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THE INVASION OF CARROTWOOD (*Cupaniopsis anacardioides*) IN NATURAL AREAS

by

Christine S. Lockhart, Daniel F. Austin, William E. Jones,

and Lisa A. Downey

Submitted to:

Greg Jubinsky
Department of Environmental Protection
Aquatic Plants Lab
3917 Commonwealth Blvd.
Tallahassee, FL 32399

Submitted by:

Christine Lockhart
Habitat Specialists
P.O. Box 3116
Boynton Beach, FL 33424-3116

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ABSTRACT

Carrotwood (*Cupaniopsis anacardioides*) was first identified as a potentially invasive tree in 1989, approximately ten years after it became popular as a landscape tree. Since then, seedlings to medium-sized trees have established themselves outside of cultivation in disturbed sites and undisturbed natural areas. Birds disperse the seeds, and contribute to a rapidly expanding wild population that includes isolated islands. As of 1996, carrotwood has invaded a wide variety of habitats in 14 southern and central Florida counties. Wild carrotwood has become reproductive in three counties. Densities range to 0.21 plants per m^2 in coastal strand, to 21.47 plants per m^2 in coastal hammocks, and to 24.16 plants per m^2 in mangroves. Presence of carrotwood is involved in alteration of the natural species diversity of mangrove and coastal hammock communities. The invasibility of carrotwood has been compared to Brazilian pepper (*Schinus terebinthifolius*). The distribution of wild carrotwood also coincides with that of all three mangrove tree species. Education and regulatory actions are essential now to reduce costly removal efforts in the near future.

INTRODUCTION

Few of the introduced alien plants that are established in the United States have succeeded in dominating our native plant communities, but those that have are disrupting native ecosystems, competing with endangered species, and costing taxpayers millions of dollars. Outside of Hawaii, there is no equal to the ecosystem devastation occurring in Florida (McKnight 1993, U.S. Congress 1993, Schmitz and Brown 1994, Simberloff 1994).

Millions of plants are imported into Florida annually. In 1990 alone 333 million plants passed through the Miami International Airport. This Miami port admits 85% of all plant shipments into the United States (U.S. Congress 1993). About 1% of these imports are inspected, and then usually only as possible carriers of insect pests (Center 1993). This flood of non-native plants into Florida largely results from active agricultural and horticultural communities, a $1 billion a year industry (U.S. Congress 1993).

On the opposite side of the economic scale, it costs Florida citizens many millions of dollars in taxes to combat invasive exotics. Exotic plants have caused an economic drain on the US of over $1 billion per year since 1906 (U.S. Congress 1993). To our knowledge, no one has figured exactly how much they cost Florida in tax money.

To focus attention on the multitude of economic and ecological problems being caused by alien plants, the Exotic Pest Plant Council has prepared ranked "most invasive" plant lists for the past several years (EPPC 1995). In the following discussion we focus on an alien species that was first noted in native ecosystems in 1989. That tree is *Cupaniopsis anacardioides* (A.Rich.) Radlkf., more commonly known as carrotwood or tuckeroo.

DESCRIPTION AND HISTORY

Carrotwood (*Cupaniopsis anacardioides*) is a native of the northern and eastern coastal districts of Australia, where it occurs naturally on stabilized sand dunes, rock outcrops, rocky beaches, in hilly scrub, monsoon forests and vine thickets and riverine forests (Jessup 1985, Brock 1988). This tree thrives in nutrient poor soils (Oakman (1964) in Hawkeswood 1983). Older trees are able to withstand temperatures to about 22° F (-6° C), which cause frost damage on the outer canopy (Stresau 1986). These trees are also tolerant of smog polluted urban areas in California (E. Golby, personal communication, 1996).

Carrotwood is a tree that achieves heights to 10m in Australia and has a dark grey bark. Leaves are variable, even or odd pinnately compound, with 4-12 oblong leaflets, whose blades are 4.5 - 19 cm long and 1.5 - 7.5 cm wide with a rounded or slightly indented apex, and a swollen petiole base. Small, numerous white or greenish-yellow flowers, up to 0.8 cm diameter, erupt on axillary panicles up to 35 cm long. Fruits

are woody capsules with three distinctly ridged segments on short stalks, up to 2.2 cm in diameter, and appear yellow-orange when ripe, exposing three shiny elliptical black seeds covered by a yellow to red aril when open (Jessup 1985, Brock 1988).

Flowering occurs in late winter, usually January to February, and typically fruits mature in April to June. This period corresponds to similar seasons of Australia's southern hemisphere. Australian references cite flowering and fruiting in late summer and fall, respectively (Jessup 1985, Brock 1988). Unfortunately, some Florida plant books have not made the hemispheric seasonal adjustment, because the reproductive season has been erroneously listed as summer to fall (Broschat and Meerow 1996, South Florida Water Management District, 199?).

This tree has been introduced in subtropical parts of the world, including California and Florida (Oliver 1992). Naturalized populations in peninsular Florida are mostly coastal so far, with occasional inland sightings. Bird dispersal explains carrotwood populations on isolated islands in the Gulf and Atlantic Intracoastal Waterways, and numerous seedlings under trees and telephone poles. Fish-eating crows, which roost on those islands, and mockingbirds have been observed fighting over the seed (D. Austin, personal observation, 1990-1996). Seedlings have been observed under telephone poles where starlings perch in a Broward County park (G. Phillips, personal communication, 1996).

Fast-growing, evergreen, symmetrical canopy growth, salt-tolerant, xeric, tolerant of sunlight, shade, poor soils and poor drainage - these are qualities that made carrotwood popular in southern California and are increasing its popularity in Florida. An article published in the Pacific Coast Nurseryman's Magazine praising these qualities caught the eye of Florida nurserymen. In the early 1960s, seeds and a live specimen were shipped from southern California to a southwest Florida nursery (E. Golby, personal communication, 1996). The live specimen was planted on Siesta Key (Sarasota County) and is said to still be there. By the late 1970s and early 1980s, nurseries throughout the state were growing and selling carrotwood to landscapers and developers throughout the southern part of the state. Carrotwood was also planted as a quick growing barrier or privacy screen. Easy to propagate and fast-growing, this tree became an easy money maker for nurseries.

During 1989 and 1990, carrotwood began to appear voluntarily outside of cultivation in a variety of habitats in disturbed and natural areas (Oliver 1992; M. Hurchalla 1990, E. Freeman, R. Moyroud, J. Smith, personal communication, 1996).

The growth of carrotwood has been compared with Florida's worst invasive exotics, including *Schinus terebinthifolius* (Brazilian pepper) (J. Doyle, correspondence 1991, Hamner 1992). Carrotwood appears to successfully compete with other aggressive exotics. Seedlings and saplings have been found growing alongside *Schinus* and through *Casuarina equisetifolia* leaf litter (Ann Cox, personal communication, 1996). An understory of over 250 carrotwood plants of varying sizes was observed within a

predominate stand of Melaleuca quinquenervia (Roger Clark and Bill Jones, personal observation). Within the past few years, a few counties and municipalities have passed ordinances with varying degrees of restriction.

Within 10 years of landscape use, carrotwood escaped into the wild, not only appearing in native habitats, but also in hedge rows and under trees in disturbed areas of peninsular Florida. The invasive nature of carrotwood is recognized by many park managers, naturalists, and field biologists, yet the lack of published scientific documentation of the problem has left some skeptics. The objectives of this study are: 1. To determine the geographic distribution of wild carrotwood within the state of Florida; 2. To record plant associations where non-cultivated carrotwood is found; 3. To determine carrotwood size classes and density in natural areas; and 4. To calculate species diversity in natural areas where non-cultivated carrotwood is found.

METHODS

DISTRIBUTION MAP

The locations of naturalized populations of carrotwood were identified from: a 1995-1996 survey by the Exotic Pest Plant Council (EPPC) provided by the Department of Environmental Protection, field biologist reports from various parts of the State of Florida, and responses to a published request for information (Lockhart 1996). Herbarium specimens were collected from sites in which plants exceeded one meter in height . A minimum of two reports were required for each county to be included in a distribution map which was generated with the use of "MapArt" by Micromaps Software (1992).

CARROTWOOD DENSITY , SPECIES DIVERSITY, AND PLANT ASSOCIATIONS

Six study sites were chosen on the basis of presence of non-cultivated carrotwood in natural areas, accessibility, and the recommendations of field biologists. Exotic removal records from Blowing Rocks Nature Preserve (The Nature Conservancy), were useful in approximating the initial appearance of carrotwood, and document re-infestation by new seedlings in a natural area.

To sample carrotwood density, belt transects were laid, starting where carrotwood seedlings were present. Transects were 25 m long, and consisted of five adjacent plots in the same compass heading, 2 m wide by 5 m long. Plot corners were staked during data collection, and field tape was tied on vegetation to mark the corners of test plots for future reference. A minimum of three and a maximum of six transects per location were studied, producing a representative sample of habitats where carrotwood was observed within that natural area. A minimum of 3 m was maintained between transects. Longitudes and latitudes for study sites were obtained using a GPS (Global Positioning

System), when available, or using geographical maps. Alternatively, section, township and range are given.

Within each 2 m x 5 m plot, plants were identified and the following data recorded: a) the number of individuals of each species; b) the size class of each individual (size class categories were < 0.5 m, 0.5 to 2 m, > 2 m); and c) the dominant canopy species. Carrotwood seedlings and saplings were removed from within each transect.

Each plot was identified by habitat type (mangrove, coastal hammock, coastal strand) and degree of disturbance. While arbitrary, our chosen definition of disturbed is meant to reflect human and natural events. Because signs of natural disturbance result from multiple time events, we have chosen to focus on woody species in the shrub or tree layers. For this study, a disturbed plot is defined three ways: 1) having obvious signs of human impact, such as spoil mounds, branch piles, or trash piles; 2) having alien species dominate the plot canopy; or 3) having any naturalized, alien species in the shrub or tree layers. Presence of carrotwood and herb layers were not included in this evaluation.

Density was determined (average carrotwood number per m^2) per plot in each size class by habitat and by disturbance. The Student's t-test was used to examine differences between disturbed and undisturbed plots. Comparisons were made using shrub and tree layer data in the mangrove, hammock and coastal strand habitats at each site where paired data were available. The seedling layer of data (<0.5 m) was not used for these comparisons because it is a less reliable indicator of plant establishment.

Species diversity was calculated using the Shannon Weiner Index,

$$H' = \frac{n \log n - \sum_{i=1}^{k} f_i \log f_i}{n}$$

., where k is the number of categories, *i* denotes a category (species), *n* is the sample size, and f_i represents the number of observations in category *i* (Zar 1984). All three strata were used in the computation. Results were compared to diversity indices of undisturbed, native habitat types from Molnar (1990) for hammocks and from good quality undisturbed plots in this study (no exotics) for coastal strand and mangroves, in which references for diversity indices are lacking.

A list of plant associations was compiled from the data for each study site. The list consists of any species that was growing within the test plots.

HABITAT TYPES

Habitat types within each study site are modified from ecosystem descriptions in Myers and Ewel (1990). The following are habitat descriptions as used for this study, with examples of identifying species given for mangrove, coastal / tropical hammock and coastal strand plant communities.

The mangrove habitat is a tidal forest whose species, while able to utilize both fresh and salt water, have an adaptive mechanism for salt exclusion or excretion. Salt water is the primary element that limits competitors (Kuenzler 1974 in Myers and Ewel 1990). Other factors that minimize competition in the harsh mangrove community are anaerobic sediments and fluctuating water levels. The key inhabitants of this forest are *Rhizophora mangle* (red mangrove), *Avicennia germinans* (black mangrove), and *Laguncularia racemosa* (white mangrove). An understory, which is usually lacking except near ecotonal regions, often includes *Sesuvium portulacustrum* (sea purslane), *Batis maritima* (saltwort) and *Iva imbricata* (marsh elder) (Corlett 1986). While plant species diversity is low in mangrove forests, primary productivity and nutrient levels are high, and mangroves provide habitat for a wide range of animals, particularly birds, fish and invertebrates. Mangrove communities on the eastern coast have high wave energy and high salinity, while those on the western coast have low wave energy and salinity gradients (Myers and Ewel 1990). Mangrove forests may grade into *Juncus - Spartina* salt marshes.

The coastal strand habitat typically occupies the transitional dune or "prickly zone" of beach communities (Myers and Ewel 1990). More variable and species rich than the fore dune, vegetation in this ecosystem tend to be spiny and consist primarily of herbaceous and shrub strata. Species composition differs between east and west coasts, but all are dominated by *Serenoa repens* (saw palmetto)(Austin, et al. 1977). Other species found in the coastal strand include *Yucca aloifolia, Agave decipiens, Coccoloba uvifera, Caesalpinia bonduc, Randia aculeata*, and *Dalbergia ecastophyllum*. On the southwestern coast, *Bumelia* may also be present.

Tropical hammocks occupy stable dunes inland from beach plant communities and have a tree canopy. Species in tropical hammocks compete well on drained calcareous soils. By contrast, temperate hammocks compete on acid soils. In comparison to other beach ecosystems and mangroves, tropical hammocks have a higher species diversity. Species diversity is greater on the eastern coast than on the western coast where 30 species like *Metopium toxiferum* (poisonwood) and *Krugeriodendron ferrium* (black ironwood) are absent (Little 1978). Eight western coast species, like *Pithecellocium unguis-cati* (Cat's claw) are not found in eastern hammocks. Typical species of coastal hammocks include *Bursera simarouba, Masticodendeon foetidissimum, Sabal palmetto, Coccoloba diversifolia,* and *Eugenia* spp. in the canopy. *Psychotria nervosa, Ardisia escollonioides, Forestiera segregata,* and *Chiococca alba* are common in the understory.

STUDY SITES

Lake Wyman Park, Boca Raton, Palm Beach Co., 26°21'49.62" N, 80°04'38.71" W. Lake Wyman Park is located on the western bank of the Atlantic Intracoastal Waterway in southern Palm Beach County. The park consists of patches of tropical hammock (disturbed sites) and mangrove swamp (disturbed and undisturbed sites). Manmade mosquito ditches run through part of the mangrove area. Transects were run

through both the tropical hammock habitat near the shore, and the mangrove habitat between the mosquito ditches.

Blowing Rocks Nature Preserve, Jupiter Island, Martin Co., 26°58'48.8 N", 80°04'94.8" W. The preserve is located on both sides of U.S. A1A (S.R. 707), partly along the shore of the Atlantic Ocean, and partly along the eastern shore of the Intracoastal Waterway. While the preserve consists of a several coastal habitats, transects were run through the coastal tropical hammock (mostly undisturbed), coastal strand (mostly disturbed) and disturbed mangrove remnant. The Preserve is managed by The Nature Conservancy.

MacArthur Beach State Park, North Palm Beach, Palm Beach Co., 26°50.138' N, 80°02.75' W. MacArthur Beach State Park covers about 700 acres of land along the Atlantic Ocean in northern Palm Beach County. The area recommended for study by park managers was at the northern end of the park, beginning in disturbed tropical hammock and continuing into mangrove swamps and across a small mosquito ditch. Parallel transects were run through these habitats.

John MacDonald Island, in Robert's Bay, Sarasota Co., T37 South, R17 East, S1, 27°30' N, 82°60' W. Also known as "Skier's Island", this 7.4 acre spoil island was formed ca. 1960 from sand dredged to form the Gulf Intracoastal Waterway. While mangroves dominate the island coast, exotics dominate the interior, e.g., *Casuarina equisetifolia, Schinus terebinthifolius*, and carrotwood. Transects were run through a disturbed inland *Casuarina* forest, an inland mangrove swamp, and a coastal ecotonal area (mangrove swamp / *Casuarina* forest).

Delnor Wiggins Pass State Recreation Area, 26°16'23" N, 81°49'08" W, occupies approximately one mile of coastal area in northern Collier County. Eighty percent of the 166 acres consists of mangrove forests. The other 20 percent is either parking area or relatively undisturbed coastal hammock. The northern end of the recreation area is heavily populated with *Casuarina equisetifolia*. Transects were run through the hammock on the southwest side of the park road and bordering a mangrove forest on the east side of the road.

Carl Johnson County Park, Lee Co., 26°50' N, 81°90' W, consists of 260 acres bordering the southwestern coast of Florida, between Fort Myers Beach and Bonita Beach. The narrow 1.5 mile (2.5 km) beach front strand consists of a monospecific canopy layer of *Casuarina equisetifolia*. The eastern edge consists of a series of mangrove bays dominated by *Rhizophora mangle* in the lower areas, and *Conocarpus erectus* and *Avicennia germinans* in the transition areas between *Casuarina* and *Rhizophora*. Transects ran through a narrow coastal strand of *Casuarina* which bordered on a mangrove bay.

RESULTS

DISTRIBUTION MAP

Escaped carrotwood currently grows in 14 counties from Brevard to Hillsborough and southward (Figure 1). A compilation of 70 field reports indicates the occurrence of wild carrotwood on spoil islands, in native habitats, and in disturbed and undisturbed areas. Habitat types in which wild carrotwood have been found are: mangrove swamps, cypress swamps, beach dunes, coastal strand, coastal hardwood hammocks, inland hammocks, pine flatwoods, sand pine scrub, and freshwater marshes. Carrotwood densities range from 0.11 to 17.71 plants per m^2 by location (Figure 1).

A summary of the reported sites of naturalized carrotwood are given in Table 1. The entries may only partially reflect the magnitude of invasion. The table does list the counties and habitats already impacted, and where further expansion is likely.

Plant sizes described for Table 1 included seedlings to five meter tall trees, and incidences per site ranged from a single or a few plants to dense nearly monoculture populations. While field reports cited reproductive carrotwood trees in Sarasota, Martin, and Brevard counties, there were no reproductive trees within the test plots used for density sampling.

CARROTWOOD DENSITY

There was a broad range of carrotwood density between sites, between habitats, and between disturbed and undisturbed plots. A total of 1,240 square meters were sampled during this study (Table 2). The lowest densities occurred in the coastal strand, ranging from 0.03 to 0.21 plants per m^2. The highest densities occurred in the mangroves, ranging from 0 to 24.16 plants per m^2. Hardwood hammocks were almost as dense as mangroves, with a range of 0.1 to 21.47 plants per m^2.

A significant difference appears to exist between disturbed and undisturbed plots at most study sites when looking at the raw data (Table 2). Results from Student's t-tests comparing the shrub and tree layers for each habitat and site with paired data, however, indicate that the only statistically significant difference occurred in the mangroves of southern Palm Beach County ($p<0.02$).

SPECIES DIVERSITY

Like density, there was much variation in diversity indices, particularly in the mangroves and hammocks (Table 3). Using diversity indices for undisturbed, native coastal hammocks from Molnar (1990) ($H'=1.07$), and from this study for undisturbed, native mangroves ($H'=0.34$), and coastal strand ($H'=0.59$), some effects of disturbance can be detected.

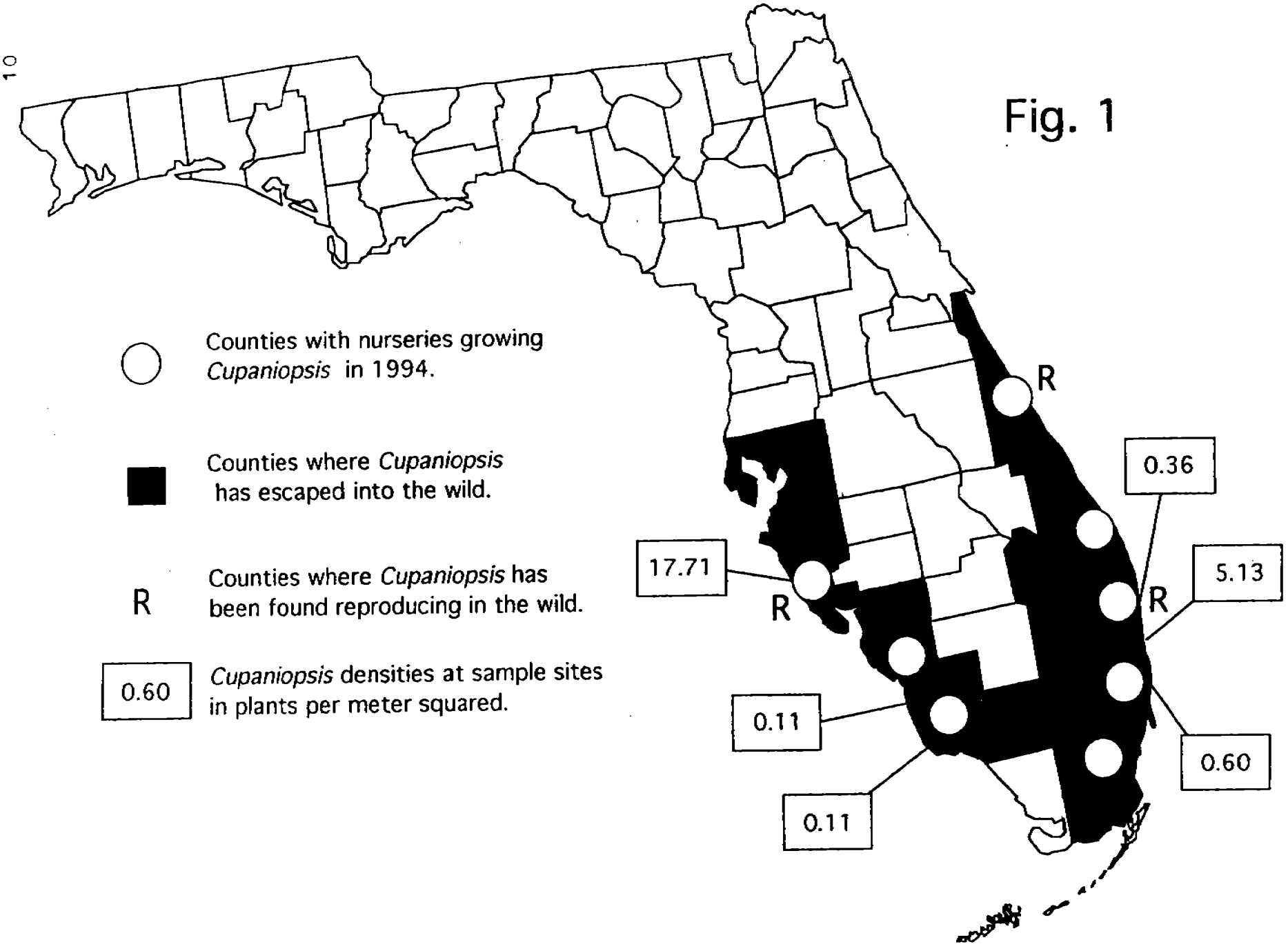

Counties with nurseries growing *Cupaniopsis* in 1994.
Counties where *Cupaniopsis* has escaped into the wild.
R
Counties where *Cupaniopsis* has been found reproducing in the wild.
0.60
Cupaniopsis densities at sample sites in plants per meter squared.
R
0.36
17.71
R
5.13
R
0.11
0.60
0.11

Fig. 1

TABLE 1. Habitat types invaded by *Cupaniopsis*, by county. These results are a compilation of 70 field reports. This may not reflect the total extent of invasion.

COUNTY	HABITAT TYPES*
1. Broward	3,4,7,10
2. Brevard	7,9
3. Charlotte	0,1
4. Collier	2,7,9,10
5. Dade	9,10
6. Hillsborough	2,9
7. Indian River	7,9,10
8. Lee	6,7,9
9. Manatee	1,2,7
10. Martin	0,6,7,8,9,10,
11. Palm Beach	1,2,4,7,9,10,
12. Pinellas	0,9,10
13. St. Lucie	0,7,9,10
14. Sarasota	0,1,2,4,5,7,9,10

*Most habitat descriptions are modified from Myers and Ewel (1990): 0 = Unknown; 1 = Pine Flatwoods / dry prairie; 2 = Sand pine scrub / high pine; 3 = temperate hardwood / inland hammock; 4 = Freshwater swamps; 5 = Freshwater marshes; 6 = Dunes / coastal strand; 7 = Mangroves; 8 = Rivers, springs; 9 = Disturbed / developed; 10 = Coastal hardwood hammock / tropical hammock

Table 2. *Cupaniopsis* density, by habitat, disturbance, and location. Locations: Sarasota Co.: John McDonald Island; Palm Beach Co. (South): Lake Wyman Park; Palm Beach Co. (North): MacArthur Beach State Park; Martin Co.: Blowing Rocks Preserve; Lee Co.: Carl Johnson Park; Collier Co.: Delnor Wiggins Pass Recreation Area. Not all categories are represented at all locations, as indicated by 'N". Data given for size classes are actual plant counts. NS indicates t-test results were not significantly different.

Mangrove

	Sarasota		Palm Bch S.		Palm Bch N.		Martin		Lee		Collier	
	[1]Dist.	[1]Und	[2]Dist.	[2]Und.	Dist.	Und.	Dist.	Und	Dist.	Und.	Dist	Und.
Density (#/m^2)	24.16	6.70	1.15	0	0.05	0.05	0.30	N	0	0.12	N	0
<0.5m	1033	337	68	0	1	1	8		0	7		0
0.5-2.0m	165	65	40	0	0	1	1		0	0		0
>2.0m	10	0	7	0	0	0	0		0	0		0
#plants/m^2 sampled	1208/ 50	402/ 60	115/ 100	0/ 40	1/ 20	2/ 40	9/ 30		0/ 10	7/ 60		0/ 30
t-test	[1]NS, p>0.1		[2]p<0.02		NS							

Hammock

	Sarasota		Palm Bch S.		Palm Bch N.		Martin		Lee		Collier	
	Dist.	Und	Dist.	Und	Dist.	Und.	Dist.	Und.	Dist	Und	Dist.	Und.
Density (#/m^2)	21.47	N	0.39	N	10.74	0.75	0.12	0.63	N	N	0.10	0.14
<0.5m	1722		46		735	15	3	70			0	7
0.5-2.0m	195		10		16	0	3	5			1	8
>2.0m	15		2		1	0	0	1			0	0
#plants/m^2 sampled	1932/ 90		58/ 150		752/ 70	15/ 20	6/ 50	76/ 120			1/ 10	15/ 110
t-test					NS		NS					

Coastal Strand

	Martin		Lee	
	Dist.	Und.	Dist.	Und.
Density (#/m^2)	0.21	0.05	0.16	0.03
<0.5m	14	0	8	1
0.5-2.0m	3	1	0	0
>2.0m	0	0	0	0
#plants/m^2 sampled	17/ 80	1/ 20	8/ 50	1/ 30
t-test	NS		NS	

Table 3. Diversity indices and *Cupaniopsis* densities, by habitat and location. Diversity indices (H') and density values are per habitat by location, combining disturbed and undisturbed data. Locations: Sarasota Co.: John McDonald Island; Palm Beach Co. (South): Lake Wyman Park; Palm Beach Co. (North): MacArthur Beach State Park; Martin Co.: Blowing Rocks Preserve; Lee Co.: Carl Johnson Park; Collier Co.: Delnor Wiggins Pass Recreation Area.

HABITAT	COUNTY	H'
Mangrove	Sarasota	0.654
	Lee	0.763
	Collier	0.236
	Martin	0.933
	Palm Beach N.	0.674
	Palm Beach S.	0.507
Hammock	Sarasota	0.108
	Collier	1.210
	Martin	0.581
	Palm Beach N.	0.665
	Palm Beach S.	0.446
Coastal Strand	Lee	0.733
	Martin	0.623

The diversity index for the hammock plots in Collier County (H'=1.21), which were mostly undisturbed with few exotics, is consistent with Molnar's values. By sharp contrast, the hammock plots in Sarasota County, which were nearly all disturbed with many exotics, had a diversity index of 0.11.

Mangroves have a reversed response to disturbance. The diversity index for undisturbed plots (no exotics) in Collier County (H'=0.236) is similar to the low diversity value for good quality mangroves. By contrast, the plots in Martin County, which were all disturbed and contained several exotics had a high index (H'=0.93).

Disturbance in coastal strand communities had a less dramatic effect, with only a slight elevation in diversity index. In addition to disturbance, other factors that can affect diversity indices are transitional areas and seasonally high numbers of seedlings of one species. The latter appears to be the case for Martin County undisturbed hammocks which would have a diversity index over 1 were it not for over 2400 black ironwood seedlings.

PLANT ASSOCIATIONS

Appendix 1 lists all the species found within all test plots by location. Habitat types where plants were found are also indicated.

DISCUSSION

This study confirms that carrotwood (*Cupaniopsis anacardioides*) is yet another exotic tree which has not only escaped into the wild, but is also invasive and becoming reproductive in Florida's natural areas. A summary of our findings are:

- Carrotwood has escaped cultivation in 14 southern and central Florida counties.
- Habitats already invaded are: mangrove swamps, cypress swamps, beach dunes, coastal strand, coastal hardwood hammocks, inland hammocks, pine flatwoods, sand pine scrub, and freshwater marshes.
- Woody habitats are more prone to invasion.
- Birds are a major dispersal agent.
- Wild trees are already reproductive in Brevard, Martin and Sarasota counties.
- Carrotwood densities are high in mangroves (to 24.16 plants per m^2) and in hammocks (to 21.47 plants per m^2).
- Carrotwood contributes to the alteration of species diversity, particularly in mangrove and hammock communities.

The current distribution of wild carrotwood (Figure 1) suggests that its range may be limited by cold tolerance. While there are reports of some cold damage, particularly to young trees (Jubinsky and Oliver 1991), its northern range in the wild may not truly

reflect its ability to expand northward, nor determine its potential to adapt to cooler climates. Trees planted in Tallahassee for experimental purposes, continue to persist after several days of sub-0°C. weather in 1989 and 1996 (Jubinsky and Oliver 1991, G. Jubinsky, personal communication, 1996). More study is needed to determine carrotwood's cold tolerance limits, and thus its potential northern range.

A major element in the expansion of carrotwood is its dispersal mechanism. Like *Schinus terebinthifolius*, the fruit of carrotwood is bright-colored and attractive to birds. With generalists such as mockingbirds and fish-eating crows fighting over and gorging themselves with carrotwood fruit (D. Austin, personal observation, 1990-1996; E. Freeman, A. Cox, personal communication, 1996), it should be no surprise that this tree has escaped to spoil islands, and can be found miles from the nearest tree. Bird dispersal also explains frequent observations and reports of carrotwood seedlings and saplings growing under trees (amidst bird droppings) and under telephone poles. Starlings (G. Phillips, pers. comm., 1996) and other bird species may be assisting in carrotwood expansion.

In California, carrotwood is not known to be invasive, perhaps due to a dryer climate. In Florida, carrotwood growth patterns appear to parallel those of Australia, based on the range of habitat types where it grows (Jessup 1985).

Of the habitat types where it has been found in Florida, carrotwood seems most prevalent in hammocks and mangroves (Table 3). It is not known if this is a product of habitat affinity, habitat susceptibility, or merely the popularity of perching and roosting areas for carrotwood-fed birds. All habitats appear to be at risk, however, and few habitats are not listed among those already invaded.

The effects of disturbance on carrotwood density were unexpected. Unlike most exotics which tend to favor disturbed sites, carrotwood is not selective. Densities were not significantly different between disturbed and undisturbed areas in all but one sample site. This tolerance suggests that intact habitats are at the same risk to carrotwood invasion as impacted habitats.

The broad variation in plant density appears to be a product of time and exposure. The tolerance of carrotwood to a broad range of soils, soil moisture, elevations, and salt, reduces the factors that could limit its growth or occurrence in different locations or habitats. The highest densities occur in Sarasota County, where it was first introduced. Sarasota County has had 10 to 15 more years of exposure than other parts of Florida. As in other counties, carrotwood has been available as a landscape tree in Palm Beach County since the early 1980's, and has been widely planted in the northern part of the county (S. Farnsworth, personal communication, 1996). The wide use there has allowed it to achieve the second highest density.

The effects of invasive species on native habitats are not immediately evident. Species diversity is compromised by disturbance, including the presence of naturalized,

non-native species. The normally high diversity in hammocks tends to be driven down by disturbance, including the presence of carrotwood (Table 3). The normally low diversity of the mangrove community, is artificially raised by disturbance. It is too early to say how the invasion of carrotwood affects the floristically simple, but highly productive mangroves. Many organisms rely on the unique mangrove community as part of their food chain, and many Florida industries depend on those organisms.

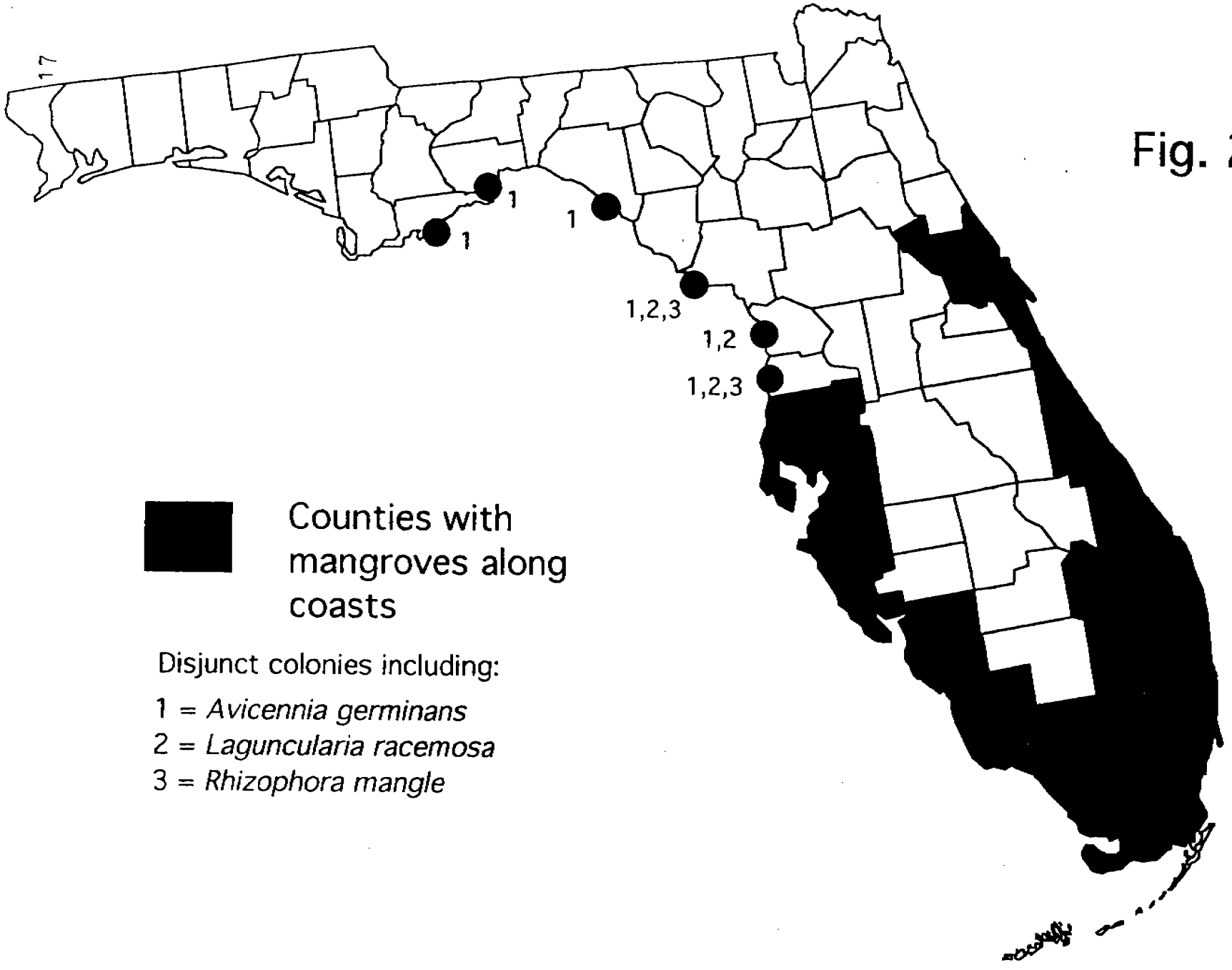
The distribution of carrotwood is nearly identical to that of all three mangrove tree species (Figure 2). Mangroves are highly adapted, not highly competitive. The effects of the replacement or reduction of mangrove leaf litter, on which early stages of the food chain feed, is unknown, but should be a great concern to all.

Based on observations in the field, carrotwood was more prevalent in wooded areas with breaks in the canopy. Mangrove areas damaged by improper 'trimming' as a result of the 1995 Mangrove Trimming Law, or where trimming has opened the canopy may also be at higher risk of carrotwood invasion. As urban sprawl continues and our native habitats diminish, all potentially negative impacts need to be examined and addressed.

Are there any observable trends? Carrotwood is a very popular ornamental tree which is being promoted similarly to the way *Schinus* was promoted in the 1960s and 1970s. Kowarik (1995) describes the average time elapsed between plant introduction and escape into the wild as being 147 years in Europe. *Schinus* was introduced in the late 1890's and appeared outside of cultivation by the 1960's (Alexander and Dickson 1970, Morton 1978). *Melaleuca* was introduced in 1906 and by the 1930s saplings were harvested from the wild for ornamental use (Meskimen 1962). Carrotwood was introduced in the 1960s, sold in most areas in the late 1970s or early 1980s and observed in spoil islands and natural areas by 1989 (M. Hurchalla 1990, Austin 1990, Burzycki 1990 and Jordan 1990, correspondence, E. Freeman, personal communication, 1996). The speed at which carrotwood has escaped in Florida makes it a good rival to its predecessors.

As carrotwood's invasive reputation has spread, various counties and municipalities have begun to develop ordinances of varying degrees of restriction. To date, the city of Naples, the town of Sanibel, and the following counties have ordinances: Dade, Palm Beach, Lee, Pinellas, Charlotte and Sarasota. Sarasota County has one of the strictest ordinances, allowing neither the propagation, sale, nor the transport of the tree within the county. Palm Beach County's ordinance is among the weakest, only requiring removal in new developments and preserve areas approved since 1989. It is unfortunate and short-sighted for counties with strong nursery interests and minimal to moderate carrotwood invasion to ignore the serious nature of this pest tree.

Field reports from Sarasota County differed from the usual " few scattered plants" in this or that habitat. Reports from two Sarasota County professionals were hauntingly similar - "throughout the county from spoil islands to cracks in the pavement to range lands", "any undisturbed mangrove fringe or island", "starts as understory, spread by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Counties with mangroves along coasts
Disjunct colonies including:
1 = Avicennia germinans
2 = Laguncularia racemosa
3 = Rhizophora mangle

Fig. 2

birds, then forms monoculture." "This tree must be banned now! Nurseries need to be educated."

What does the future hold? A development in northwestern Broward County may give us a clue. A cypress swamp remnant is part of the park and 'green space' for the upscale community. Several homes included carrotwood as part of their landscaping. The carrotwood density in this mostly undisturbed, but partly drained cypress swamp is about 12.68 plants per m^2(D. Scofield, unpublished data, 1996), or about half that of Sarasota County within less than 15 years.

Sarasota may be a model for other counties. At a later level of plant succession, their experiences look 10 to 15 years into the future. Gardening articles in an eastern Florida newspaper praise the qualities of carrotwood, and comment that mowing seedlings will keep them under control (Haehle 1996). Sarasota newspapers cite the ongoing problems of this tree, and describe budgetary plans by condominium associations to replace carrotwood within their complex (King 1995, Hanson 1996).

What can be done to avoid further impacts to natural resources, to dependent industries and their related costs?

- Stricter ordinances will reduce the availability of seed to birds who readily disperse it. Strong regulatory actions can minimize further expansion and moderate local populations.

- Heed the recommendations ("do not plant ") of the Florida Department of Agriculture, Division of Forestry (1993) which lists carrotwood as an invasive in their tree selection guide.

- Plant alternatives to carrotwood. Recommendations from the South Florida Water Management District and a Naples nurseryman include the following: paradise tree (*Simarouba glauca*), pigeon plum (*Coccoloba diversifolia*), inkwood (*Exothea paniculata*), gumbo limbo (*Bursera simarouba*), Jamaican dogwood (*Piscidia piscipula),* magnolias (*Magnolia virginiana* or *M. grandiflora*), loblolly bay (*Gordonia lasianthus*), mahogany (*Swietenia mahogani*), laurel cherry (*Prunus caroliniana*) and a relative of carrotwood which is native to the Florida Keys, *Cupania glabra* (A. Ferriter, W. Jones, personal communication, 1996).

- Education and active management of this exotic are the key to control:
  Educate college and university horticultural staff and county extension staff to be cognizant of the problems already being caused by invasive plants, including carrotwood, and to warn about the dangers of their use.
  Educate homeowners, developers, nurserymen and groundskeepers to help them to choose landscape plants more responsibly and better manage

existing trees, e.g., trim trees regularly each Spring before trees have mature fruit (and in preparation for hurricane season), OR replace the tree next Arbor Day.

Educate members of local, county and state governments to help them act more fiscally responsible to the taxpayers by taking early measures to control invasive exotics as they are identified.

- Control of carrotwood can be achieved in uplands by the use of a basal bark treatment with Garlon IV (E. Freeman, personal communication 1996). Information is not available for treatment in wetlands. Small trees can be girdled and sprayed with Roundup or Rodeo, but stump sprouts may need retreatment. Chemical treatment, however, should be used judiciously and as a last resort. Caution is indicated not only because of the sensitivity of mangroves to chemicals, but also because many such chemicals mimic hormones that disrupt fertility (Colburn, et al., 1996).

Much is still unknown about carrotwood - its germination rate, its elevation limits, its success rate in the wild, its effects and rate of impact and displacement in native habitats. While understanding the nature of the beast can help us to deal with it, it is important not to wait for these answers to act upon the problem. We have learned from previous invasive exotic plants that playing catch-up is a costly game. It is time to take off the blinders and be pro-active.

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REFERENCES CITED

Alexander, T.R., & J.D. Dickson, III. 1970. Vegetational changes in the National Key Deer Refuge. Quarterly Journal Florida Academy of Sciences 33(2):81-89.

Austin, D.F. and Coleman-Marois. 1977. Vegetation of Southeast Florida II. Boca Raton hammock site. Florida Scientist 40:331-338.

Borschat, T. K. & A. W. Meerow. 1996. Betrock's Reference Guide to Florida Landscape Plants. Betrock Information Systems, Inc.: 94.

Brock, J. 1988. Top End Native Plants: A comprehensive guide to the trees and shrubs of the Top End of the Northern Territory. Northern Territory, Australia.

Center T. 1993. Invasive plants in conservation areas and possible solutions with biological controls. Paper presented at the 34th Annual Meeting of the Society for Economic Botany; 23-26 June 1993; Miami, Florida.

Colborn, Theo, John P. Myers and Dianne Dumanoski. 1996. Hormonal Sabotage. Natural History 105 (3):42:49. [extracted from the book by Colborn, T., D. Dumanoski, and J. P. Myers. 1996. Our Stolen Future: How We Are Threatening Our Fertility, Intelligence, and Survival - A Scientific Detective Story. Dutton Signet, a division of Penguin Books USA, Inc.]

Corlett, R. T. 1986. The mangrove understory: some additional observations. Journal of Tropical Ecology 2: 93-94.

Exotic Pest Plant Council Committee on Invasive Species. 1995. Exotic Pest Plant Council's 1995 List of Florida's Most Invasive Species.

Florida Department of Agriculture, Division of Forestry. 1993. Replanting the urban forest after Hurricane Andrew: A South Florida tree planting and selection guide.

Haehle, R. October 11, 1996. "Growing Concerns: Think before you dig when adding exotic pest plant". Sun Sentinel. Fort Lauderdale.

Hamner, J. October 28, 1992. "Carrotwood: The New Punk in Town - A Threat to Native Vegetation." Sarasota Herald Tribune. Sarasota.

Hanson, J. March 28, 1996. "No place to hide for these banished trees". Pelican Press. Sarasota.

Hawkeswood, T. J. 1983. Pollination and fruit production of Cupaniopsis anacardioides (A. Rich.) Radlkf. (Sapindaceae) at Townsville, North Queensland. 1. Pollination and floral biology. Victorian Naturalist. 100:12-20.

Jessup, L.W. 1985. Anacardiaceae, *Flora of Australia* 25: 170-187

Jubinsky, G. And J. D. Oliver. In house report. Suppression and survival of carrotwood (*Cupaniopsis anacardioides*) and Chinese tallow (*Sapium sebiferum*) in varying salinity, temperature, light and inundation conditions.

King, R. October 16, 1995. "Import threatens to take over Florida" Sarasota Herald Tribune. Sarasota.

Kowarik, I. 1995. Time lags in biological invasions with regard to the success and failure of alien species, Pages 15-38 in Pysek, P., K. Prach, M. Rejmanek and M. Wade. Plant Invasions. General Aspects and Special Problems. SEB Academic Publishing, Amsterdam.

Kuenzler, E. J. 1974. Mangrove swamp systems. In "Coastal Ecological Systems" (H.T. Odum, B. J. Copeland, and E. A. McMahon, eds.), Vol. 1, pp 346-371.

Little, E. L. Jr. 1978. Atlas of the United States Trees. Vol. 5. Florida. Washington, D.C., USDA Miscellaneous Publication No. 1361.

Lockhart, C. S. 1996. "Pest Plants: Carrotwood Lookout." The Palmetto, Florida Native Plant Society 16(1): 8.

McKnight BN, ed. 1993. Biological Pollution: The Control and Impact of Invasive Exotic Species. Indianapolis: Indiana Academy of Science.

Meskimen, G. F. 1962. A silvical study of the Melaleuca tree in south Florida. Master's thesis, University of Florida, Gainesville.

Molnar, G. 1990. Succissional Dynamics of a Tropical Hardwood Hammock on the Miami Rockridge. Master's thesis, Florida International University, Miami.

Morton, J. 1978. Brazilian Pepper - It's impact on people, animals and the environment. Economic Botany 32(4): 353-359.

Myers, R. L., & J. J. Ewel. 1990 Ecosystems of Florida. Univeristy of Central Florida Press, Orlando.

Oakman, H. 1964. *Cupaniopsis anacardioides*. Australian Plants 2: 183-184.

Oliver, J.D. 1992. Carrotwood: A Review of the Literature. Florida Department of Environmental Protection, Bureau of Aquatic Plant Management;

Schmitz DC, Brown TC, ed. 1994. An Assessment of Invasive Non-Indigenous Species in Florida's Public Lands. Department of Environmental Protection, Bureau of Aquatic Plant Management, Technical Report No. TSS-94-100, Tallahassee, FL.

Simberloff D. 1994. Why is Florida being invaded? Pages 7-9 in Schmitz DC, Brown TC, q.v.

South Florida Water Management District. 199?. Xeriscape Guide II, Home Owners edition. West Palm Beach

Stresau, F.B. 1986. Florida, My Eden. Florida Classics Library. Port Salerno, FL.

U.S. Congress. 1993. Harmful Non-Indigenous Species In the United States. Office of Technology Assessment, Government Printing Office, OTA-F-565, Washington, DC.

Zar, J. H. 1984. Biostatistical Analysis, 2nd edition. Prentice Hall, Englewood Cliffs, N.J.

Appendix 1. Plant associations within plots of study sites.

An 'x' indicates presence. Locations: Sar = Sarasota Co.: John McDonald Island; Lee Co.: Carl Johnson Park; Collier Co.: Delnor Wiggins Pass Recreation Area. Mar = Martin Co.: Blowing Rocks Preserve; PB-N = Palm Beach Co. (North); MacArthur Beach State Park;PB-S = Palm Beach Co. (South): Lake Wyman Park. Habitat types: H = Hammock; M = Mangrove; S = Coastal Strand. Some sites were ecotonal.

	Counties						
Species	**Sar**	**Lee**	**Col**	**Mar**	**PB-N**	**PB-S**	**Habitat**
Abrus precatorius						x	H
Acacia auriculiformis						x	H
Agave decipiens				x			H
Agave americana			x				H
Alternanthera philoxeroides			x				H
Ambrosia artemisiifolia					x	x	H
Andropogon glomeratus					x		H
Annona glabra						x	H
Ardisia escallonioides				x	x		H
Arecastrum romanzoffianum	x						M
Argusia gnaphalodes		x					S
Asparagus densiflorus				x	x		H,S
Avicennia germinans	x	x			x	x	M
Baccharis sp.				x	x		H,S
Bacopa monieri	x						H
Bidens alba			x	x	x	x	H,M
Bischofia javanica					x		H
Borrichia floridana			x				M
Bumelia sp.		x					S
Bursera simarouba			x		x	x	H
Caesalpinia bonduc				x		x	H,M
Canavalia rosea	x		x	x			H
Capparis cynophallophora				x			H
Capparis flexuosa				x			H
Carica papaya				x			H
Casuarina equisetifolia	x	x		x		x	H,M,S
Catharanthus roseus					x	x	H
Chamaesyce sp.						x	H
Chiococca alba			x	x	x		H
Cissus sicyoides			x				H
Coccoloba diversifolia				x	x		H
Coccoloba uvifera		x	x	x	x	x	H,M,S
Colubrina asiatica				x			H
Commelina sp.	x				x		H,M
Conocarpus erecta	x	x					H,M
Crinum americanum			x				H
Cupaniopsis anacardioides	x	x	x	x	x	x	H,M,S
Cyperus ligularis				x			S
Cyperus sp.						x	M

Species	Sar	Lee	Col	Mar	PB-N	PB-S	Habitat
Dalbergia ecastophyllum			x	x		x	H,M,S
Dodonaea viscosa				x			M
Drypetes lateriflora				x			H
Emilia fosbergia					x	x	M
Eugenia axillaris			x	x			H,M
Eugenia foetida				x	x		H
Eugenia uniflora				x		x	H
Eupatorium serotinum				x			S
Ficus aurea			x	x	x	x	H,M
Ficus microcarpa	x						M
Forestiera segregata	x		x		x	x	H,M
Grass #1						x	M
Guapira discolor				x	x	x	H
Heliotropium angiospermum						x	H
Hydrocotyle spp.	x						H,M
Ipomoea alba				x	x	x	H,M
Ipomoea indica				x		x	H,S,M
Krugeriodendron ferreum				x		x	H
Laguncularia racemosa	x	x		x	x	x	M
Lantana involucrata			x				H
Mastichodendron foetidissimum				x			H
Melothria pendula	x			x			S,H
Mentzelia floridana				x			S
Mikania scandens				x			H,S
Momordica charantia			x			x	H
Morinda royoc				x			H
Myrsine guianensis			x				H
Nectandra coriacea				x			H
Ochrosia elliptica						x	H
Opuntia compressa			x				H
Opuntia spp.	x						H
Opuntia stricta		x					S
Oxalis sp.						x	H
Parthenocissus quinquefolia		x	x	x	x	x	M,H
Passiflora suberosa		x		x	x		H,S
Phlebodium aureum			x		x		S
Pilea microphylla				x	x		H,S
Plumbago scandens				x			H
Podocarpus sp.							H
Psychotria nervosa				x	x	x	H
Quercus myrtifolia					x		H
Randia aculeata			x		x		H
Rhizophora mangle	x	x	x		x	x	M
Rhoeo spathacea				x		x	H
Rivina humilis	x			x	x	x	H,M,S
Sabal palmetto	x		x	x	x	x	H.S
Sansiveria hyacinthoides				x			H
Schefflera umbellata						x	H
Schinus terebinthifolius			x	x	x	x	H,M
Senna pendula				x			H,S

Species	Sar	Lee	Col	Mar	PB-N	PB-S	Habitat
Serenoa repens				x			S
Sesuvium portulacastrum	x			x		x	H,M
Setaria ? geniculata			x				H
Severina monophylla				x	x		H
Sida acuta						x	M
Simarouba glauca				x			H
Smilax auriculata				x			H
Sonchus sp.				x			S
Spartina repens				x			M
Stenotaphrum secundatum				x	x		M,H
Suriana maritima		x					S
Syzygium cumini					x		H
Thespesia populnea		x				x	H,S
Tillandsia usneoides	x						H
Toxicodendron radicans			x		x		H
unknown #1	x						H,M
unknown #2	x						H,M
unknown #3	x						H,M
unknown #4	x						H,M
unknown #5				x			S
unknown #7	x						M
unknown vine #1	x						M
unknown vine #2	x						M
Verbesina virginica			x				H
Vitis rotundifolia					x		H,M
Vitis shuttleworthii					x		H
Wedelia trilobata			x				H
Xanthoxylum fagara				x		x	H
Yucca aloifolia			x				H