

# Air Potato Management Plan



Recommendations from the  
Air Potato Task Force  
Florida Exotic Pest Plant Council

# **Air Potato (*Dioscorea bulbifera*)**

## **Management Plan**

### **Recommendations for the**

### **Air Potato Task Force**

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## Preface

The Air Potato Management Plan was developed to provide a synthesis of the information available on *Dioscorea bulbifera* and its management in Florida. Information is also included on related species occurring in Florida, including winged yam, *D. alata*, which is also considered to be invasive. The pertinent literature from both the native and exotic ranges is reviewed and organized in sections on taxonomy, distribution, ecology, economic uses, management and legislation. Additionally, case studies on air potato management from Palm Beach Co. and the Everglades National Park are included. A major milestone in air potato management was reached in late 2011 when the USDA/ARS Invasive Plant Research Laboratory began releasing the beetle, *Lilioceris cheni*, for biological control. This management plan was updated in February 2014 to provide information on the biological control program.

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## **I. Introduction**

The estimated annual cost of invasive organisms in the United States is 138 billion, with invasive plants accounting for approximately \$34 billion (Pimentel et al., 2000). Florida is unique among the continental states because of its tropical/sub-tropical environment which predisposes the state to invasion by organisms from other tropical areas of the world. Moreover, much of Florida's environment is highly disturbed, which allows invasive species to gain a foot-hold (Simberloff 1997). Nearly one-third of the plants found growing in natural areas in Florida are exotic, and about 11% of those are considered to be invasive. In FY 2003-2004, the state of Florida spent an estimated \$103 million to manage invasive plant and animal species (ISWG, 2006).

One of Florida's most troublesome invaders is air potato (*Dioscorea bulbifera*), a member of the family of true yams. Air potato, like most other yams, is a vine which cannot support its own weight. In order to capture sunlight, air potato climbs by twining on other plants. Air potato is a dioecious plant, with male and female flowers occurring on separate plants. In its native range, air potato reproduces sexually by seed, and clonally through the production of aerial tubers (bulbils). In Florida, sexual reproduction appears to be absent or extremely rare. Although plants occasionally flower in Florida, only female plants have been confirmed, and thus all, or nearly all, reproduction is through bulbils.

The native range of air potato is vast, and includes much of Asia, tropical Africa and northern Australia (Coursey, 1967). It was first observed in the United States in 1777 in Mobile, Alabama (Bartram, 1998), and was later introduced into Florida in 1905 (Morton, 1976). The pathway of introduction into the United States is unknown, although Coursey (1967) speculated that it may have been introduced by slave ships arriving from West Africa. However, recent molecular evidence strongly suggests that Florida air potato originated from Asia (Croxtton et al. 2011)

The life cycle of air potato in Florida begins in the late spring (April/May) when bulbils and subterranean tubers from the previous year begin to sprout. Growth of vines is rapid through the summer with bulbils appearing in mid-summer and increasing in size and numbers until late fall/early winter when the vines die back and the bulbils fall to the ground. The bulbils lie dormant until the following spring or early summer.

Air potato causes ecological damage by climbing other vegetation and forming dense canopies that shade out, and may cause the collapse, of native plants (Gordon et al., 1999; Schmitz et al., 1997; Schultz, 1993). Air potato is listed by the Florida Exotic Pest Plant Council as a Category I invasive plant – species which are altering native plant communities by displacing native species, changing community structures or ecological functions, or hybridizing with natives.

## **II. Goal Statement**

The goal of the Air Potato task force is to develop a state-wide plan to protect and preserve the native biodiversity of Florida from deterioration by air potato.

### III. Objectives

1. To provide a central source of information about the taxonomy, ecology, and distribution of air potato for use in the development of methods to reduce its presence in Florida's natural areas.
2. To provide land managers with the most recent information on control methods for air potato in Florida, including the release of *Lilioceris cheni* for biological control.
3. To serve as a resource for raising public awareness about the dangers of exotic plants, and air potato in particular.

### IV. Recommendations

1. Encourage and support air potato management efforts on Florida's public and private lands
2. Improve control efforts by seeking out and encouraging cooperative partnerships, including the provision of assistance to community-based 'air potato roundups'.
3. Support the on-going effort on biological control of air potato using the leaf feeding beetle, *Lilioceris cheni*.
4. Support research efforts to develop improved management alternatives, including chemical, mechanical and biological.
5. Encourage efforts to better quantify the ecological impacts of air potato to Florida's environment.
6. Support the production of training materials to increase awareness of the negative impact of air potato to Florida natural areas.

### V. Biology of *Dioscorea bulbifera*

#### Vernacular names

Air potato, air yam, potato yam, bitter yam, aerial yam, cheeky yam, bulbil-bearing yam

#### Synonyms

*D. sativa* Thumb., *D. latifolia* Benth., *D. anthropophagorum* A. Chev., *Helmia bulbifera* (L.) Kunth. (Wilkin, 2001), *D. crispata* Roxb., *D. dicranandra* Donn. Sm., *D. heterophylla* Roxb., *D. hoffa* Cordem., *D. pulchella* Roxb., *D. tamnifolia* Salisb., *D. tenuiflora* Salisb., *Smilax decipens* Spreng. (Wunderlin and Hansen, 2003), *D. oppositifolia* Campbell, *D. papilaris* Blanco, *D. tunga* Hamilton (Coursey, 1967).

## Taxonomy and morphology

The genus *Dioscorea*, published in 1753 by Linnaeus (*Genera Plantarum*), was named after the Greek physician Pedinius Dioscorides, who was a medical officer in the Roman army at the time of Nero and authored the most comprehensive tome on herbal medicine of the time, *De Materia Medica Libri quinque* (Coursey, 1967). Several species of this genus serve as staple crops in many parts of the world (Mabberley, 1997; Martin, 1974). Major yam producing areas include West Africa, where nearly two thirds of the world supply originates, most of which is *D. cayenensis* subsp. *rotundata*, and Southeast Asia, the Pacific Islands, and the Caribbean, where the staple yam crop is *D. alata* (Al-Shehbaz and Schubert, 1989; Purseglove, 1972).

*Dioscorea* is in the family Dioscoreaceae, which is assigned to the order Dioscoreales. Recent molecular evidence suggests that two other families should be included in the order; the Burmanniaceae and the Nartheciaceae (Caddick et al. 2002), both of which are represented in North America. The Burmanniaceae genera found in North America are: *Apertia*, *Burmannia* and *Thismia*. *Apertia* is represented by one species, *A. aphylla*, *Burmannia* by three; *B. biflora*, *B. capiata* and *B. flava*, and *Thismia* by one, *T. Americana* (Lewis, 2003). *Apertia aphylla* and the three *Burmannia* spp. occur in Florida (Wunderlin and Hansen, 2003). The Nartheciaceae is represented by three genera in North America (*Nathecium*, *Aletris* and *Lophiola*) (Utech, 2003), the later two of which occur in Florida. There are five *Aletris* species in the state (*A. aurea*, *A. bracteata*, *A. obovata*, *A. lutea* and *A. farinosa* and one *Lophiola* (*L. aurea*) (Wunderlin and Hansen, 2003).

Following the circumscription of Caddick et al. (2002), the family Dioscoreaceae includes 4 genera; *Dioscorea*, *Trichopus*, *Tacca* and *Stenomeris*, although molecular phylogenetic studies by Merckx et al. (2006) place *Tacca* as a sister to the tribe Thismieae of the Burmanniaceae. In the New World, only *Dioscorea* and *Tacca* are found. *Tacca* is represented by one South American species, *T. parkeri*. *Dioscorea* is by far the largest genus in the family, with the number of species estimated to be from 350-400 (Caddick et al. 2002) to 850 (Al-Shehbaz and Schubert 1989). *Dioscorea* has a pan-tropical distribution, with native species found in Asia, the Americas, Australia and Africa. A few are found in temperate areas of the world (Ayensu and Coursey, 1972).

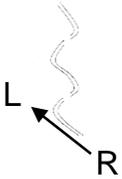
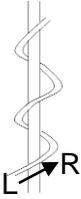
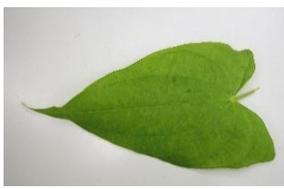
An early treatment of *Dioscorea* divided the genus into 4 sub-genera, which were further divided into 60 sections (Knuth, 1924). Using this classification, *D. bulbifera* was placed in the sub-genus *Helmia*, in section *Opsophyton* subsection *Euopsophyton*. Burkhill (1960) introduced an alternate classification of the Old World yams, but he did not use sub-genera. He recognized 23 sections of *Dioscorea*, including a redefined *Opsophyton* in which he placed *D. bulbifera*. The other invasive yam in Florida, *D. alata* (winged yam), was placed in the section *Enantiophyllum* (Knuth, 1924; Burkhill, 1960).

Based on anatomical characters, Ayensu (1972) recognized 30 sections of *Dioscorea*, including section *Opsophyton* in which *D. bulbifera* was placed (under sub-section *Euopsophyton*). Wilkin et al. (2005) indicated that the genus required a complete taxonomic revision, which should be based on DNA. He tentatively separated species into 8 clades based on sequences of two plastid genes. *Dioscorea bulbifera* was placed in the 'compound leaf' clade (even though air potato does not have compound leaves), which also included three species from Thailand, two from

Madagascar and one from Malawi. Wilkin et al. (2005) placed *D. alata* in the *Enantiophyllum*, as had previous classifications.

Within the continental United States, two native *Dioscorea* are found; *D. floridana* and *D. villosa*, along with four exotic species; *D. alata*, *D. bulbifera*, *D. polystachya* (formerly *D. oppositifolia*) and *D. sansibarensis*. The latter species, which was only known from Miami-Dade Co. and one location in Collier Co., may now have been eradicated (Pemberton, pers. comm.). A seventh species, *D. quaternata*, was reported in the past (Al-Shehbaz and Schubert 1989; USDA, NRCS 2002; Wunderlin and Hansen, 2003) but has recently been synonymized with *D. villosa* (Raz, 2002). Raz (2002) states that *D. floridana* 'is undoubtedly a close relative of *D. villosa*, but because it is identifiable using characters that vary discretely, with states not manifest in plants occupying similar habitats outside of its range, I have chosen to retain it at the rank of species'. All six *Dioscorea* species found in North America can be found growing in Florida. Raz (2002) provides a useful key to the species of *Dioscorea* (native and exotic) which occur in North America. Table 1 indicates some of the characters that can be used to separate the species.

Table 1. Selected characteristics of *Dioscorea* found in North America.

Species	Bulbils present	Distinguishing characters	Leaf image
<i>D. bulbifera</i>	Yes, roundish	Roundish stem, twines to the left 	
<i>D. alata</i>	Yes, somewhat pear-shaped	Square stem, twines to the right 	
<i>D. sansibarensis</i>	Yes	Leaf margins 3-5 lobed, leaf apex caudate (extending in a slender tail-like appendage)	
<i>D. polystachya</i>	Yes	Leaf margins 3 lobed, apex acute or with a short projection at tip	
<i>D. villosa</i>	No	Rhizomes brownish, nodes not articulate	

<i>D. floridana</i>	No	Rhizomes yellowish, nodes articulate  Low climbing, small plant	
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Photo credits: *D. polystachya* leaf, Mr. Rob Broekhuis. *D. sansibarensis* leaf, Kwan Han at www.NatureLoveYou.sg. All others, W. A. Overholt.

## Habit

Air potato is a glabrous, twining, vine with alternate heart-shaped leaves (Figure 1). The vines may reach 20 m in length during a growing season, which in Florida begins with the increase in



precipitation in late spring/early summer. Vines continue to grow through the summer and into fall/early winter when they senesce. Air potato is dioecious, although only female plants have been observed in North America (Raz 2002). Reproduction in the native range is achieved sexually and vegetatively through the production of bulbils - bulblike growths produced in the leaf axils (Figure 2). Although



Figure 3. Flowering *D. bulbifera*.

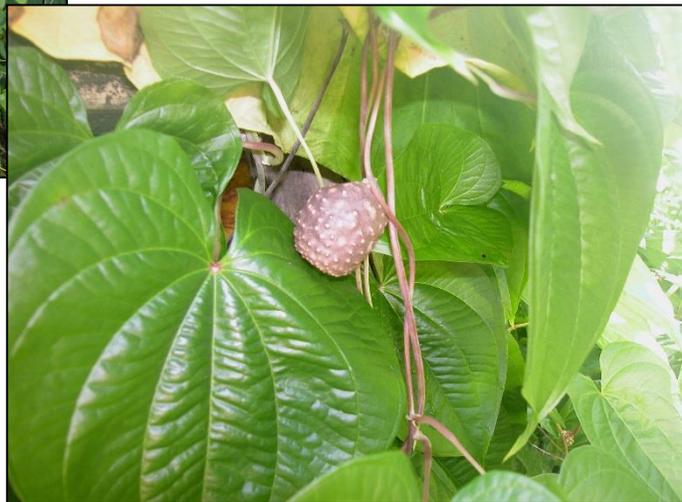


Figure 2. *Dioscorea bulbifera* with bulbil.

flowering in Florida is uncommon (Figure 3), *D. bulbifera* reproduces quickly and prolifically by bulbil propagation. As an aggressive high-climbing vine, air potato grows into and often over the tops of low-lying vegetation and into tree canopies.

## Vegetative morphology

Leaves are cordate-shaped with elongated tips, thin and glabrous, and range from 10-20 cm in length and 5-15 cm in width. Leaves are long-petioled, often  $\geq 8$  cm on mature leaves and between 2-3 cm on newer leaves nearest the terminal bud, and occur in an alternate arrangement along a branching, hairless, stem. Leaves are generally a vibrant green on the upper surface and a lighter green on the lower surface depending upon conditions. Basal lobes of leaves are broadly rounded. Leaf margin is entire. Leaf venation is parallel and converges at the leaf base. Leaves of *D. bulbifera* and other *Dioscorea* species have three arcuate primary nerves which radiate from the central base of a given leaf to converge at the leaf tip. The remaining primary nerves, while converging at the base, do not reach the leaf tip (Coursey, 1967). Petioles are distinctly flattened along the upper surface and, at the point of attachment to individual leaves, flare out to create small wing-like structures which are ruffled in appearance (Miller, 2003). Coursey (1967) notes that individual leaf tips develop prior to the development of the rest of the lamina and are termed forerunner tips. Each forerunner tip contains a pore that serves to exude water, a necessary requirement of this and other rapidly growing *Dioscorea* species which allows for a properly maintained hydrostatic balance.

Stems are not winged but often have a noticeable ridge along the margin. Internode cross sections are round. Both the petioles and the stems often have a reddish-purple color (Miller, 2003). With the exception of a few of the dwarf species, the stems of the *Dioscorea* cannot support



Figure 4. Left twining habit of *D. bulbifera*.

their own weight to any great height. As such, the plants of this genus have evolved to climb by twining (Coursey, 1967). Vine twining is an important identifying characteristic of species of *Dioscorea*.

The characteristic is categorized at the section level. Vines of *D. bulbifera* climb in a counterclockwise (sinistrorse) pattern to the left (Figure 4). Coursey (1967) states that sinistrorse twining is a trait typical of yams species that belong to the section Opsophyton (e.g., *D. bulbifera*, *D. sansibarensis*) as well as sections

*Lasiophyton*, *Combilium* and *Macrogynodium*. In contrast, dextrorse twining (clockwise twining to the right) is a growth trait definitive of yam species of the section *Enantiophyllum*, which is comprised, in part, of several species that are of major importance as food plants (e.g., *D. alata*, *D. cayenensis* subsp. *rotundata*) (Coursey, 1967).

Root structure and development of *D. bulbifera* and, in general, most *Dioscorea* species involves a simple and comparatively weak rooting system (Figure 5) (Coursey, 1967). At the

beginning of the growing season, which in south Florida may be as early as mid-April, the previous year's tubers and new bulbils produce thick spaghetti-like roots from the rhizomatous (or head) end of a given tuber or bulbil. This region of a tuber or bulbil also gives rise to the stem of the plant (Coursey, 1967). The roots grow quickly and development begins shortly before and during stem development and growth. One of the primary functions of the thick, primarily unbranched, roots is that of providing a firm hold in the ground for the rapidly developing stem. Further along in the plant's annual growth cycle, a thinner, branching, fibrous root mass is produced (Coursey, 1967).



**Figure 5. Roots of underground tuber of *D. bulbifera*.**

those which have aerial and underground parts visible all year round; and 3) species which have aerial parts which are annual or biannual and underground parts which are perennial. They categorized *D. bulbifera* as belonging to the first group, with both aerial and subterranean parts renewed each year. In contrast, Okagami (1986) stated that all *Dioscorea* spp. produce perennial subterranean tubers. Species that constitute the food yams (primarily species of the section *Enantiophyllum*) typically form only one tuber which can grow to be quite large - normal production of *D. alata* and *D. cayenensis* subsp. *rotundata* can yield tubers that weigh between 10-15 kg. Underground tubers of *D. bulbifera*

Tubers of all *Dioscorea* species consist of starch-bearing tissue which is covered by a suberin layer which ultimately forms skin or bark (Coursey, 1967). Subterranean tubers (Figure 6) of the *Dioscorea* belong to one of two main types: perennial tubers, which survive for the lifetime of the plant, and annual tubers, which are renewed yearly (Coursey, 1967). Hamon et al. (1995) suggests that yams can be divided into three categories based on seasonal life cycles; 1) species which renew aerial and subterranean parts every year; 2)



**Figure 6. Subterranean tuber of *D. bulbifera*.**



staminate flower is white and becomes purple over time. The fertile stamens are in two equal whorls of three. The anther of an individual stamen is as long as, or longer than, the supporting filament (Raz, 2002).

The fruit-type produced by female plants in the native range of *D. bulbifera* is a dry, dehiscent, trilobular capsule which is a pale brown at maturity (Figure 7) (Coursey, 1967; Hamon et al., 1995; Raz, 2002). Capsules range from 1.8-2.8 cm in length and from 1-1.5 cm in width (Hamon et al., 1995; Raz, 2002). Seeds are unilaterally winged, elongated and are slightly curved at the point of attachment (Hamon et al., 1995; Raz, 2002). Seeds range in length from 12-22 mm (Raz, 2002).

Aerial tubers (bulbils) may be produced throughout the active growing cycle of the plant but tend to be more prevalent later in the annual growth cycle when stem and leaf development is complete (Coursey, 1967; Miller, 2003). Bulbils are vegetative organs that have a morphology that may be likened to that of a condensed stem (Coursey, 1967).

Bulbils are axillary, with one to four produced per leaf axis. Bulbils can reach 12 cm in length and are roughly spherical in shape, having a potato appearance. Bulbils produced by *D. bulbifera* in Florida are of two types (Figure 8). The majority of bulbils have a dark coffee-colored hue with a warty texture. Some plants, however, have been found to produce



Figure 8. Types of *D. bulbifera* bulbils in Florida.

light tan or grey bulbils with smoother skin (Hammer, 1998; Overholt et al., 2003). According to Coursey (1967) and Miller (2003), mature bulbils float, a trait that may aid in dispersal of the plant in moving bodies of water. However, recent evidence suggests that most bulbils sink in water (Overholt, unpubl., Pemberton unpub).

## Reproductive biology, phenology and growth

Fruit production by air potato in Florida has only been reported by Hammer (1998), and therefore must be very rare. No seed production has been documented. In the plant's native range, flowers of all *Dioscorea* species are pollinated by night-flying insects (Coursey, 1967). The small size and inconspicuous nature of the flowers of *Dioscorea* species suggested to early researchers that fertilization was achieved by wind-pollination rather than entomophily. Pollen produced by staminate flowers is glutinous and cannot be transferred to pistillate flowers by the wind. Staminate flowers have evolved in such a way as to force any insect entering them to contact the anthers (Coursey, 1967). Coursey (1967) states that the aromatic smells produced by many of the *Dioscorea* species serve as attractants for nocturnal insect species which do not require visual attractants. In general, very little has been documented about insect pollination of *Dioscorea* spp.,

and nothing is known about pollinators of *D. bulbifera*. Observations by Sadik and Okereke (1975) lead to the identification of a thrips (*Larothrips* sp.) that was found to be moving pollen from the staminate flowers to the pistillate flowers of *D. cayenensis subsp. rotundata*.

Documentation of the peak flowering months of the species in its native ranges of Africa and Asia is sparse. *D. bulbifera* has been noted to flower from February through March in regions of South-Central Africa, with fruit production beginning in March (Wilkin, 2001). In Florida, the few flowering specimens on record, all of which are pistillate, indicate the flowering period of *D. bulbifera* may extend into the latter months of fall (i.e., October through November). The unilaterally winged seed typical of *D. bulbifera* found growing in less densely vegetated areas of the plant's native range has evolved into its present shape to allow for whirling flight in windy conditions (Coursey, 1967). Such a design serves to aid in seed dispersal.

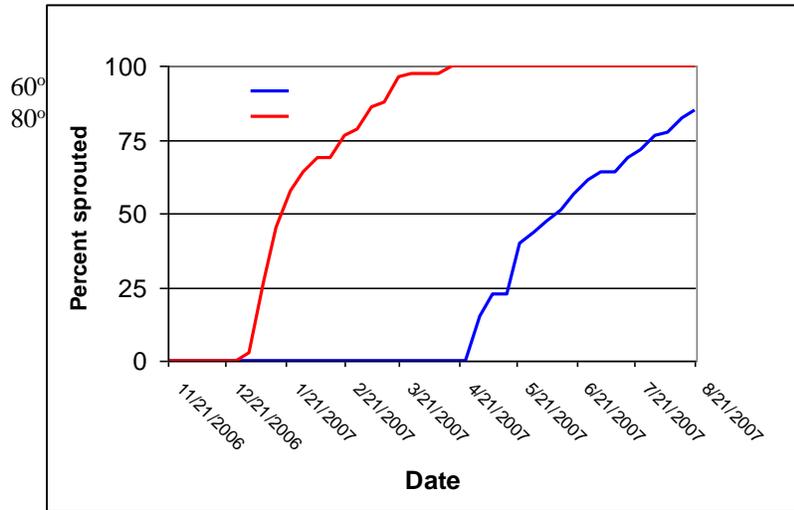
In its native range, *D. bulbifera* grows in loamy soils and soils of loose clay that have good drainage (Martin, 1974; Wilkin, 2001). In Florida, *D. bulbifera* is found from the northern most counties to the Keys. The primary soil orders found supporting growth of the plant, from the most frequent to least frequent are: Spodosols, Entisols, Histosols, Entisols underlain by limestone, and an Alfisol/Utisol mix.

In its native range, seeds and bulbils of *D. bulbifera* grow in partially to fully shaded areas that contain a substrate composed of high levels of organic material (Martin, 1974). In Florida, *D. bulbifera* is most often found invading ecotones that provide similar such conditions. Such a growing environment is essential for maintaining the appropriate soil moisture and providing protection from dry conditions that can inhibit tuber and bulbil germination (Martin, 1974). Tubers of *D. bulbifera* may exhibit signs of new growth as early as mid-April in South Florida, however, in general, tubers and bulbils throughout the state begin to exhibit shoot sprouting at the start of the rainy season in late May or early June. The start of the rainy season in Florida is characterized by high daytime temperatures, high humidity, and increased precipitation.

There is some debate regarding tuber dormancy (i.e., established subterranean tubers and bulbils from the previous growing season) and the mechanisms involved in the initiation of shoot sprouting. Studies have been conducted to test the influence of sprouting inhibitors, temperature, length of photoperiod, available soil moisture, and relative humidity on bulbil sprouting, however, to date, the control of dormancy is still not well understood (Ile et al., 2005; Okagami and Tanno, 1991; Passam, 1982; Suttle, 1996). Coursey (1967) suggests that yams follow a repeated annual cycle of growth and dormancy that corresponds to the wet and dry seasons of the climatic cycle. Coursey (1967) states that sprouting is also controlled by an endogenous mechanism that defines the length of dormancy, which explains the documented phenomenon of shoot sprouting and growth at the start of the plant's annual growth cycle in the absence of light, soil, or water. Okagami and Tanno (1991) reported that bulbils of *D. bulbifera* contained a sprouting inhibitor which accumulated during the growing season, and then gradually decreased after bulbils reached maturity. The same authors also indicated that bulbils required a chilling period before they would sprout. Martin (1974) states that sprouting of bulbils in the plant's native range is variety-specific. Certain varieties of *D. bulbifera* produce bulbils throughout the growing season that, upon dropping, may germinate within a few weeks. Other varieties produce bulbils that remain dormant until the following growing season, dependent upon photoperiodism rather than seasonal precipitation. Martin (1974) further suggests that bulbils produced by all varieties of *D. bulbifera* go through a dormant stage that is specific to the variety. Such periods may be shortened, to a limited extent, by stimulating sprouting through maintaining a moist substrate, however, for the most part, bulbils will not germinate until they are ready (Martin, 1974). In Florida, bulbils

produced by *D. bulbifera* tend to exhibit shoot meristem sprouting contingent upon available precipitation and mean temperature. Consistent with finding of Coursey (1967), bulbils in Florida have been observed to sprout in the absence of light, soil, or water.

A recent study demonstrated that temperature, and to a lesser extent bulbil weight, were the only factors which influenced sprouting of bulbils collected from two locations in Florida (Overholt et al. 2007). Humidity, day length, and origin of bulbils (Gainesville vs. Fort Pierce) played no role. At 60°F, bulbils began sprouting after 23 weeks and 50% of the bulbils had sprouted by 29 weeks. At 80°F, sprouting began at 6 weeks, and 50% of bulbils had sprouted by week 9 (Figure 9).



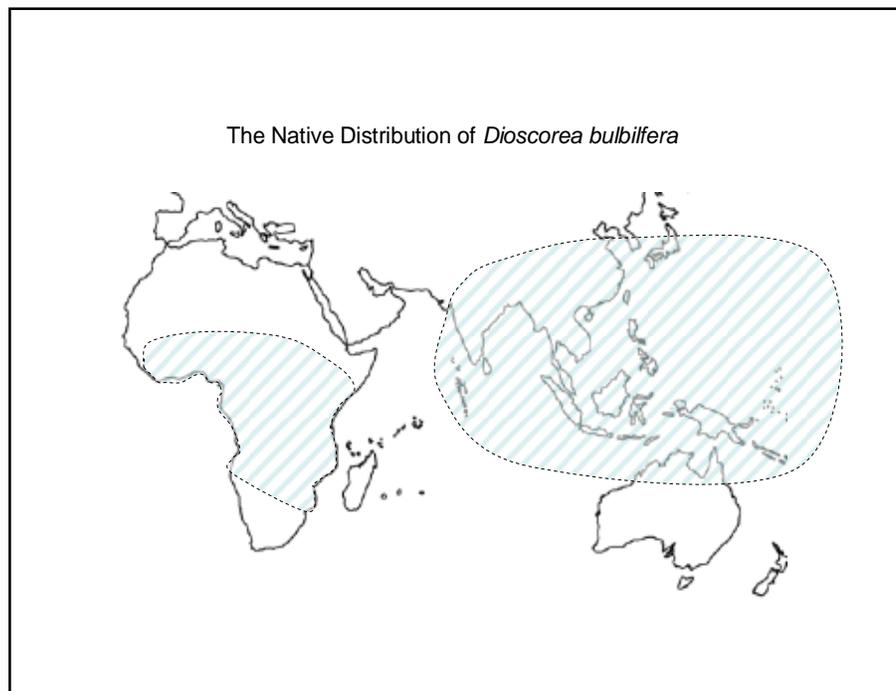
When the study was terminated after 39 weeks, 100% of the bulbils at 80°F, and 85% of those at 60°F had sprouted. Smaller bulbils took longer to sprout than larger bulbils, both at 60 and 80°F, but there was little variation in sprouting date for bulbils that weighed more than 20 grams (Figure 10).

## VI. Distribution, Ecology and Economic Impact

### Distribution and ecology in native range

*Dioscorea* spp. are native to tropical, temperate, and montane regions of numerous countries in Africa, Asia (Asia-Temperate and Asia-Tropical) and Australasia (Figure 11). Of all the species of *Dioscorea* documented to exist in this region of the world, *D. bulbifera* is the only species believed to be native to both Asia and Africa (Martin, 1974; Wilkin, 2001). The native range of *D. bulbifera* in Africa includes:

the east tropical Africa countries of Tanzania and Uganda; the southern African countries of Zambia, Zimbabwe, Malawi, Mozambique and Namibia; Cameroon in west-central tropical Africa; and, the west tropical Africa countries of Benin, Burkina Faso, Ivory Coast, Ghana, Guinea, Liberia, Nigeria, Senegal and Sierra Leone (Coursey, 1967; Wilkin, 2001). In Asia, *D. bulbifera* exists as a native species in two distinct regions referred to by the USDA, ARS,



**Figure 11. Native distribution of *Dioscorea bulbifera* (based on literature reports).**

National Genetic Resources Program (GRIN) as Asia-Temperate (namely, China) and Asia-Tropical which is composed of the Indian subcontinent, Indo-China and Malesia. Countries of the Indian subcontinent in which *D. bulbifera* is native include: Bhutan, India, Nepal and Sri Lanka. *D. bulbifera* is native to the Indo-China countries of Cambodia, Laos, Myanmar, Thailand and Vietnam. The Malesia countries where *D. bulbifera* is native include Indonesia, Malaysia, Papua New Guinea and the Philippines. *D. bulbifera* is also indigenous to portions of northern coastline of Australia: Queensland, the Northern Territory and Western Australia. To date, in addition to

the wide distribution of *D. bulbifera* in its native range, it is naturalized in Central and South America and the West Indies, and cultivated in Oceania and the West Indies (Schultz, 1993; Martin, 1974).

Research conducted to date on *D. bulbifera* shows that there exists considerable intraspecific diversity. This diversity has allowed for a distinction between accessions of African and Asian origins (Ramser et al., 1996; Terauchi et al., 1991). Work conducted by Terauchi et al. (1991) showed that at the molecular level, air potato from Asia and Africa are quite different and can be readily distinguished by examining chloroplast DNA. Although preliminary examination of chloroplast DNA of Florida air potato suggested an African origin (Overholt et al., 2003), later more in-depth studies pointed to an Asian origin, with Florida air potato being most closely related to plants from China (Croxtton et al. 2011).

The “civilization of the yam,” or “the yam zone” as it has also been referred to, includes regions of West Africa extending from central Ivory Coast in the west to the Cameroon mountains on the eastern edge of the range and from the forested areas in the north to the more humid savannahs comprising portions of the southern perimeter of the region (Ayensu and Coursey, 1972). Within this region, wild varieties of *D. bulbifera* are widely distributed (Martin, 1974) and can be found growing in a number of habitat types in which high temperatures and humidity are the principal climatic elements (Martin, 1974). Habitat types ideal for the growth and proliferation of the plant are those that receive full to partial sunlight and have well drained loamy soils rich in organic material that can maintain sufficient moisture to support the water requirements of sprouting bulbils (Martin, 1974). In West Africa, *D. bulbifera* is predominantly found in forest gaps and forest edges (Overholt, pers. obser.).

In general, all of the principal yam species are frost-intolerant and vigor is affected at temperatures below 20°C. A temperature range of 25-35°C is common in the majority of the yam producing districts and Coursey (1967) suggests that the rate of growth of *Dioscorea* increases with an increase in temperature. Coursey (1967) does note that extremely high temperatures coupled with dry conditions are deleterious to the vigor and growth of the plant. The majority of yams, both wild and cultivated, are found in regions of the yam zone that receive anywhere from 1-3 m of rainfall annually (Al-Shehbaz and Schubert 1989, Coursey, 1967). The plant is documented to occur at altitudes between 200-1300 m (Wilkin, 2001).

## Economic uses in native range

Throughout the plant's native range in three continents, several domesticated varieties, and in some areas, wild varieties, of *D. bulbifera* serve as food sources for local consumption and/or commercial distribution (Figure 12) (Al-Shehbaz and Schubert 1989; Bhandari and Kawabata, 2005; Coursey, 1967; Milne-Redhead, 1975; Webster et al., 1984). The species has been in cultivation for several millennia in both Asia and Africa. In Africa, edible cultivars have been reported in the literature as *D. bulbifera* var. *anthropophagoram* (Martin, 1974; Milne-Redhead, 1975), whereas in much of Asia var. *sativa* is reported as



**Figure 11. Tuber of edible variety of *D. bulbifera* from Ghana**

the principal culinary and commercial cultivar (Milne-Redhead, 1975). Cultivars of importance in other regions of its natural range include: var. *rotunda* (Australia; tubers consumed) and var. *suavior* (Asia). Although cultivars of several other *Dioscorea* species provide more palatable tubers and/or bulbils than *D. bulbifera* (e.g., *D. alata*, *D. cayenensis* subsp. *rotundata*, *D. trifida* and *D. esculenta*), all of the cultivars of the plant grown for consumption can be prepared, with varying degrees of difficulty, as table fare. Tubers of edible varieties of *D. bulbifera* from Africa, Australia, Nepal, and Thailand are documented to have well textured flesh and a distinctly bitter taste in contrast to the softer flesh and sweeter taste of tubers produced by the varieties cultivated in much of Asia (Bhandari and Kawabata, 2005; Martin, 1974; Webster et al., 1984). The primary bitter components present in the tubers of *D. bulbifera* have been identified as furanoid norditerpenes (diosbulbins A and B) (Bhandari and Kawabata, 2005; Martin, 1974; Webster et al., 1984). Various preparation techniques are used to lessen or fully eliminate bitterness. Techniques typically involve boiling/steaming and/or baking over coals after either cleaning (bulbils) or cleaning and peeling (tubers) (Bhandari and Kawabata, 2005; Martin, 1974). Martin (1974) states that in areas of the plant's native range, tubers of several of the toxic varieties of *D. bulbifera* are made palatable and can be used as a food source in emergency situations (i.e., periods of drought and or famine). The process of detoxification is involved and time consuming and requires pounding the tubers with lime or sand and then slow-roasting or repeated boiling with wood ashes followed by steeping sliced pieces in running water (Martin, 1974; Webster et al., 1984).

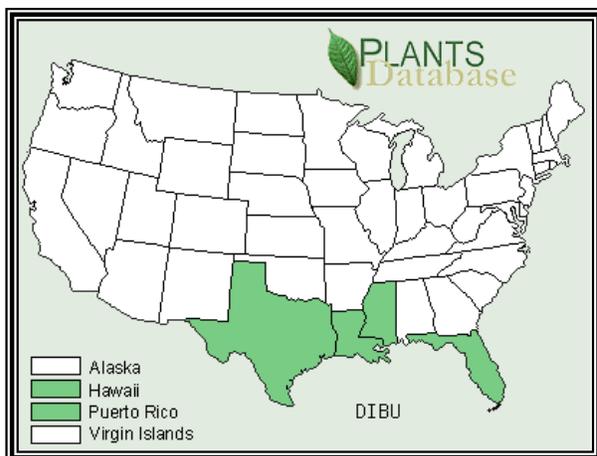
Aerial and underground tubers of *D. bulbifera* have long been used in many ways in folk medicines in the plant's natural range (Martin, 1974). Among the many documented medicinal folk uses of the plant, some of the most well known include: the use of bulbils for external treatment of sores and internal treatment of hemorrhoids (India); the use of a paste created from the tubers to treat swelling and as a cure for snakebite and scorpion stings (Africa, Central Asia); the use of the tuber for treatment of sore throat and struma (China); use of the tuber to remedy diabetes (Japan); use of the tuber for treatment of leprosy and tumors (northern regions of Bangladesh) (Gao et al., 2002; Komori, 1997; Martin, 1974). Indeed, recent research conducted

by Gao et al. (2002) and Komori (1997) indicates the existence of anti-tumor promoting agents present in the tubers of *D. bulbifera*. Research by Komori (1997) identified eight isolates present in tubers of *D. bulbifera* that exhibit anti-tumor promoting capabilities, all of which are furano-norditerpenes or glycosides: biosbulbin A-H and diosbulbinosides D and F. Gao et al. (2002) indicated that inhibitory effects are promoted by several compounds characterized as flavonoids.

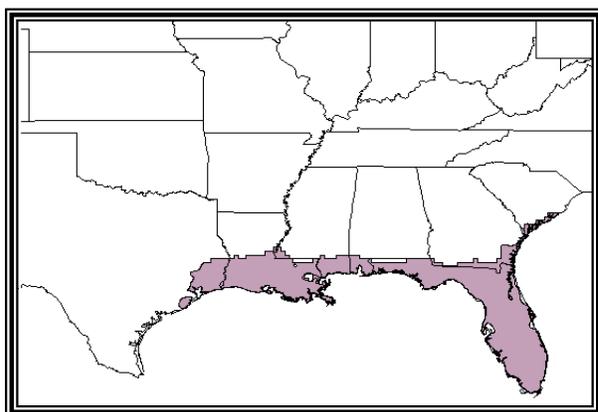
Tubers and/or aerial bulbils of unpalatable varieties of *D. bulbifera* have been used to create poisons for various uses (Martin, 1974). Poisons are derived from alkaloids (i.e., dioscorine), saponins, sapogenins and/or tannins present in tubers of a given variety (Al-Shehbaz and Schubert, 1989; Martin, 1974). In various parts of Africa and on the island of Java, aerial tubers are used to make a fish poison (Al-Shehbaz and Schubert, 1989; Martin, 1974). The poison released by grated tubers placed in a stream acts to stun fish at fairly long distances (Al-Shehbaz and Schubert, 1989). Poisonous varieties of the plant are often used by farmers to confuse and deter potential thieves through the planting of unpalatable varieties in with the main crop variety (Martin, 1974).

### **Distribution in introduced range**

In the U.S., *D. bulbifera* has been reported in Florida, Mississippi, Louisiana, Texas, and Hawaii (Figure 13). The species has also been reported in Puerto Rico (USDA, SCS 1982; USDA, NRCS, 2002). It is found in several habitat types ranging from pinelands, tropical hammocks, alluvial flood plain forests, and scrub to urban lots and disturbed uplands. Within the continental United States and Hawaii, *D. bulbifera* is confined to areas with tropical to subtropical climates. Based on the known range of *D. bulbifera* in North America, the plant can survive in areas with an average annual minimum temperature range of -12.2 to -9.5 C (10 to 15°F) — zone 8b on the USDA Hardiness Zone Map. Climatic data (minimum January temperature and annual rainfall) from locations where *D. bulbifera* is known to occur in Florida have been extrapolated outside of Florida to estimate its potential distribution in the United States (Figure 14). These data suggest that *D. bulbifera* may be able to spread throughout much of the Gulf coast and along the Atlantic coast as far north as Savannah, Georgia.



**Figure 13. U.S. States reporting the presence of *Dioscorea bulbifera* (USDA, NRCS Plants Database).**



**Figure 14. Predicted distribution of *Dioscorea bulbifera* in the United States based on an extrapolation from location occurrence in Florida (Overholt, unpublished).**

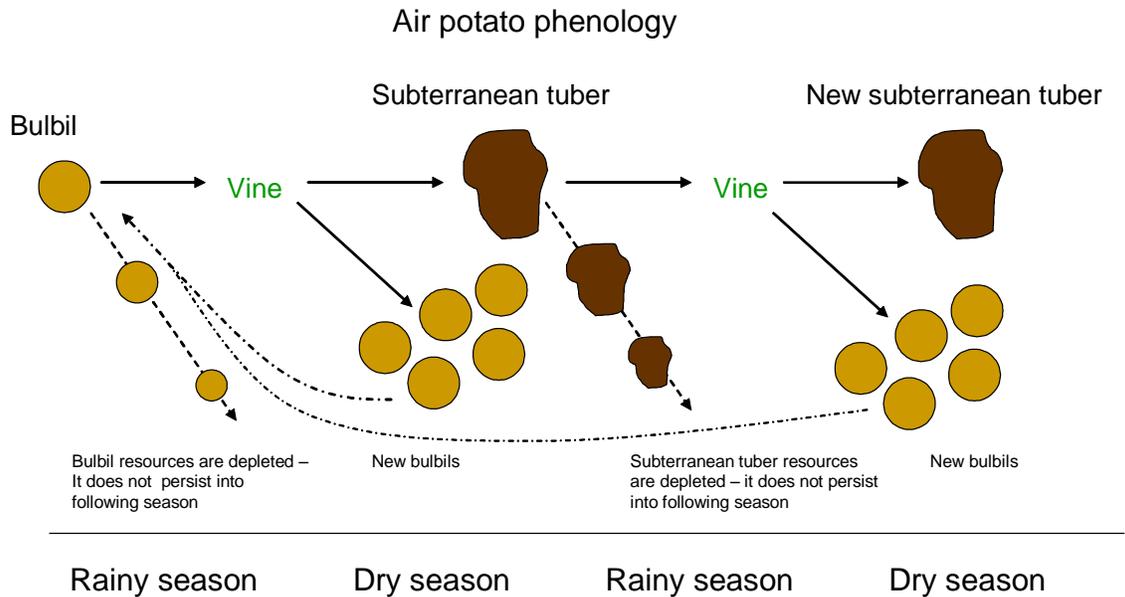
In Florida, the plant has been documented in 26 counties (Wunderlin and Hansen, 2003) from the Panhandle to the Keys. It would seem likely that it occurs throughout the state, but voucher specimens have not been submitted from many counties.

The beginnings of yam cultivation in Latin America is a matter of speculation. Coursey (1967) suggests that cultivation of *D. trifida*, dates to prior to the arrival of Columbus in the western hemisphere, and other species were probably harvested from the wild. A process of cultivation similar to that which took place in West Africa may have occurred in areas of Central America in the pre-Mayan period (Chevalier, 1946). The precise range of *D. bulbifera* in Central and South America and the Caribbean is still not fully charted. Specimens collected in this region, with corresponding coordinates, are on record with Missouri Botanical Garden (Missouri Botanical Garden, 2006). In Mesoamerica, *D. bulbifera* has been collected in Belize, Costa Rica, Guatemala, Honduras, Mexico (Yucatan), Nicaragua and Panama. In South America, it has been collected in Columbia, Ecuador, Peru and Venezuela. In the Caribbean, specimens have been collected in Cuba (1860) and Puerto Rico.

## Ecology in Florida

The first record of air potato in Florida was in 1905, when the USDA sent bulbils to Henry Nehrling for studies on its potential as a medicinal plant (Morton, 1976). Although there does not appear to be any record of the origin of the bulbils sent to Nehrling, Coursey (1967) speculated that air potato was introduced into the US during the slave trade. The oldest record of air potato in the US is from the noted naturalist William Bartram who reported its presence in a garden in Mobile, Alabama in 1777 (Bartram, 1998). Hammer (1998) points to the Bartram record, and states that ‘this early account of air potato cultivation in the United States indicates that it was introduced by the earliest European colonists prior to the African slave trade’. However, the first slaves entered North America in 1619, and continued to arrive until around 1800 (Wikipedia, 2006).

The life cycle of air potato in Florida begins in the late spring (April/May) when bulbils and subterranean tubers from the previous year begin to sprout. Growth of vines continues through the summer with bulbils appearing in mid-summer and increasing in size and numbers until late fall/early winter when the vines die back and the bulbils fall to the ground. The bulbils lie dormant until the following spring or early summer. There is conflicting information regarding the longevity of subterranean tubers, with many authors characterizing them as perennial (Gordon et al., 1999; Milne-Redhead, 1975; Okagami, 1986; Schmitz et al. 1997; Schultz, 1993), while others indicate that they are annual (Coursey, 1967; Hamon et al. 1995). Some experienced observers in Florida are convinced that the subterranean tubers are perennial and increase in size from year to year (K. Brown and K. Langeland, personal communications). We suspect that the typical life cycle may be as follows: bulbils sprout in the spring/early summer, leading to the growth of a vine. The vine stores energy in new bulbils and a subterranean tuber. The subterranean tuber produces a vine the following year, but in doing so, it depletes its energy stores, and does not persist to the next growing season. The vine produced from the subterranean tuber, stores energy in new bulbils and produces a new subterranean tuber. This entire seasonal cycle is illustrated in Figure 15. However, there may be variation in the typical life cycle, as suggested by Martin (1974), who indicated that some varieties produce no subterranean tubers, while other varieties produce very large tubers.



**Figure 15. Air potato seasonal cycle.**

Air potato has been found in a number of different habitats in Florida, including disturbed uplands, floodplain forests, maritime hammocks, pine rocklands, prairie hammocks, rockland hammocks, scrub, scrubby flatwoods, shell mounds, sink holes and xeric hammocks (Gann et al., 2006). This wide variety of invasible habitats suggests that air potato is rather broadly adapted. However, air potato is most commonly reported in hardwood forests, pinelands and disturbed areas (Al-Shehbaz, 1989; Hammer, 1998; Langeland and Burks, 1998; Schmitz et al. 1997). Schultz (1993) states that air potato is not salt tolerant and therefore is not invasive in marine areas. *D. bulbifera* is one of the most common exotic weeds in natural areas in South Florida, found in 15.2% of conservation areas (48 of 315) and 25% (12 of 48) of habitats surveyed (Gann et al., 2006).

Although Nehrling (1944) stated that ‘with the exception of Kudzu vine, I have never seen a more aggressive and dangerous weed in Florida’ (Nehrling, 1944), there are few studies that attempt to quantify air potato’s effects on native vegetation or ecological processes. Schmitz et al (1997) noted that plant species that constitute new habitats by producing dense canopies where none once existed and/or affect ecological processes are the non-native plant species that are having the greatest ecosystem impact in Florida. Several authors indicated that the primary ecological threat of air potato is its ability to climb vegetation and form dense canopies that shade out the understory (Gordon et al., 1999; Schmitz et al., 1997; Schultz, 1993). Gordon et al. (1999) investigated the efficacy of hand-pulling and herbicide application on air potato control, and found that densities of native species increased in treatment as well as control plots, however, these results were likely influenced by hurricane Andrew which occurred during the course of the experiment. Both Horwitz et al. (1998) and Gordon et al. (1999) have pointed to an interaction between hurricanes and air potato, with opening of tree canopies after hurricane damage leading to increased prevalence of air potato and other invasive vines. Discussing the impact of hurricane Andrew on air potato, Gordon et al. (1999) state that ‘air potato impedes the recovery of vertical canopy cover’ and it creates and maintains gaps in tropical hardwood forest canopy ‘changing

ecological conditions and community structure'. Horwitz et al. (1998) suggests that invasive vines, including air potato, may create a moist barrier that impedes fire movement into invaded plant communities. Additionally, Gordon (1998) mentions the twining growth form of air potato and several other invasive vines, and suggested that this growth habit, which differs from most native vines which climb by adhering to bark, 'increases the probability that the supporting plants will eventually collapse, resulting in a significant change in vertical structure of the community'.

## **Economic uses in introduced range**

No records have been found indicating past or present cultivation of *D. bulbifera* as a food crop in Florida. The presence of cyanogens and the toxic alkaloid dioscorine have been documented to exist at varying levels in certain varieties of *D. bulbifera*, making them unpalatable or poisonous to eat without proper processing. Chemical analyses of the compounds known to contribute to bitterness and toxicity in the tubers and bulbils of the plant are still required in order to better define the levels of these components as they exist in the invasive population we have in the United States. Ward (1977) states that the bulbils from the variety present in the U.S. maintain the bitterness that is commonplace in several varieties in the plant's native range and causes nausea if ingested, regardless of repeated washings and/or boiling.

Despite its invasiveness, *D. bulbifera* is still regarded in some areas as an ornamental plant. Fast growth, attractive foliage, and tolerance of a wide range of growing conditions make the species desirable to some people for landscaping. A recent (2006) posting at Dave's Garden website (<http://davesgarden.com/pf/go/32235/index.htm>) states 'my experience with *Dioscorea bulbifera* has been very positive. This beautifully green, rapidly growing vine gives a lush tropical rainforest appearance to my Florida garden. It thrives in deep shade and if there is nothing to climb will provide a very wonderfully dense ground cover (do not walk on it frequently). Those who prefer to micro-control their environments may use exaggerated descriptions such as "invasive", "noxious" and "damaging to the ecosystem" (how?!), but this plant can easily be contained in your garden with the usual gardening practices of trimming and uprooting every few days if you wish'. Air potato, however, is illegal in Florida. Due to the status of *D. bulbifera* as a noxious weed, the plant can no longer be introduced, possessed, moved, or released without a permit.

Research, although limited, is underway in the United States (and other regions of the plant's range) on the extraction and use of diosgenin from the bulbils of *D. bulbifera* (Budavari, 1989; Oboh et al., 2001). Diosgenin can be chemically converted to cortisone, estrogen, progesterone and testosterone. The beneficial uses of cortisone are many. Inflammation resulting from joint injuries or arthritis can be reduced through the use of dihydrocortisone. Cortisone, as a topical ointment, has long been used to minimize symptoms of allergic reactions. The potential uses of estrogen and testosterone chemically synthesized from diosgenin range from hormone replacement therapy and treatment of infertility to the use of progesterone in preventing miscarriages or as a form of birth control.

In regions of Latin America several species of *Dioscorea* are widely cultivated as food crops with *D. alata*, *D. cayenensis subsp. rotundata* and *D. trifida* serving as four of the major crop species (Bressan et al., 2005; Coursey, 1967). Although not a major crop species, edible varieties of *D. bulbifera* are grown by subsistence and traditional farmers and in "home gardens" in some of the more remote regions of Mesoamerica and South America (i.e., Chiapas, Mexico and São Paulo, Brazil) (Bressan et al., 2005; Vogl, 2002).

Medicinal uses of *Dioscorea* species by the indigenous peoples of Latin America are many and are part of folk tradition spanning many generations (Masslo Anderson, 1992). Folk medicines derived from various parts of *Dioscorea* plants by the native peoples of Latin America are similar to those developed by many of the peoples in the native range of the genus: a form of contraceptive (Mexican Indians), poultices for treatment of pimples and tumors (Colombia), a form of leaf extract used in baths for skin irritations and centipede bites (Colombia), a paste derived from tubers to treat hemorrhoids (Colombia) (Masslo Anderson, 1992). Specifically, plant parts from *D. bulbifera* have been documented to be used by many local populations in parts of Latin America in several capacities: crushed raw pulp is used to create poultices to place on boils; tubers are considered alexeteric, antidotal, diuretic, anti-inflammatory and hemostatic; tubers are used in the treatment of cancer, fever, dysentery, hernia, goiter, piles, sores, tumors and syphilis (Vasquez Martinez, 1990).

Research conducted recently in Latin America regarding possible technological uses of the tuber has produced some interesting results (Ferrera, 1995; Rincon, 2000). Rincon et al. (2000) evaluated the physical attributes, conducted chemical analyses and determined the pasting properties of the flours of *D. bulbifera* and *D. trifida*. Results from these tests on *D. bulbifera* showed that the absence of a viscosity peak and the stability of the paste at high temperatures make it an ideal ingredient for instant soup mixes. An article written by Ferrera (1995) studying various aspects of fried processing of the bulbils of *D. bulbifera* (regionally known as “cara-de-rama”) verifies the use of the bulbils to make cara-de-rama chips and french fries.

## VII. Management of air potato

### Herbicides

*Foliar application:* In a brief note, Mullholland (1996) reported that staff at Ravine Gardens State Park found 2- to 2.5-percent solutions of triclopyr amine with added spreader (Kinetic) and cuticle cutter (d-limonene) to be effective in controlling air potato when applied to foliage in mid- to late-summer.

Mullahey and Brown (1999) evaluated six products as foliar sprays. While triclopyr ester (Remedy), triclopyr amine, and glyphosate (Roundup) completely controlled air potato after 13 weeks (Table 2), these treatments were not significantly different from four other treatments. Triclopyr ester was recommended due to its ability to limit bulbil development following application (Table 3). Like Garlon 4, the active ingredient in Remedy is triclopyr ester, but Remedy is labeled for pasture applications.

Table 2. Effects of selected herbicides on control of air potato vines.

Treatments <sup>1</sup>	Percent control of air potato			
	2 WAT	5 WAT	8 WAT	13 WAT
Finale (25%)	72a <sup>2</sup>	77ab	82ab	81ab
Remedy (25%) + Kinetic (0.1%)	38bc	73ab	76ab	100a
Remedy (25%) + JLB Oil Plus	44bc	77ab	85ab	100a
Garlon 3A (25%) + Kinetic (0.1%)	38bc	45bc	45bc	73ab
Garlon 3A (50%) + Kinetic (0.1%)	50abc	70ab	78ab	100a
Weedmaster (25%) + JLB Oil Plus	25c	20c	22c	32b
Banvel (25%) + JLB Oil Plus	25c	28c	32c	57ab
Roundup (25%) + Kinetic (0.1%)	58ab	83a	95a	100a

<sup>1</sup> Treatments were applied August 1, 1997  
<sup>2</sup> Within columns, means followed by the same letter are not significantly different ( $P \leq 0.05$ ).

Table 3. Effects of selected herbicides on aerial bulbil production.

Treatments <sup>1</sup>	Presence of aerial bulbils <sup>2</sup>		Stem number	Stem height (m)
	2 WAT	5 WAT		
Finale (25%)	0.0b <sup>3</sup>	0.0b	2.7b	44.0b
Remedy (25%) + Kinetic (0.1%)	1.0ab	0.0ab	6.0b	7.0b
Remedy (25%) + JLB Oil Plus	1.0ab	0.0ab	2.3b	16.0b
Garlon 3A (25%) + Kinetic (0.1%)	0.7ab	0.7ab	2.7b	36.0b
Garlon 3A (50%) + Kinetic (0.1%)	0.7ab	0.7ab	4.7b	22.0b
Weedmaster (25%) + JLB Oil Plus	1.0a	1.0a	10.0b	75.0a
Banvel (25%) + JLB Oil Plus	1.0a	1.0a	13.7ab	104.0a
Roundup (25%) + Kinetic (0.1%)	0.3ab	0.3ab	3.0b	28.0a
Check	1.0a	1.0a	26.0a	196.0a

<sup>1</sup> Treatments were applied August 1, 1997  
<sup>2</sup> Absence of tubers = 0, presence = 1  
<sup>3</sup> Within columns, means followed by the same letter are not significantly different LSD test ( $P \leq 0.05$ ).

In a study done by Haller et al. (2001), potted plants approximately 1 meter tall were sprayed. Five herbicides were sprayed at six rates, with triclopyr ester at 2.5 and 5.0 % providing complete control (Table 4). They also found limited success with glyphosate, and good results with two 2,4-D products (Weedone LV4 and Weedar 64). Their results contradicted Mullahey and Brown (1999), who found another 2,4-D product (Weedmaster) provided the least control of air potato for all herbicides evaluated in their study (Table 2). Results in both studies varied

Table 4. Mean percent tissue kill after herbicide application. Means that share letters are not significantly different ( $\alpha = 0.05$ ) using Duncan's New Multiple Range Test. Shaded values represent the highest level of control.

Herbicide	Application rate (percent v/v)					
	0.315	0.625	1.25	2.5	5	10
triclopyr ester (Garlon 4™)	75 ABCDE	97.5 AB	98.3 AB	100.0 A	100.0 A	
triclopyr amine (Garlon 3A™)	28.3 HIJ	40.0 FGHI	82.5 ABC	98.3 AB	99.5 AB	
glyphosate (Roundup Pro™)		20.0 IJ	10.2 J	59.2 CDEFG	50.0 EFGH	75.8 ABCD
2,4-D (Weedone™ LV4)		6.7 J	38.3 GHI	64.2 CDEF	72.8 BCDE	98.5 AB
2,4-D (Weedar™ 64)		20.0 IJ	55.0 DEFG	43.3 FGH	97.3 AB	96.3 AB

Table 5. Percent change in mean cover of air potato after treatment by selected herbicides.

Treatment	Percent reduction in mean % cover from Nov-Dec	Percent increase in mean % cover from Feb-May
Control	45	82
Escort 0.5g/gal	76	76
Escort 1.0 g/gal	79	71
Garlon 3A 1%	43	36
Garlon 3A 5%	73	21
Plateau 0.5%	42	50
Plateau 1%	28	25
RoundUp Pro 1.5%	96	49
Roundup Pro 3%	98	69
Roundup Pro 1% and Escort 0.5 g/gal	100	15
Veteran 720 1%	63	25
Veteran 720 2%	62	28

widely yet lacked statistical significance, suggesting a high level of variance existed among replications.

The ability of triclopyr ester to achieve 100% control of air potato in the Haller et al. (2001) study could be linked to the herbicide's ability to be absorbed through the stem. One-meter tall plants may not have adequate leaf surface area for foliar-absorbed herbicides, such as glyphosate, to be effective. Bodle (1996) recommended the application of 10% triclopyr ester to stems emerging from bulbils.

Pandion Systems (2004) evaluated 5 different herbicides at 11 strengths and combinations (Table 5). Unlike the earlier studies, the results from triclopyr amine were not comparable to those of glyphosate. Glyphosate (Roundup Pro at 1.5 and 3%) provided very good control, as did

glyphosate (Roundup Pro at 1%) with metsulfuron (Escort at 0.5 grams/gallon) (Table 5). The addition of metsulfuron seemed to suppress regrowth the following year.

Three of the previously described studies compared multiple herbicides, and all indicated triclopyr or glyphosate performed better than other products. Treatment applications were done at different times of the year, with the two earliest (Haller et al. 2001, Mullahey and Brown 1999) indicating that triclopyr gave the best results. The work by Pandion Systems was done much later in the year (November) than that of the others. Results from these studies suggest that triclopyr may give better results for treatments earlier in the year, and glyphosate may be the preferred herbicide for late-season treatments.

*Cut-stem treatments of vines:* Research indicates that air potato may be controlled with several herbicides, and eradication of isolated populations might be possible when annual applications are made over the course of several (perhaps 4-5) years.

Literature describing basal or cut-stem applications is limited to two sources and somewhat contradictory. Bodle (1996) stated that a basal application of triclopyr ester (Garlon 4) is recommended, but cut-stem applications with 50% Garlon 3A (triclopyr amine) or 10% triclopyr ester are also effective. Kline and Duquesnel (1996) recommended the same herbicides at the same rates, but contradicting Bodle (1996), stated that the cut-stem applications were the preferred method over basal applications.



**Figure 16. Non-target effects of metsulfuron to palms.**

Both papers cite Sandra Vardaman as a source of information, suggesting one of the authors may have mistaken which was the preferred treatment method. Bodle also stated that basal applications should be used when bulbils are on vines because herbicide will translocate into bulbils, but did not mention whether translocation into bulbils and its subsequent inhibition of sprouting had been formally evaluated.

More information has been published concerning the effectiveness of herbicides when applied as a foliar spray, with studies suggesting that solutions of triclopyr (either as an ester or amine formulation) or glyphosate work well.

*Recent Work Evaluating Herbicides:* To clarify the results of previous herbicide studies, Meisenburg et al. evaluated various products on air potato at three sites in 2005 (Table 6, data not published). Percent leaf cover was estimated at the time of spraying and at 30-day intervals

through the following year. Glyphosate (Accord XRT) provided the best results after 30 days. Some treatments included metsulfuron (Escort), but results were no different than glyphosate treatments alone. In addition, palms cannot tolerate metsulfuron (Figure 16), and the product resulted in high mortality of these plants when they occurred in test plots.

Table 6. Herbicides evaluated for the control of air potato, and the resulting change in leaf cover following application.

Date treated	herbicide (and rate)	surfactant	% leaf cover						
			Jul-05	Aug-05	Sep-05	Oct-05	Nov-05	Jun-06	Jul-06
<b>Gainesville</b>									
7/14	Garlon 3A (2%)	Scythe (1oz/gal)	95	45	45	15	4	5	15
7/14	Garlon 4 (1%)		95	50	10	4	1	5	15
7/14	Garlon 3A (1.5%) and Vista (0.5%)		95	50	15	8	2	5	12
7/21	Vista (0.25%)		95	92	80	60	40	15	60
7/21	Vista (0.5%)	Nu-Film IR (.25%)	95	50	30	35	3	10	55
7/21	Vista (1%)		95	60	10	10	3	5	50
7/21	Garlon 3A (1.5%)		95	40	8	8	2	5	5
7/21	Accord XRT (1.1%) and Escort (0.3g/gal)		95	10	1	1	1	1	3
7/21	Plateau (1%)		95	95	90	75	15	1	10
7/21	Escort (0.3 g/gal) and Plateau (1%)		95	95	90	90	45	1	10
7/21	Overdrive (6 ozs/gal) and Krenite (3%)	MSO, 1%	95	65	50	20	1	3	5
7/21	Overdrive (6 ozs/gal) and Garlon 3A (2%)		95	25	1	2	1	1	1
	Control		95	95	95	92	25	40	90
<b>St. Petersburg</b>									
7/25	Garlon 4 (1%)		90	35	50	25	45	8	20
7/25	Garlon 3A (1.5%) and Vista (0.5%)		90	45	30	20	10	10	12
7/28	Vista (0.25%)		60	30	45	35	15	15	20
7/28	Vista (0.5%)	Nu-Film IR (.25%)	70	40	55	30	10	15	35
7/28	Vista (1%)		50	25	15	5	5	5	15
7/28	Garlon 3A (1.5%)		95	15	5	1	1	3	10
7/29	Accord XRT (1.1%) and Escort (0.3g/gal)		95	3	1	1	1	1	1
7/29	Plateau (1%)		95	80	70	15	1	5	10
7/29	Escort (0.3 g/gal) and Plateau (1%)		95	40	35	10	1	4	3
7/29	Overdrive (6 ozs/gal) and Krenite (3%)	MSO, 1%	95	45	10	5	1	4	8
7/28	Overdrive (6 ozs/gal) and Garlon 3A (2%)		95	10	5	1	1	2	5
	Control		95	95	95	90	15	40	90

Date treated	herbicide (and rate)	surfactant	% leaf cover						
			Jul-05	Aug-05	Sep-05	Oct-05	Nov-05	Jun-06	Jul-06
<b>Frostproof</b>			Jul-05	Aug-05	Sep-05	Oct-05	Nov-05	Jun-06	Jul-06
9/28	Garlon 3A (2%)	Scythe (1oz/gal)			95	45	5		75
9/27	Garlon 4 (1%)				95	85	45		95
9/27	Garlon 3A (1.5%) and Vista (0.5%)				95	65	65		85
9/28	Vista (0.5%)				95	45	10		95
9/28	Vista (1%)				95	55	25		85
9/28	Garlon 3A (1.5%)				95	50	20		90
9/28	Accord XRT (1.1%) and Escort (0.3g/gal)				95	15	10		70
9/28	Plateau (1%)	MSO (.5%)			95	90	60		95
9/28	Escort (0.3 g/gal) and Plateau (1%)				95	85	35		85
9/28	Overdrive (6 ozs/gal) and Krenite (3%)				95	75	35		65
9/28	Overdrive (6 ozs/gal) and Garlon 3A (2%)				95	75	35		60
9/28	Accord XRT (1.1%)				95	20	5		20
	Control				95	90	75		95

Meisenburg, M., D. Mayo, and K. Langeland. Unpublished data. University of Florida.

Triclopyr amine performed nearly as well as glyphosate, but took longer to show effects. Off-target damage to native vegetation was greater in triclopyr amine plots, with single applications appearing to kill susceptible species such as oaks (*Quercus* sp.), grapes (*Vitis* sp.), and American beautyberry (*Callicarpa americana*). Two treatments—diflufenzopyr (Overdrive) with fosamine (Krenite), and diflufenzopyr with triclopyr amine—gave good results as well. However, the Overdrive label specifies that no more than 8 ozs per acre can be applied at a time (10 ozs/acre/year), and the Meisenburg et al. treatments consisted of 6 ozs on plots that were approximately 1/20<sup>th</sup> of an acre. Thus, while diflufenzopyr had good activity on air potato, the rates applied were not appropriate for large applications in the field.

Data from Pandion Systems (2004) suggested that metsulfuron added to glyphosate might inhibit regrowth the year following treatment (Table 5), a finding not substantiated by Meisenburg et al. (Tables 7 and 8). The difference in results could have been due to variation in the timing of treatments and follow-up site visits: Meisenburg et al. treatments were applied in July and September and assessed the following summer, while Pandion Systems applications were done in November and evaluated in spring.

*Timing of Applications:* There appears to be a trade-off for when to spray, as leaves are closer to the ground (and the applicator) early in the growing season, while later in the year many vines have climbed too high to reach with a handheld or backpack sprayer. Applicators may also want to treat vines before bulbils are produced (which begins in late summer), especially if bulbils will not be gathered after the stems die back.

Table 7. Effects of adding metsulfuron to air potato foliar treatments on bulbil sprouting rates.

	Accord XRT + Escort	Accord XRT	control	treated 9/15/05 collected 1/3/06
Total collected	137	149	105	
Sprouting	36	14	76	
Not sprouting	101	135	27	assessed 5/17
Percent sprouting	26.3%	9.4%	72.4%	
Total collected	135	139	93	
Sprouting	32	11	90	
Not sprouting	103	128	3	assessed 8/29
Percent sprouting	23.7%	7.9%	96.8%	
	Plateau + Escort	Plateau	control	treated 7/21/05 collected 1/15/06
Total collected	200	200	200	
Sprouting	109	73	162	
Not sprouting	91	127	38	assessed 5/17
Percent sprouting	54.5%	36.5%	81.0%	
Total counted	200	200	200	
Sprouting	130	124	193	
Not sprouting	70	76	7	assessed 8/29
Percent sprouting	65.0%	62.0%	96.5%	

Meisenburg, M., D. Mayo, and K. Langeland. Unpublished data. University of Florida.

Table 8. Effects of adding metsulfuron to air potato foliar treatments on controlling regrowth the year following application.

herbicide (and rate)	estimated % cover		
	7/21/05	6/10/06	7/11/06
Plateau (1%)	95	1	10
Plateau (1%) + Escort (0.3 g/gal)	95	1	10
	9/20/05	7/21/06	
Accord XRT (0.8%)*	95	3	
Accord XRT (0.8%)* + Escort (0.3 g/gal)	95	2	

Meisenburg, M., D. Mayo, and K. Langeland. Unpublished data. University of Florida.

Bulbils present a problem in that they do not all sprout at the same time. Many bulbils that had been collected in the winter and bagged in burlap sacks had still not yet sprouted by mid-May (Table 6). For those that had sprouted, most did not have enough leaf surface area for adequate foliar-absorbed herbicide uptake. Thus, early-season applications may require repeat treatments as bulbil sprouting and leaf development continues.

Glyphosate applications in 2005 suggested that applications in July gave better results than September (Table 5), both for the year of treatment as well as the following year. However, ideal dates for herbicide applications may be relative to latitude. When the 2005 herbicide applications were being made, it was found that plants at the southern-most site (located between Frostproof and Avon Park) were more mature than plants in St. Petersburg and Gainesville at the same time, including some that were beginning to yellow.

To evaluate the time-of-year effects, Meisenburg et al. (unpublished data) sprayed plots at a single site monthly May through October 2006 with glyphosate (Accord XRT at 1.1%) and triclopyr amine (Garlon 3A at 1.5%). Final assessments will not be made until early summer 2007, but results through fall 2006 indicate that the results from spraying early in the growing season were short-lived and plants appeared to recover by the end of the growing season (Figure 17). September and October treatments had the greatest control on air potatoes. Again, glyphosate had more activity on air potato than did triclopyr amine.

Meisenburg et al. (unpublished data) sprayed two plots in 2006 to determine whether adding additional surfactant to a glyphosate solution increased efficacy (Accord XRT was used, which

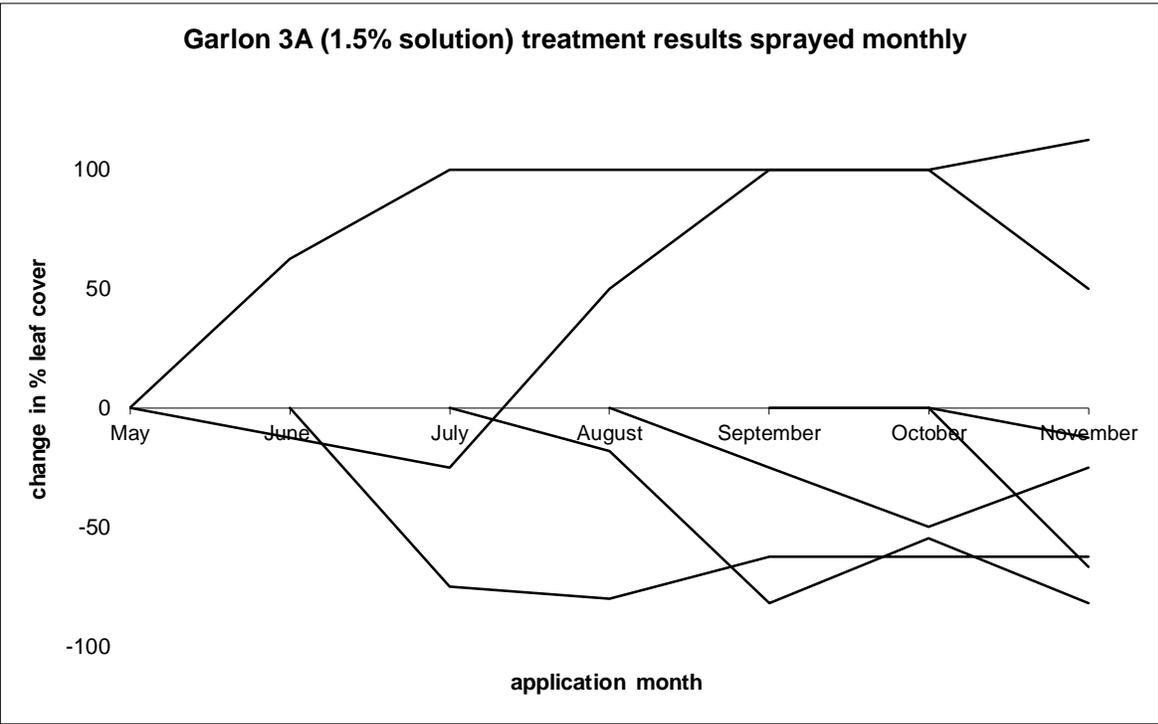
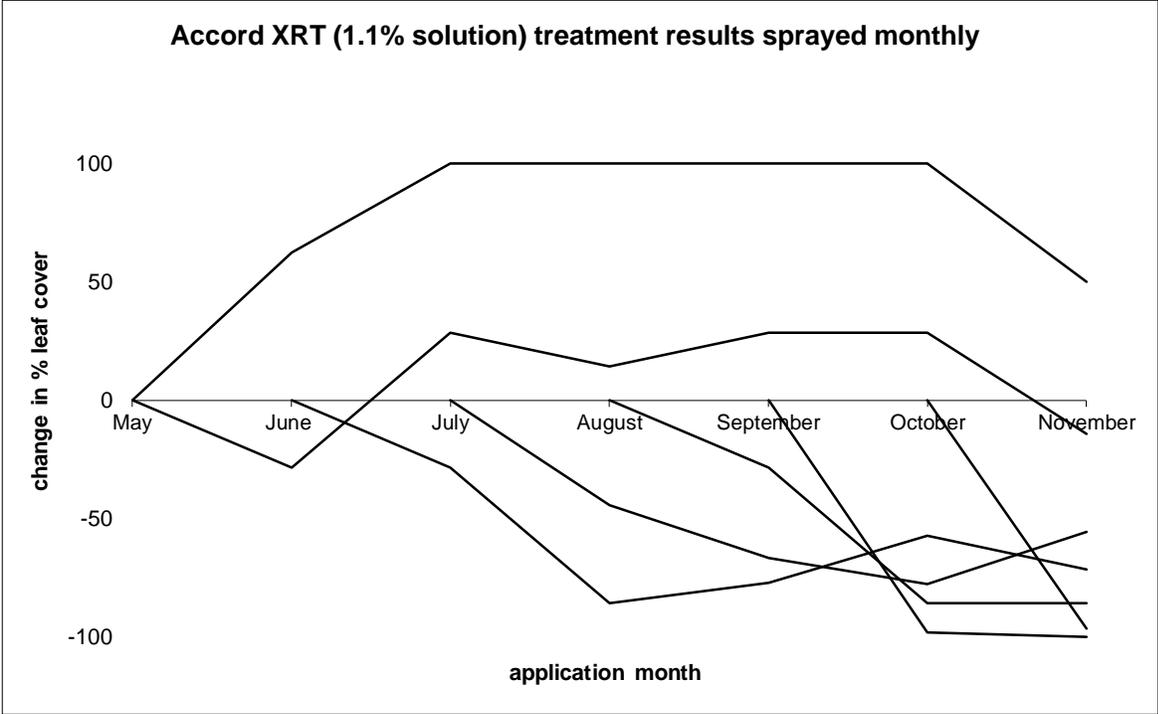


Figure 17. Effects of time of application on efficacy of Accord XRT and Garlon 3A on control of *D. bulbifera*.

contains surfactant). After 33 days (Table 8), there was no noticeable difference between plots, indicating adding surfactant does not improve glyphosate efficacy at the rate used.

Table 8. Change in % leaf cover of air potato following glyphosate applications with and without added surfactant.

herbicide (rate) and surfactant	% cover	
	7/21/06	8/23/06
Accord XRT (1.5%)	95	1
Accord XRT (1.5%) + DyneAmic (0.3%)	95	3

Meisenburg, M., D. Mayo, and K. Langeland. Unpublished data. University of Florida.

All herbicide foliar applications from the Meisenburg et al. trials were sprayed to the point of runoff and at heights as high as possible—typically 8’-12’ tall. Herbicide coverage was as thorough as possible while off-target application was minimal.

*Conclusion:* From trials conducted by Meisenburg et al., glyphosate treatments at rates equivalent to Roundup Pro at 1 to 1.5 % yield good results when applied when vines are well-developed and beginning to produce bulbils; typically September in northern Florida, but may be August in southern Florida. If herbicides are applied later, gathering bulbils after stems die back will help curtail regrowth the following year. Thoroughly covering as many leaves as possible was very important in getting good results.

*Killing bulbils:* Haller et al. (2001) sprayed bulbils with triclopyr ester at 13.6% (Pathfinder), which delayed sprouting by as much as 5 mos., but bulbils still sprouted. A better solution is freezing. Jameson (2001) killed potatoes with temperatures as warm as 32° for one week. Meisenburg et al. (unpublished data) killed bulbils by placing them into a chest freezer for eight hours, and damaged bulbils have been observed in the field after severe freezes (e.g. low 20’s) when not protected by a forest overstory.

## Classical Biological Control

Classical biological control – the importation of host specific natural enemies from a plant’s native range – is one strategy that has potential for the management of air potato in Florida. A leaf feeding beetle from Asia, *Lilioceris cheni* Gressitt and Kimoto (Coleoptera: Chrysomelidae), was released in Florida as a biological control agent of air potato in late 2011.



**Figure 18. Chinese (left) and Nepalese (right) biotypes of *Lilioceris cheni*.**



**Figure 19. *Lilioceris cheni* larvae feeding on an air potato leaf.**

The beetle was discovered in Nepal by scientists from the USDA/ARS Invasive Plant Research Laboratory in Fort Lauderdale (IPRL), and later the same species was found in Yunnan Province of China. Adult beetles are either bright red (Chinese biotype) or brown (Nepalese biotype) (Figure 18), and about 9 mm (3/8”) long. They live for up to six months, during which they lay as many as 4000 eggs. Females lay eggs in clusters on the undersides of young, expanding air potato leaves. Adult females bite the veins of the leaves on which they oviposit, causing the expanding leaves to curl at the edges and cup the eggs, perhaps providing some protection from inclement weather or egg predators. Eggs hatch in about 4 days, and the reddish colored larvae (Figure 19) feed on leaves for around 10 days. Late stage larvae and adults occasionally feed on bulbils. Fully mature larvae drop to the ground and burrow into the soil where they secrete a whitish oral substance that hardens into a cocoon. Several pupae often clump together within this material. Adults emerge from the soil after about 16 days and begin to lay eggs 15 days later (Tishechkin et al. 2011). Larvae are often found feeding in groups on the growing tips, which inhibits vine elongation and reduces the ability of the plant to climb vertical structures. The leaves and vines of air potato die back in the winter depriving the beetles of a food source. During this time, the adult beetles enter a resting state beneath leaf litter or other debris on the ground. The overwintered adults emerge during spring when air potato vines sprout from bulbils and subterranean tubers, and the adults begin once again to feed and lay eggs.

Host range testing conducted at the IPRL quarantine facility prior to field-release demonstrated that both Nepalese and Chinese biotypes of the air potato beetles would only feed and complete development on *Dioscorea bulbifera* (Pemberton et al. 2010, Center et al. 2013). They do not feed on any other species of *Dioscorea*, including the two Florida native species, *D. floridana* and *D. villosa*, or the other invasive yam in Florida, *D. alata*. Based on this safety data, a



**Figure 20. Infestation of air potato heavily damaged by *Lilioceris cheni* feeding.**

permit for field release was granted in February 2011. The first beetle field-releases were made by USDA/ARS in November 2011 at Long Key natural area in Broward County and at Kendall Indian Hammock Park in Miami-Dade County. The Florida Department of Agriculture and Consumer Services, Division of Plant Industry joined the rearing and release program in 2012 and UF/IFAS began rearing and releasing beetles in May 2014. The combined efforts by the IPRL, DPI and IFAS have resulted in the release of nearly 310,000 beetles at 986 locations in 44 counties. Beetle survival and establishment has been demonstrated at several release sites (Figure 20), and resulted in a reduced height of vines, decreased bulbil production, and most importantly, an increase in native vegetation. Releases and evaluation of impact will continue in 2015.

## VIII. Enacted laws

**Federal:** *D. bulbifera* is not listed on the Federal Noxious Weed List and there is currently no effort to have it listed. The Federal List includes only ‘quarantine pests’ on the list – ie, those likely to enter the USA or spread within the USA, it is unlikely that air potato would be considered for the federal list.

**Florida:** Air potato and winged yam (*D. alata*) are both included on the state noxious weed list maintained by the Florida Department of Agriculture and Consumer Services. Plants on this list cannot be introduced, multiplied, possessed, moved, or released except under permit issued by the the department.

**Other states:** Air potato is listed as a Class A noxious weed in Alabama. The movement of plants on this list is probited. Class A noxious weeds are defined as those that are not native to the State, not currently known to occur in the State, and pose a serious threat to the State.

**Local ordinances**

<b>County</b>	<b>Ordinance</b>
Broward	The Department of Strategic Planning and Growth Management, Code and Zoning Enforcement Division prohibits the use of FLEPPC Category I species to satisfy landscaping requirements in new developments
Collier	Land Development Code, section 2.4.4.12 prohibits planting, growing, offering for sale or transporting inter-county or intra-county <i>D. bulbifera</i> and 10 other invasive plants. Section 3.9.6.6.3 requires removal of plants listed in 2.4.4.12 prior to the issuance of a Certificate of Occupancy
Hernando	Section 10-27 of Chapter 10, Community Appearance Ordinance prohibits the planting of <i>D. bulbifera</i> , <i>D. alata</i> and a number of other species for installed plantings.
Lee	Resolution 98094 discourages (but does not prohibit) the use of <i>D. bulbifera</i> and four other invasive species.
Martin	Ordinance 494 prohibits the planting of FLEPPC Category I plant species. Where such species exist, their removal shall be a condition of development approval.
Miami-Dade	Chapter 24-27.1 of the Miami-Dade County Code prohibits the importation, sale, propagation and planting of several invasive species including <i>D. bulbifera</i> .
Palm Beach	Section 9.5(D)(2) and section 9.5(F)(2)(a) of the Palm Beach County Vegetation and Protection Code requires complete eradication of <i>D. bulbifera</i> and eight other invasive species prior to the issuance of a Certificate of Occupancy

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## X. Case studies

### Air potato Treatment in Everglades National Park (Jonathan Taylor)

Everglades National Park encompasses a million acres of the only subtropical wilderness in the continental United States. It is located at the terminus of the Florida peninsula in both Monroe and Dade counties. The south Florida climate allows plants of tropical origin to become established and flourish here, but they are absolutely on the northern limit of their range and are unable to persist very much further north.

Non-native exotic plants (hereafter referred to as Exotics) threaten the native plant communities of Everglades National Park. There are approximately 1000 plant species recorded from the Park. Of these, approximately 240 species are exotic. Unfortunately, only 10 to 15 of these exotic plant species are routinely controlled by contracted work crews. The most commonly targeted exotics are Brazilian pepper (*Schinus terebinthifolius*), melaleuca (*Melaleuca quinquenervia*), Australian pine (*Casuarina equisetifolia*), seaside mahoe (*Thespesia polpunea*), latherleaf (*Colubrina asiatica*) and lygodium (*Lygodium microphyllum*).

However, there are sites in the Park, small in scale and with relatively small populations of exotic species, that NPS employees and volunteers are able to treat. Even though they are small scale, localized projects they have tremendous impact, often tackling a problem before it becomes too large. This component to the exotics program keeps the program responsive and proactive. Examples of volunteer groups in EVER include the Youth Conservations Corps and Outward Bound and high school and college groups that contact the park and request service projects. This case study focuses on the removal of air potato from an abandoned hotel site in Royal Palm Hammock.

The approximate 2 acre work site is located in Royal Palm Hammock in an area where there once stood a hotel. The hammock surrounding the work site is a dense plant community comprised of both tropical and temperate broad-leaved hardwood trees. Except for a very small shed there are no other hotel structures that remain. Back in the early 1900's, when the hotel was managed by the Florida Federation of Women's Club the site was called Paradise Key. It is presumed that most of the exotic species found at the work site are a result of the landscaping activities supporting the hotel. Exotic plants found there include but are not limited to baker peacock-fern (*Selaginella willdenovii*), royal Poinciana (*Delonix regia*), avocado (*Persea americana*), shoebutton ardisia (*Ardisia elliptica*), sour orange (*Citrus aurantium*), grapefruit (*Citrus x paradise*), nephthytis (*Syngonium podophyllum*), spiderwort (*Tradescantia spathacea*), (*Croton* sp), pothos (*Epipremnum pinnatum*), cut-leaf philodendron (*Monstera deliciosa*), (*Pandanus* sp.), loquat (*Eriobotrya japonica*), sapodilla (*Manilkara zapota*), santa maria (*Calophyllum antillanum*) and air potato (*Dioscorea bulbifera*).

#### Management effort

Treatment efforts first started in 2000, with work conducted by a contract crew using herbicides (Glyphosate). Air potato was only one of a number of species targeted for treatment but approximately 1200 hrs of labor were involved in that effort. Cost was \$30,000.

Every year since 2000, work treating air potato has been conducted by NPS employees and volunteers working individually or in small groups. Approximately 588 hrs of work have been

invested in the treatment effort. We have tried to minimize the use of chemical treatments in the hammock so consequently all of the work treating air potato has been done with hand pulling.

In general monitoring efforts start in May. Once juvenile plants are detected, work days are organized approximately every 2 to 3 weeks and lasting until September. Some recommendations suggest longer intervals between hand pulling events but the emphasis of our efforts is to prevent adult plants from climbing up into the canopy and developing aerial tubers. Occasionally, this happens anyway but when it does, every effort is taken to pick off any tubers before pulling down the vine. Because, unfortunately, removing the vine causes most of the tubers to fall off and once the tubers are in the leaf litter they are very difficult to find.

Air potato is now down to a maintenance level. It is hoped that air potato could be extirpated from the site in the next couple of years. However, monitoring will be conducted every summer even after it is thought that air potato has been successfully eradicated. One missed adult plant can quickly re-colonize an area.

In closing, the success of this project can be attributed to the small size of the infestation, accessibility of the site and periodic visits for control of other exotic species which allowed repeated surveillance for air potato. Furthermore, the site's easy accessibility made organizing work days very easy.

## **Palm Beach County Invasive Vine Strike Force (Matthew King)**

Currently, Palm Beach County has an ordinance that requires all properties within the County to remove two vines, Old World climbing fern, *Lygodium microphyllum*, and air potato, *Dioscorea bulbifera*. In February 2003, the County created the Invasive Vine Strike Force Program in order to assist property owners with the treatment and removal of these vines.

This program provides free treatment of the two vines for properties with infestations of approximately two-acres or less. Higher priority is given to properties that are near a designated conservation area and/or properties where the vines cover native vegetation as opposed to covering other invasive non-native vegetation. Interested property owners submit a registration form to have the property inspected by staff and, if qualified, treated by a County contractor. If necessary, the County will perform one re-treatment within six months of the initial treatment after which the property owner is required by County ordinance to keep their property free and clear of the two vines. To date, over 1,268,000 square feet of *Lygodium microphyllum* (1,900,000 ft.<sup>2</sup>) and *Dioscorea bulbifera* (381,000 ft.<sup>2</sup>) have been treated on over 220 properties.

Palm Beach County has several large-scale neighborhoods where the minimum property size is 1.25 acres and a majority of the properties still retain large stands of native vegetation. These “exurban” areas encompass over 44,000 acres, contain approximately 24,000 buildable lots, and contain large populations of numerous invasive plant species. These areas contain the largest concentrations of *Dioscorea bulbifera* in Palm Beach County and are, therefore, the primary target of the Invasive Vine Strike Force.

This exciting program offered by Palm Beach County is an excellent example of the type of local government driven program that fulfills a role in helping to control the spread of *Dioscorea bulbifera* on private lands.

## **The Great Air Potato Round-Up**

In the late 1990s, staff from the City of Gainesville’s Nature Operations Division began a program aimed at raising awareness of the role of the public in the health of their local nature parks. The goal was to help people understand how landscaping decisions they make can affect the natural communities in nearby conservation areas. The initial campaign consisted of native landscaping workshops, a brochure, and guided nature walks. The program enjoyed limited success: the message was getting through, but we often had low attendance, and many of the participants were already aware of the problems of non-native invasive plants. We were preaching to the choir, and failing to attract the public who had little or no knowledge of the issue, who were a large portion of our desired audience.

A new approach was clearly needed. The solution was to be found in a single large-scale education event, disguised as a volunteer exotic plant removal day and celebration. To make the event fun for everyone, we decided to have prizes, competitions, and a free T-shirt for participants. Once we came up with a catchy name, The Great Air Potato Round-Up was on its way.

## **Why Air Potato?**

We chose air potato (*Dioscorea bulbifera*) for three reasons. First, air potato's prevalence and distinctiveness helped volunteers recognize the plant during and after the event. Air potato has large populations established along most of Gainesville's creeks; it is a menace to both public nature parks and private landowners. Second, picking up bulbils that resemble baking potatoes required little training, and could be done by volunteers of all ages and abilities; few if any tools were required. Lastly, removing air potato bulbils allowed us better scheduling opportunities: the spring and fall in Gainesville are booked with festivals, plant sales, and football games and the summer is just too hot to attract many people outside. That left winter, when most of the bulbils have fallen to the ground, and those that have not are easy to see on the dead vines.

## **Organization**

The Great Air Potato Round-Up was modeled after popular litter cleanups, with participants collecting bulbils instead of trash. We targeted areas in nature parks or properties that have direct creek connections to nature parks. Prospective volunteers are asked to pre-register for the event, which allows us to assign volunteers to specific sites. Site leaders at each site are a key component of the round-up: in addition to orienting and supervising volunteers, theirs is the most important task of the day: education. We recruited people who were knowledgeable about ecology, Florida's natural communities, and invasive non-native plants to volunteer as site leaders, focusing on colleagues in the environmental field and members of organizations such as the Florida Native Plant Society. On the day of the event, armed with pressed plant samples, line drawings, photos, maps, and fact sheets, our site leaders give short presentations about air potato and other invasive plants prior to letting the volunteers loose to collect bulbils.

After about two hours of work, volunteers receive tickets from the site leaders and go to the celebration festival. At the festival, participants turn in their tickets for free food and a t-shirt, and then enjoy music, educational displays from environmental groups, and a guest speaker. Recognition is given to the individuals who collected the largest and the most unusual bulbils, and to the group that brought the most volunteers. The celebration culminates with a raffle for numerous prizes, including a grand prize, generally a mountain bike or kayak.

## **Sponsorship**

To obtain sponsorship for the event, we send letters to businesses and organizations, and follow up with phone calls. Whenever the opportunity presents itself, we give presentations about the event. The old saying, "persistence does pay off," is true when it comes to sponsorship. The Florida Exotic Pest Plant Council (FLEPPC) and the Paynes Prairie Chapter of the Florida Native Plant Society (FNPS) enthusiastically supported us. They were followed by donations from environmental consulting firms and chemical companies. In addition to monetary sponsorships, several sponsors donated services or products, including signs and buckets for the collection sites. In addition, local businesses are willing to donate prizes that have included movie and restaurant gift certificates, birdhouses, native plants, and guided canoe trips.

As the event has increased in size, the associated costs have gone up, and much of the event is paid for out of the Nature Operations Division's operating budget. However, we continue to work on finding new sources of sponsorship dollars and finding ways to run the event more efficiently while still reaching a large segment of the public.

## **Advertising**

During the first year of the event, a significant amount of effort was put into both paid and unpaid advertising. Paid advertising included a radio ad in the week prior to the event, posters in business windows, small signs placed at strategic intersections (these turned out to be prohibited by city code), and ad space on the side of two public buses. Free advertising sources included the local public radio station, which played public service announcements daily about the event, and local newspapers, which ran articles before and after. We put listings in local volunteer announcements, and wrote articles for several local newsletters. We contacted representatives from every local club and organization we could find, including Boy Scout and Girl Scout troops, neighborhood associations, and every student organization at the University of Florida and Santa Fe Community College. In subsequent years, staff and volunteers directly contacted past participants by phone or email well in advance of the event, to make people aware of the date and encourage them to register.

## **Lessons Learned and Changes Over Time**

With several years of experience with the event, there are a few areas where some modifications have been necessary. However, for the most part, the round-up has changed relatively little since its origin.

One area that continually changes from year to year is the selection of sites for bulbil collection. On public lands where herbicide treatments occur in conjunction with the round-up, the density of bulbils is greatly reduced. Although bulbil collection in such sites may have a significant impact on the air potato population, volunteers seem to get less enjoyment at low-density sites. The educational impact of low-density sites is also probably less: it's harder to convince participants that a plant is a menace when it's not even easy to find, whereas sites overrun with vines and bulbils speak for themselves.

Issues have also arisen over the recognition of the largest and most unusual bulbils. Too much emphasis on this has resulted in volunteers abandoning their task of picking up bulbils, instead disregarding smaller bulbils in their quest to find a prize winner. To reduce this possibility, one solution that has been tried is to include recognition for the smallest bulbil as well; this is somewhat impractical due to the fact that tiny bulbils are easy to lose in transit, and judging them is difficult without precision equipment. A similar issue arose one year, when it was decided that too many donated prizes(!) would result in an overly long raffle; an intern suggested reducing the number of raffled prizes by placing "golden potatoes" at the sites, which were bulbils with a golden ticket attached that could be turned in for a prize. Emphasis on the golden potatoes again resulted in volunteers being distracted from picking up bulbils, and the golden potato concept was abandoned in subsequent years.

One effort that has met with mixed success has been continued attempts to have a contest for children to submit their designs for the t-shirt. Such a contest could provide early publicity for the round-up among one of our core audiences. Unfortunately, participation has been limited, although it has resulted in some of our best t-shirt designs.

Over time, as the event has become better-known, paid advertising has been less necessary, and free publicity, along with word of mouth and direct emails and phone calls to previous participants, have proven to be sufficient to recruit large numbers of volunteers. Media coverage has also proven to be a low-cost, low-effort recruitment and education tool. For example, city staff has been interviewed by our local public radio affiliate, and for the program "The Florida Environment" which has continued airing the segment at "air potato round-up time" in subsequent

years. These segments reach large audiences and provide more substance than can be conveyed in a public service announcement.

## **Conclusions**

The event clearly succeeds in getting the word out to people who might not otherwise be aware of invasive plant issues. When the first round-up was being planned, staff imagined getting 150 volunteers and decided to shoot for 300. Two weeks prior to the event it was clear that even this goal would be exceeded; the final tally for the 1<sup>st</sup> annual Great Air Potato Round-Up was 675 volunteers, participating at 21 sites around Gainesville, and collecting a total of 11,748 pounds of bulbils. Despite weather and competing special events, participation in the round-up every year since 2000 has exceeded 800 people, with 2008's round-up drawing over 1,100 volunteers. A large proportion of the participants are children. Volunteers knowledgeable about invasive plants work side-by-side with the general public, so that participants learn from other volunteers as well as their site leaders. It's also clear that some people who are not able to participate in the event itself still learn about air potato from the large amount of publicity that surrounds it: City staff regularly receives calls from people who heard about the event and who want information on removing air potato from their yards, and from others seeking advice on organizing small round-ups with their neighbors, schools, or groups. Participants who wear their round-up t-shirts in the community raise the profile of the event and invasive plant issues year-round.

Coordinating the Great Air Potato Round-Up demands a large amount of staff time and effort, and since it continues to be a free event, it requires a fair amount of money to run as well. However, after 9 years and some 8000 volunteers, this effort has more than paid off in terms of its impact.

*City of Gainesville staff is willing to share information about this event with anyone interested in coordinating their own round-up. Contact us at 352-334-2231 or [parkmgr@cityofgainesville.org](mailto:parkmgr@cityofgainesville.org).*