their leaves, and died, while others recovered from leaf chlorosis, wilting and partial leaf abscission. Flooding levels of less than 9.5 inches of water created little or no stress. Trees with lateral roots which could reach areas of decreased inundation exhibited less stress than would be indicated by the inundation level of the main trunk. Soils in the lower areas (15 to 22 inches of inundation) tended to be more organic in nature and may have been more conducive to creating an anaerobic state which caused severe root stress. Other encroaching plant species which were stressed include wax myrtle (*Myrica cerifera*) and saltbush (*Baccharis halimifolia*). Similar results were observed on a larger scale in 1995. In the Spring of this year, a new water control structure was completed on Sanibel Island. The crest elevation is 3.2 NGVD. The capacity of the structure to release water through the opening of gates was offset by the ability to hold water 0.7 feet (8.4 inches) higher than previously possible. This allowed for higher water levels in Brazilian peppertree-infested interior wetlands in the western half of the island. Brazilian peppertree exhibited signs of severe stress in areas of low elevations. During periods of high summer rains (July 18-October 29), water levels averaged 3.1 feet NGVD with a high of 3.7 feet and a low of 2.6 feet. Two significant impacts were observed: stress on hardwood vegetation, predominantly Brazilian peppertree in low-lying areas, and the restoration of open water sites, especially in areas where prescribed burns were performed in early June 1995. Brazilian peppertree stress ranged from total leaf loss and death in low-lying areas, to partial leaf loss in transition zones, to leaf yellowing in lower ridge areas. Other encroaching plant species that were stressed included wax myrtle (*Myrica cerifera*) and saltbush (*Baccharis halimifolia*).

APPENDIX IV. CURRENT TASK FORCE MEMBERS

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