Dioscorea spp.

INTRODUCTORY

Water yam (*Dioscorea alata*)
Photo © Chris Evans, River to River CWMA, Bugwood.org

AUTHORSHIP AND CITATION:
Gucker, Corey L. 2009. Dioscorea spp. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2009, November 20].

FEIS ABBREVIATION:
DIOSPP
DIOALA
DIOBUL
DIOPEN
DIOPOL
DIOSAN

NRCS PLANT CODE [85]:
DIAL2
DIBU
DIOP
DIPE2

DISA17

COMMON NAMES:
water yam, white yam, winged yam, greater yam=*D. alata*
air yam, air-potato, bitter yam=*D. bulbifera*
fiveleaf yam, five-leaved yam=*D. pentaphylla*
Chinese yam, cinnamon vine=*D. polystachya*
Zanzibar yam, West African yam=*D. sansibarensis*

TAXONOMY:
The scientific name for the genus commonly known as yams is *Dioscorea* L. (Dioscoreaceae) [21,36]. This review summarizes information available as of 2009 on the following 5 yam species:

Dioscorea alata L. (section Enantiophyllum), water yam
Dioscorea bulbifera L. (section Opsophyton), air yam
Dioscorea pentaphylla L. (section Lasiophyton), fiveleaf yam
Dioscorea polystachya Turcz. (section Enantiophyllum), Chinese yam
Dioscorea sansibarensis Pax (section Macroura), Zanzibar yam [13]

Common names identified in the above list will be used throughout this review. The common name for the genus, yams, will be used when discussing information applicable to 2 or more of the above species. *Dioscorea* spp. will be used when information applies to the entire genus.

SYNONYMS:
for *Dioscorea polystachya* Turcz. [21,43]:
Dioscorea batatas Decne. [24,29,50]
Dioscorea oppositifolia L., misapplied [36]

The name *Dioscorea oppositifolia* has been consistently misapplied to Chinese yam in North America. *Dioscorea oppositifolia* occurs only in India [21,93].

LIFE FORM:
Vine-forb

FEDERAL LEGAL STATUS:
None

OTHER STATUS:
Information on state-level noxious weed status of plants in the United States is available at Plants Database.

DISTRIBUTION AND OCCURRENCE

SPECIES: Dioscorea spp.

GENERAL DISTRIBUTION:
North American distributions: The five yam species covered in this review are not native to North America. Of these species, Chinese yam is the most widely distributed in the United States. It occurs from Texas north to Kansas

and Illinois and in all eastern states as far north as Vermont and as far south as Florida [29,50,69,78]. Water yam and air yam are generally restricted to the US Gulf Coast region, although both also occur in Hawaii [89]. Water yam is reported in the Florida peninsula and panhandle [94] and is considered "escaped locally" in central and southern Florida [30]. It is reported in Georgia, but may also occur in other Gulf Coast states [21]. Air yam is frequent in Florida and occurs in Mississippi, southern Louisiana, and eastern Texas [3,94]. Zanzibar yam occurs in Florida and, as of 2003, was reported from 4 locations in Collier and Miami-Dade counties [30,94]. According to a 2008 report, Zanzibar yam may have been successfully eradicated from Florida (Pemberton cited in [3]). Air yam, water yam, and fiveleaf yam occur in Hawaii, and air yam is the most widespread [89]. Fiveleaf yam is also considered widespread in Hawaii, occurring on Kauai, Oahu, Molokai, Maui, and Hawaii islands [70,89]. Flora of North America and Plants Database provide maps of the distribution of all 5 yam species.

Native origins: Yams not native to North America originated in tropical regions of Asia or Africa. Due to widespread early cultivation and transport of yams, exact origins for some species are unknown [14,51,89]. Chinese yam is native to eastern Asia [21]. Fiveleaf yam is native to tropical Asia or eastern Polynesia [89]. Zanzibar yam is native to Africa [21,51,94]. Water yam has been reported as native to southeast Asia [14,51], but Coursey [13] indicates that water yam is "unknown in the wild state anywhere in the world" but was first cultivated in Assam or Burma. Water yam was likely transported to the eastern coast of Africa 2,000 years before present (review by [14]). Air yam is known from both Asia and Africa [13,21], but it is unclear if air yam is native to both continents or was introduced from one to the other [51]. Indigenous air yam populations were also reported on Australia's northern coastline (review by [3]).

Methods and timing of North American introductions: There is both speculation and evidence regarding the method and timing of yam introductions in the United States. Once yams were introduced, cultivation was encouraged because of their food value and ability to quickly develop into attractive shading vines.

Yams in Hawaii: As early as the 4th century, Polynesians brought air yam, water yam, and/or fiveleaf yam to Hawaii [7]. Fiveleaf yam was brought at least once by southern Polynesians as recently as 800 years ago. Depending on the number of successful introductions, yam populations in Hawaii may represent one or many clones [70].

Air yam: Natural air yam populations occur in both Asia and Africa; these types have several morphological differences (see Botanical description). Most if not all air yams in Florida are the African type [58]. In 1777, an early American botanist reported air yam growing in a garden in Mobile, Alabama (Bartram 1998 cited in [3]). In 1905, Nehrling [55] grew air yam in his garden. Nehrling was known for the introduction, promotion, and dissemination of plants for the Florida nursery trade [30]. Later Nehrling sent air yam bulbils to Bureau of Plant Industry officials who were evaluating the plant's medicinal uses. Nehrling's comments on the substantial growth and vigor exhibited by air yam are presented in Impacts.

Chinese yam: Chinese yam was likely planted as an ornamental or edible crop in the 1800s in the United States [21,69]. In the Bearcamp Creek watershed in the western Carolinas, Chinese yam was common at homesteads abandoned around 1900 [64]. In Illinois, Chinese yam was reported as escaped from cultivation by 1986 [50].

Water yam: Water yam may have arrived on slave ships from Africa as early as the 17th century (reviews by [13,14]). By 1897, water yam was available for sale from Florida's Royal Palm Nursery (Pemberton 1997 personal communication cited in [5]). After water yam's introduction, it was widely cultivated.

Zanzibar yam: The method by which Zanzibar yam was introduced to Florida is unknown [51], but Hammer [30] speculates that Zanzibar yam, which is considered to have magical properties in parts of Africa, may have been brought to the United States for use in religious rituals by members of Santería, an Afro-Cuban religion.

Current and changing local US distributions: Population increases and expanded ranges are described in the southern United States for Chinese yam, water yam, and air yam. Increased ranges are also reported for Chinese yam in Illinois. In 1977, water yam was reported as cultivated and "sparingly escaped" in Florida's Escambia, Leon, Alachua, Lee and Dade counties (Ward 1977 cited in [41]). By 1996, water yam was disrupting native plant communities, especially coastal hammocks in southern Florida (EPPC 1996 cited in [41]).

In Florida in 1977, air yam was described as "becoming extensively naturalized". By 1978, air yam was well established in Dade and Broward counties, and by 1996 occurred in 23 Florida counties (review by [41]). In 2006, air yam occupied 15.2% of conservation areas and 25% of habitats surveyed in southern Florida (Gann and others 2006 cited in [3]).

Chinese yam has increased its range in northern as well as southern US habitats. In 2008, an estimated 24,110 acres (9,760 ha) of southern forests were invaded by air yam or Chinese yam [48]. Chinese yam was not reported in an Oklahoma flora printed in 1969, but as of 1996, populations occurred along fence rows and in thickets and woodlands in McCurtain, Grady, and Cherokee counties [74]. In Great Smoky Mountains National Park, a survey conducted in the late 1980s estimated that 1% of the Park contained Chinese yam and reported that the species was "rapidly expanding and severely impacting various habitats" (Clement unpublished data cited in [52]). In 1987 and 1988, Chinese yam occupied an estimated 161,000 feet² (15,000 m²) of Park area on 125 surveyed sites. When just 45 of the 125 original survey sites were visited in 1994 and 1995, researchers estimated that Chinese yam occupied 380,000 feet² (35,000 m²) [54]. A previous resident of the Park reported that in the past Chinese yam did not "grow all over the place like it is now" (Oble 1995 personal communication cited in [54]). In Illinois, Chinese yam was not known outside of cultivation in 1970, but by 1986 was reported in disturbed areas of Jackson County. In 2001, escaped populations were reported from 21 Illinois counties (review by [8]). For more information on the expansion of Chinese yam populations in southern Illinois and in Great Smoky Mountains National Park, see Bulbil dispersal and Spread.

HABITAT TYPES AND PLANT COMMUNITIES:

Native habitats: In tropical areas of Asia and Africa, yams occur at the edges or in the canopy gaps of rainforests and woodlands. In Asian habitats, water yam occurs in shady rainforests [46]. In West Africa, air yam is found primarily at the forest edge or in forest gaps (Overholt personal observation cited in [3]). In East Africa, Zanzibar yam occurs in lowland rain forests, acacia (*Acacia* spp.) woodlands, and coastal evergreen shrublands. Populations are often persistent in secondary forests (Milne-Redhead 1975 cited in [82]).

Nonnative US habitats: Yams are generally most common in partially shaded, moist habitats that include forests, woodlands, and thickets in the United States. In Hawaii, water yam, air yam, and fiveleaf yam occur in mesic habitats and are common on abandoned agricultural and pasture lands dominated by Brazilian peppertree (*Schinus terebinthifolius*) [89]. Fiveleaf yam is described as persistent in moist areas of lower Hawaiian forests and often occurs with Indian walnut (*Aleurites moluccana*), 'ohi'a lehua (*Metrosideros polymorpha*), and 'ohi'a ha (*Eugenia sandwicensis*) [70]. In Florida, air yam and Zanzibar yam grow in hammocks and swamps (reviews by [21,51]). In Dade County, Florida, air yam is abundant and occurs in nearly every county park with hammock vegetation (Lippincott 1992 personal communication cited in [66]). In central and northern Florida, air yam is common in mesic hammocks (Gordon 1992 personal communication cited in [66]) and on alluvial floodplains (Putz 1992 personal communication cited in [66]). Salinity is not tolerated, so air yam does not occupy saline marshes or vegetation types. Although rare in pinelands, some air yam vines occur in xeric uplands (reviews by [51,66]).

Chinese yam has a much broader distribution than the other yams but is still most common in moist habitats. It often occurs at forest edges, along waterways, in floodplain forests, on developed land, and in the drainages of upland forests in southern Illinois. Native species consistently found in plots invaded by Chinese yam included Virginia creeper (*Parthenocissus quinquefolia*), poison-ivy (*Toxicodendron radicans*), Pennsylvania blackberry (*Rubus pensilvanicus*), and white ash (*Fraxinus americana*) [8]. In Oklahoma, Chinese yam occupies thickets and woodlands [74].

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Dioscorea spp.

Air yam (*D. bulbifera*)
Photo © Karen Brown, University of Florida, Bugwood.org

Chinese yam (*D. polystachya*)
Photo © Jack Ranney, University of Tennessee, Bugwood.org

GENERAL BOTANICAL CHARACTERISTICS:

Botanical description: This description covers characteristics that may be relevant to fire ecology and is not meant for identification. Keys for identification are available (e.g., [21,72,89]).

Yams are herbaceous, climbing, twining, perennial monocots [13,72,89]. Vines are without tendrils and use dead stems from the previous year's growth to climb into other vegetation [51,89]. Most nonnative yams occurring in the United States grow belowground tubers annually; perennial tubers are generally restricted to the Testudinaria section of the *Dioscorea* genus [13,46]. None of the 5 nonnative yams belong to the Testudinaria section (see Taxonomy). Most yams also produce aerial tubers or bulbils [89]. Both belowground tubers and bulbils are comprised of stem tissue [45,46]. Regeneration of yams in the United States has been exclusively asexual from tubers or bulbils [51,66,78]. Additional information on asexual regeneration by yams is presented in Regeneration Processes and Vegetative regeneration. Yams are dioecious [89] and produce very small flowers, if any [21,72]. Sexually produced fruits are 3-winged capsules [72], but yam fruits are extremely rare in the United States and, if produced, are often sterile [21,24,61]. Even when male and female water yams grew in close proximity, fruits were rare and seeds were typically aborted before reaching maturity [46]. Yam seeds are winged but have not been observed in the United States [78].

For thousands of years, yams have been a staple food for humans. They have been widely cultivated and domesticated throughout the world. Selection and adaptation have occurred in native and nonnative habitats, producing an abundance of ecotypes. Variable yam forms are possible in the United States, depending on the number of types introduced and escaped. Great variation in the growth and forms of vines, leaves, bulbils, and tubers are reported for air yams and water yams [45,46] and are also likely in other species.

Aboveground descriptions:
Air yam (*D. bulbifera*): Air yam vines twine counterclockwise and may grow to 100 feet (30 m) long [21,89]. Air yam stems are not angled and do not have prickles [89]. Leaves are simple, heart-shaped, and arranged alternately along the stem. Leaves may reach 10 inches (26 cm) wide and long; leaf petioles are generally shorter than the leaf blade [21,51,89,93]. Air yam size and appearance can be variable. Variability in bulbil form and size may be partly due to the different air yam types that exist in Asia and Africa. The Asian type produces relatively smooth, spherical

bulbils that may weigh 2 pounds (1 kg). African types produce sharply angled bulbils [45]. Most or all of the air yams in Florida are considered to be the African type [58]. In US floras and other references, air yam bulbils are often described as more than 2 inches (5 cm) in diameter and up to 5 inches (13 cm) long [3,12,21,47]. Flowers, if produced, are widely spaced or reduced to a single flower in simple staminate spikes 4 to 28 inches (11-70 cm) long. Pistillate spikes are generally stiff, up to 9 inches (23 cm) long, and occur in clusters of 2 or more [21,66,89,93].

Chinese yam (*D. polystachya*): Chinese yam vines are slender, twine clockwise, and may reach 16 feet (5 m) or more in length [24,72]. Chinese yam leaves may grow to 4.3 inches (11 cm) long and wide [21,24]. Leaves are deeply lobed at the base, and upper leaves may have 3-lobed margins [21,78]. Like water yam, the arrangement of Chinese yam leaves is variable. A review by Tu [78] reports that leaves may be alternate near the top of stems or occassionally found in whorls of 3, and others report that leaves are generally alternate near stem bases and opposite near the end of stems [21]. Chinese yam produces small, rounded, warty bulbils. Bulbils are typically less than 1 inch (3 cm) long and less than 0.8 inch (2 cm) in diameter [21,47,61,69]. Flowers are rare and smell like cinnamon. Male flowers occur in bundles, spikes, or panicles at branch ends [81], and female inflorescences are few-flowered and generally less than 2 inches (5 cm) long [21].

Fiveleaf yam (*D. pentaphylla*): Fiveleaf yam vines are prickly, twine counterclockwise, and may grow to 30 feet (10 m) long [70,89,93]. Leaves are alternate and compound with 3 to 5 leaflets. Leaflets measure 2 to 4 inches (5-10 cm) long and 0.8 to 1.5 inches (2-4 cm) wide. Bulbils are horseshoe shaped and about 1 cm in diameter [89]. Bulbils were rare in Hawaii according to St John [70]. Male flowers, if produced, occur in spikes up to 12 inches (30 cm) long at the branch ends; female flowers also occur in spikes, but these are shorter, 2 to 10 inches (5-25 cm) long [89].

Water yam (*D. alata*): Water yam vines twine clockwise and may reach 100 feet (30 m) long [21,46,94]. Vines have ridged stems and are prickly at the base [93]. Water yam leaves are large, elongate, and heart-shaped [46,51]. Leaf blades typically measure 2 to 6 inches (6-16 cm) long, 2 to 5 inches (4-13 cm) wide, and have entire margins. Leaf petioles are generally as long as the leaf blade [21] Leaf arrangement appears inconsistent. Some report that water yam leaves are alternate at the stem base and opposite near the stem end [21], while others report that leaves are primarily opposite, but can appear alternate due to leaf abortion [51]. Bulbils are oblong and rough with fleshy protrusions. Bulbils may reach 4 inches (10 cm) long and 1.5 inches (4 cm) in diameter [12,21]. Staminate flowers occur in a zig-zag pattern along a rachis up to 10 inches (25 cm) long; pistillate flowers occur in 4- to 20- flowered inflorescences that may reach 14 inches (35 cm) long [21]. Water yam fruits are capsules that could produce 2 seeds per each of 3 locules, but often if 1 seed is produced it is aborted before maturity. Capsules are rare even when male and female plants are in close proximity [46].

Zanzibar yam (*D. sansibarensis*): Zanzibar yam vines twine counterclockwise. Vine stems are about 1 inch (3 cm) thick and may grow to 10 inches (25 cm) or more. Stems can reach support trees prior to producing leaves [21,51,82]. Zanzibar yam leaves and petioles are long. Leaf blades are heart-shaped and can be up to 18 inches (46 cm) long and 23 inches (58 cm) wide. Petioles may be 10 inches (26 cm) long, and leaves often have a tail-like projection at the tip [21,51,82]. Leaves are generally opposite, and the margins of juvenile leaves may be irregularly lobed [21,82,94]. Bulbils are small, smooth, often a purplish color, and can measure 2 inches (6 cm) in diameter [21,51,82]. Male inflorescences typically have 2 to 4 flowers and may be up to 20 inches (50 cm) long; female inflorescences are slightly shorter [21,82].

Belowground descriptions: Most yams produce underground tubers. Yams of the Enantiophyllum section (Chinese yam and water yam) generally produce 1 tuber per season but may produce up to 3 tubers in a single season [13]. Yams generally have "weak rooting systems". Although referred to as roots in the literature and in this review, tubers and belowground structures attached to the root crown are adventitious stem tissue [45,46]. Early in the growing season, the previous year's tubers and sprouting bulbils produce thick, unbranched roots; later in the growing season, thinner, branching, fibrous roots develop (reviews by [3,13]). True roots are only produced by seedlings, and these are short-lived.

Air yam: Most references indicate that air yam generally produces tubers, although they may be small and solitary [3,66,89,93]. However, some suggest that air yam may lack underground tubers [3,21]. Tubers are commonly 2 to 4 inches (5-10 cm) in diameter and weigh less than 2.2 pounds (1 kg) [21,66,89,93]. Tubers from air yams in Florida were usually less than 4 inches (10 cm) in diameter but were up to 8 inches (20 cm) in diameter on vines growing in sandy soil (Gann-Matzen and Line 1992 personal communications cited in [66]). A particularly large tuber was dug from Alachua County, Florida; it was 9.8 inches (25 cm) in diameter and weighed 11 pounds (5 kg) (personal observation 1992 cited in [66]). Flora of North America describes air yam tubers as globose and occurring just below the soil surface [21]. However, tuber shape is likely related to ecotype. Air yams from Asia produce spherical tubers, while air yams from Africa produce irregular branching tubers [45].

Chinese yam: Chinese yams produce 1 to many large, cylindrical tubers [21,93]. Tubers grow vertically from long stalks and typically as deep as 3 feet (1 m) below ground [24,55]. Mature tubers can weigh 8 to 10 pounds (3.6-4.5 kg) [55].

Fiveleaf yam: Fiveleaf yam typically produces single, irregular to elongated, egg-shaped tubers [70,89,93]. Tubers may occur near the soil surface or more than 3 feet (1 m) under ground [70,89]. Fiveleaf yam tubers dug in Hawaii ranged from 1 to 6.7 inches (2.6-17 cm) long and were about equally wide. The largest tuber weighed 3 pounds (1,370 g) [70].

Water yam: Tubers produced by water yams are described as massive [21,41]. Water yam may begin producing tubers 14 to 40 days after planting (review by [14]), and tubers grow rapidly near the end of the growing season [46]. Although single tubers are most common, several are possible [21,46]. Tubers are branched, grow vertically, and may be deeply buried [21,46,93]. Water yam tubers weigh 22 pounds (10 kg) to more than 110 pounds (50 kg) [3,51]. A 180-pound (81 kg) water yam tuber was harvested from a garden in Trinidad [46].

Zanzibar yam: Irregular, rounded lobes are common on the generally globose tubers produced by Zanzibar yams. Generally tubers are shallowly buried (up to 6 inches (15 cm) deep) and may reach 16 inches (40 cm) in diameter [21,82].

Raunkiaer [63] **life form:**
Hemicryptophyte
Geophyte

SEASONAL DEVELOPMENT:
Phenological descriptions for yams not native to North America focus on bulbil, tuber, and vine production and growth, since fruit production is rare, and reproduction from seeds has not been observed. Short days generally stimulate yam tuber growth and development (review and original research by [68]). In the summer, flowers are occasionally produced. Often only male or female flowers are observed; rarely are both reported from the same area [21,51,94]. For additional information, see Regeneration processes and Vegetative regeneration.

Air yam: In Florida, the primary nonnative range for air yams, vines emerge from tubers or bulbils from March to May [53,66]. Emergence occurs in March or early April in southern Florida ([3,53], Brinkley and Line 1992 personal communications cited in [66]). Emergence often coincides with the start of the rainy season when daytime temperatures, humidity, and precipitation are high [3]. Based on experiments conducted on air yam bulbils collected in Florida, researchers constructed a map with the dates at which 50% of air yam bulbils would have likely sprouted. Dates were earlier in southern than northern portions of the state [59]. Vine growth is rapid throughout summer [3]. Air yam bulbil production may occur from June to early fall. Bulbils start falling from vines in late August and may fall until vines die back in late fall or early winter [3,40,53,66]. Flowers, when produced, occur in late summer or early fall [21]. Occasional fruit set has been reported by Hammer (1998 cited in [3]), but timing was not reported.

Chinese yam: Chinese yam vine growth begins in April in Illinois, and vines can reach 15 feet (4.6 m) by late summer [90]. Bulbils are produced from June to September or October in the upper Midwest [15,76]. Flowers are possible from June to August in Illinois [50], the Blue Ridge Province [92], and the Carolinas [61]. Flowers were observed in the field in southern Illinois from 25 June to 7 July [8]. Likely only male flowers were observed, since only one female flower has been reported in the United States [21].

Water yam: In Florida, water yam produces bulbils in late summer or early fall [40]. Flowers and fruits are possible in late summer and late fall, respectively [21].

Zanzibar yam: Bulbils are produced by Zanzibar yams in late summer or early fall in Florida [40]; plants are not known to flower in the United States [21].

REGENERATION PROCESSES:
Sexual reproduction by yams has not been observed in the United States, where regeneration occurs exclusively through sprouting from tubers and bulbils [21,69]. Tubers provide for perennial regeneration within established populations, and aerial bulbils allow for dissemination of propagules that can establish new populations [44]. Flowers are rare or restricted to a single sex in most US areas. Only male Chinese yam flowers were observed in the field in Illinois [8]. Only female flowers are reported for air yams, water yams, and fiveleaf yams in North America [21,70]. Only 3 flowering air yam specimens occur in the University of Florida herbarium (review by [66]). During 10 years of observations made near the University of Singapore, Zanzibar yam fruits were rare [62].

Vegetative regeneration: Yam populations increase and persist through asexual regeneration. Although bulbil production is the primary means of regeneration, stems touching the ground are capable of producing adventitious roots and tubers [46,51]. Sprouting is possible even from small, fragmented bulbils and can occur in nearly any environment. Sprouts can develop from 2-week old bulbils (review by [78]), and small pea-sized bulbils or bulbil fragments are capable of producing new vines (Line 1992 personal communication cited in [66], review by [78]). Bulbil sprouts have been observed in environments without light, water, or soil (review by [3], Brinkley and Gann-Matzen 1992 personal communications cited in [66]). Sprouts have also been reported from discarded tuber or bulbil scraps or peels (review by [13]). A 2-pound (1 kg) water yam tuber can be divided into 112 pieces, all of which are capable of sprouting [60].

Bulbil production: Based on information from Chinese yam and air yam populations, bulbil production is little affected by light availability but may be affected by plant age and predation. Observations and experiments in Senai, Japan, indicate that Chinese yam produces bulbils with and without light [56]. Bulbil production can be substantial from mature plants. A review reports that Chinese yam vines produce an average of 20 bulbils/year [78], but a study in southern Illinois reported much greater production [8]. Along a Drury Creek tributary in Illinois' Giant City State Park, 18 of 50 Chinese yam vines produced bulbils, and production averaged 14.8 bulbils for each 3 feet (1 m) of stem length [77]. In Miami's Kendall Indian Hammock Park, volunteers collected 1,500 lbs (680 kg) of air yam bulbils in just 3 hours [30]. The number of volunteers was not reported.

Studies as of 2009 highlighted only plant age and predation as limits to yam bulbil production, although other factors likely affect production. In southern Illinois, 2 Chinese yam populations were described. Type 1 populations were the least productive and averaged 19.69 bulbils/plant; type 2 populations produced an average of 33.4 bulbils for each 3 feet (1 m) of stem length. The researcher suggested that type 2 populations were likely older and established much earlier than type 1 populations. Type 2 populations often occurred at old homesteads and may have been planted in the early 1900s, whereas type 1 populations likely represented newer, satellite populations [8].

In southern Illinois, squirrels that consumed portions of Chinese yam bulbils rarely killed the bulbils [77]. Those bulbils retaining 33% of their original size were capable of sprouting [8], but vines from fragmented bulbils produced fewer bulbils in the next growing season than vines from entire bulbils. Although production differences were not significant, bulbils with 66% of their mass removed produced vines that averaged 11.6 bulbils/plant, and vines from unfragmented bulbils averaged 23.7 bulbils/plant [8].

Bulbil dispersal: Although yam bulbils are easily dislodged from the parent [45], primarily dispersed by gravity, and often fall near the parent plant, secondary dispersal by water, animals, or humans can increase dispersal distance. During field studies in southern Illinois, most Chinese yam bulbils fell within 33 feet (10 m) of the source population. In one population an average of 152 bulbils/m² was recovered within 33 feet (10 m) of the center of the source population, and just 3 bulbils/m² occurred 36 to 98 feet (11-30 m) from the population center. Among all populations visited, the furthest bulbil occurred 72 feet (22 m) from the center of the source population [8].

Reviews report that mature yam bulbils float in water [13,51], but studies conducted in Florida found that most air yam bulbils sank in water (Pemberton and Overholt unpublished data cited in [3]). A review by Coursey [13] notes that immature yam bulbils are denser than water. Bulbil maturity was not reported for the research conducted in Florida [3]. In Great Smoky Mountains National Park, 1-year-old Chinese yam bulbils did not float but did move downstream through rolling, traction, and saltation actions [54]. Researchers in southern Illinois found that secondary dispersal by water occurred along streams in the Drury Creek Watershed. From December 2001 to February 2003, about 300 bulbils/m³ were collected from traps near the downstream boundaries of 3 Chinese yam populations, where stand density ranged from 73 to 200 vines/ha. Most recovered bulbils were viable. Just 19 of 180 marked bulbils were recovered. The maximum dispersal distance was 677 feet (206 m), measured in February following a major rainstorm. Researchers suggested that reported dispersal distances and bulbil densities likely represented minimum values due to poor downstream trapping and poor recovery of marked bulbils; they speculated that Chinese yam bulbils could disperse great distances in water [76].

Evidence of secondary dispersal of yam bulbils by rodents is somewhat speculative, and rodents may reduce bulbil viability. A review reports that some Chinese yam bulbils are dispersed when rodents drop bulbil pieces or fail to retrieve caches [78]. During field experiments conducted in central Japan's Kyoto University Kamigamo Experimental Forest, researchers found that rodents transported Japanese yam (*Dioscorea japonica*) bulbils 0.7 to 24 feet (0.2-7.4 m) from their initial location. Transport distance averaged 3.6 feet (1.1 m), and just 3% of the transported bulbils sprouted [49]. Although this species does not occur in the United States, similar dispersal is possible in North America.

In Great Smoky Mountains National Park, humans have dispersed Chinese yam bulbils. Previous Park residents recalled playing with and throwing Chinese yam bulbils (Beck and Ownby 1995 personal communications cited in [54]). Secondary dispersal likely also occurred through human collection of the odd-looking bulbils and from inadvertent kicking of the bulbils downhill [54].

Bulbil banking: Studies designed to determine the maximum amount of time a yam bulbil can remain viable in the soil, beneath litter, or in water were generally lacking (as of 2009). Reviews report that bulbils remain viable after 1 to "several" years on the vine or in the soil [51,66,78]. In a field study conducted in Illinois, a much larger percentage of Chinese yam bulbils remained viable when buried beneath leaf litter (76% sprouting after 1 year) than when buried in soil (21.2%), submerged in water (21.6%), or lying on top of leaves (5.2%) [77].

Sprouting and establishment from bulbils: Sprouting of yam bulbils often occurs with warm temperatures and moisture, but internal dormancy and time of sprouting are variable. There are reports of sprouts from bulbils without light, moisture, or soil contact ([3], Brinkley and Gann-Matzen 1992 personal communications cited in [66]). When bulbils were collected in the fall in Japan, nearly 100% of air yam and fiveleaf yam bulbils sprouted at 77 °F (25 °C), and almost all water yam bulbils sprouted at 86 °F (30 °C) [57].

Air yam: Warm temperatures and moisture are conducive to sprouting of entire and fragmented air yam bulbils (review by [45]). Although moisture maintained in leaf litter is considered beneficial for sprouting [77], one study found that humidity had little effect on sprouting [59]. Bulbils may sprout within a few weeks of detachment from the vine or may remain seasonally dormant. Cool, dry conditions discourage sprouting. Optimal planting depths may be 3 to 4.7 inches (8-12 cm) [45]. In controlled experiments, researchers found that, while temperature and bulbil weight influenced the time required for air yam to produce sprouts, humidity, day length, and bulbil origin did not. Sprout development took longer at lower temperatures and for light-weight bulbils (<20 g) that were collected in November from Gainesville and Fort Pierce, Florida. Collected bulbils weighed 0.5 to 107 g and averaged 16 g. At the end of the experiment, which lasted 39 weeks, 100% of bulbils sprouted at 80 °F (27 °C), and 85% of bulbils sprouted at 60 °F (16 °C). The findings from the study were used together with weather data to predict the dates at which half of all air yam bulbils would have sprouted (see Seasonal Development) [59].

Chinese yam: During controlled studies and field observations on Chinese yam in the United States, a high percentage of bulbils sprouted. Sprouts have developed from 2-week-old bulbils [15], and burial was not required for sprouting [54]. In southern Illinois, all marked bulbils remaining in the study area sprouted and survived to the end of the growing season. In the greenhouse, 59 of 60 bulbils sprouted, and 58 of 59 sprouting bulbils produced tubers that averaged 3.9 g (dry weight) by 4 months of age. Fifty-five of the sprouts produced bulbils, and production averaged nearly 16 bulbils/vine. Generally, plant fitness was not significantly affected by the size of the bulbil or bulbil fragment that was planted (see Plant growth) [8].

Experiments conducted on Chinese yam bulbils collected in Sendai, Japan, showed that immature bulbils demonstrated "summer dormancy" and required light to sprout. Mature bulbils exhibited "winter dormancy" and required chilling to sprout. Immature bulbils kept in the dark failed to sprout and died at 41 °F (5 °C), but mature bulbils chilled at the same temperature for 84 or 127 days produced sprouts when moved to a dark, warm environment. The optimum temperature for breaking "winter dormancy" was 41 °F (5 °C) [56].

Water yam: Water yam bulbils generally sprout when temperatures are warm and humidity is high [46]. A 2-pound (1 kg) tuber can be divided into 112 pieces, all of which are capable of sprouting [60]. Moderate temperatures 77 to 86 °F (25-30 °C) are considered optimal for sprouting of water yam bulbils. Moist conditions or short-duration submersion may encourage rapid sprouting and growth (reviews by [14,46]). Cool, dry conditions can increase the time to sprout, and high temperatures (100 to 140 °F (40-60 °C)) can decrease the time to sprout by up to 2 weeks [46]. Submerging water yam bulbils in water for 4 hours reduced the time to sprouting by 21 days when compared to unsubmerged bulbils (review by [14]). Based on studies conducted on multiple water yam varieties, Martin [46] found that dormancy in bulbils may be internally controlled. Even when sprouting conditions are optimal, water yam bulbils may not sprout immediately.

Plant growth: Yam growth can be rapid (Copeland 1916 cited in [13]), and production of bulbils has been reported on 3-month-old air yam vines [45]. Growth rates and reproductive output can differ between newly planted bulbils and established plants growing from tubers [44].

Rate of growth: When yam vines begin to grow, the rate can be as high as 5.9 inches (15 cm)/day (Copeland 1916 cited in [13]). Growth rates generally decrease as the growing season progresses [8,52]. Air yam vines from bulbils planted in outdoor pots grew 1 inch (2.5 cm)/day in their first 81 days. After being cut to 2 inches (5 cm) tall, vines grew 0.9 inch (2.3 cm)/day [19]. The growth rate of Chinese yam populations in southern Illinois decreased exponentially as the growing season progressed [8]. In Great Smoky Mountains National Park, Chinese yam growth was rapid but decreased from April to August. From May to June, vines grew an average of 1.5 inches (3.9 cm)/day and from June to August grew 1.4 inches (3.5 cm)/day. Tuber growth averaged 0.2 cm/day [52]. In field experiments conducted in India, water yam grown from tuber pieces or bulbils initially grew 0.02 to 0.03 g/g/day. During the phase of initial tuber development, growth was a little more than 0.04 g/g/day. During the tuber maturation phase, growth was about 0.01 g/g/day [73].

Underground tubers were generally small in the 1st year of growth for air yams and water yams (review by [13]). Large tubers may not be produced until yams reach 3 years old (Bois 1927 cited in [13]).

Growth from bulbils and tubers compared: Vegetative and reproductive potential increased dramatically once Chinese yam vines were established. Growth and reproductive output of 1st-year Chinese yam vines from bulbils was much less than that of 2-year-old vines from tubers near Knoxville, Tennessee. Bulbil production on vines from tubers was about 3.5 times that of vines from bulbils. Bulbils produced 1 thin vine, while tubers produced an average of 4 robust vines. There were no flowers produced on vines from bulbils, but vines from tubers did flower [44].

Comparison of Chinese yam growth from bulbils and tubers [44]			
Chinese yam vine source and age	Average maximum vine length (cm)	Average bulbil production (no./m of vine length)	Average bulbil dry weight (g/bulbil)
From bulbils (1st year)	213a	23a	0.28a
From tubers (2nd year)	479b	84b	0.43b

Differences between means within a column followed by different letters are significant (P<0.05).

Sexual reproduction: Because synchronous flowering, fruit production, and successful seed set are extremely rare for yams, information about sexual reproduction is limited and generally involves aritificial conditions. Information on flower pollination, seed dispersal, seed banking, and germination is sparse.

Pollination: Air yam and water yam pollen is sticky and not wind dispersed ([87], Coursey 1967 cited in [3]). Although air yam flowers produce a pleasant odor thought to attract bees and other insects [45], documentation of insect pollination is lacking (review by [3]). It is also possible that male water yam flowers may fail to open or open so little that pollinators cannot access the flower [46].

Seed production: In studies conducted in India, either hand pollination or staggered planting to encourage synchronous flowering were required for seed set in water yams. Water yam fruit and seed set is rare in India, and water yams are generally considered a "sexually degenerate species". When hand pollinated, however, 2 water yam vines had 45% and 54% fruit set. Although fruits can produce up to 6 seeds, the average number of seeds/fruit was 2.7 and 3.2. When seedlings produced from these seeds were artificially pollinated, none developed seed. Researchers suggested that dry conditions may have affected production [2]. During other artificial pollination experiments, fruit set by water yams could be increased by increasing relative humidity and decreasing air temperatures [1]. In a field study, male and female water yams were planted at staggered dates to encourage synchronous flowering and possibly natural fruit set. Just one female clone set fruit and seed (2.02% and 0.92%, respectively). Researchers suggested that a lack of pollinators was the reason for poor fruit set. During careful observation, just 1 small unidentified crawling insect was observed [87]. The growth of water yam seedlings produced from seed in these experimental plants is discussed in Seedling growth below.

Seed dispersal: Yam seeds are winged and likely wind-dispersed [21,45,93].

Germination: A little over half (52.6%) of the water yam seeds collected from hand-pollinated plants germinated within 40 days of sowing in a greenhouse [87].

Seedling growth: Growth of water yam seedlings from seed produced on artificially pollinated plants was variable. When researchers transplanted water yam seedlings to a field site in India, seedlings had few or no branches, few leaves, and reduced height compared to clones of the same age that had "luxuriant vegetative growth". Seedlings produced few flowers and had low tuber yields [2]. In another study in India, however, seedlings from seed collected from experimental seed-producing water yams were considered "healthy and vigorous". Small tubers developed on seedlings that were only 3 months old, and by 8 months old, seedlings produced up to 1.1-pound (500 g) tubers [87].

SITE CHARACTERISTICS:
Yams often occur in mesic habitats in the United States. In Hawaii, air yam is common in the moist regions of shaded valleys and disturbed forests, and fiveleaf yam is common in windward mesic valleys [89]. Nonnative yams in Florida often occur on disturbed sites [94]. Water yam occurs near ponds, marshes, and drainage canals in Florida and Georgia [21]. Air yam and Zanzibar yam grow in hammocks and swamps in Florida [21], but the more common air yam also occupies thickets, disturbed woodlands, fence rows, and urban lots (review by [51]). Although Chinese yam occupies a much larger range than the other yams, its habitats are similar. Disturbed sites, old homesteads, roadsides, fence rows, thickets, alluvial woodlands, stream banks, and canals all provide Chinese yam habitat throughout its range [21,43,50,54,61].

Climate: For all but Chinese yam, sub-tropical to tropical climates are preferred, and growth is limited at temperatures below 68 °F (20 °C). Optimal growing conditions for tropical yams are temperatures of about 86 °F (30 °C) and growing season precipitation of about 59 inches (1,500 mm). Although high temperatures and drought conditions are tolerated by established yams, in the early growth stages, these conditions can cause mortality (review by [13]). Based on its US distribution, growth of air yams is best where average annual minimum temperatures do not fall below 10 °F (-12.2 °C). Freezing temperatures kill air yam bulbils [3]. Water yams require a 7- to 8-month growing period (review by [13]) and seldom persist in areas where cool temperatures and/or dry periods are common during the growing season. Long rainy periods in the growing season produce the best water yam growth, but "excessive" moisture is not tolerated [46].

Chinese yam is more frost tolerant than the other nonnative yams and occurs in climates ranging from tropical to northern temperate [8]. Chinese yam is hardy at least as far north as New York [55]. In southern Illinois, Chinese yam populations occur where the growing season averages 187 days, annual precipitation averages 43 inches (1,110 mm) [76], and summer temperatures average 76.5 °F (24.7 °C) [77].

Elevation: The widespread Chinese yam is common at elevations from sea level to 1,600 feet (500 m) in the United States [21], but in Great Smoky Mountains National Park, it is reported from elevations of 950 to 3,300 feet (290-1,000 m) [54]. Air yam occurs at about sea level in Florida [21] and from 20 to 2,200 feet (5-670 m) in Hawaii. Fiveleaf yam occurs from 375 to 1,070 feet (115-325 m) in Hawaii [89].

Soils: Yams grow best in "loose, deep, free-draining, fertile soil" (review by [13]). Water yam grows well in permeable clays and does poorly in sandy soils that lack moisture and nutrients [46]. In its native habitats, air yam occurs in loams or loose clays with good drainage (review by [3]). Increased organic matter promotes vine and tuber growth. High tuber yields require high potassium levels [45].

Chinese yam often occurs on silty loams in alluvial habitats (review by [78]). Although common in rich alluvial soils, Chinese yam also occurs in semi-xeric habitats with rocky soils [81]. Soil characteristics were described for Chinese yam populations in alluvial habitats in southern Illinois. Chinese yam occurred most often in silty loams. In 7 of the 9 populations evaluated, soil moisture was high, averaging 52%. Soils were low in potassium, high in nitrogen, phosphorus, and calcium, and very high in magnesium. Soil pH averaged 6.2 [8].

SUCCESSIONAL STATUS:
As of 2009, few successional studies in yam-invaded habitats were available. Yams are reported in full sun (reviews by [66,78]) and all but the deepest shade [81]. Disturbed sites are often occupied by yam vines [94], and vines also persist in wooded areas (Milne-Redhead 1975 cited in [82], Putz 1992 personal communication cited in [66], review by [51]), suggesting early- to late-seral communities are potential yam habitat. Though reported in full sun and full shade, several sources indicate that growth may be more rapid and plants may be more "vigorous" in canopy gaps (Gordon and Putz 1992 personal communications cited in [66], review by [51]).

Air yam grows rapidly in full sun (review by [66]). In Hawaii, air yam also occurs in shaded valleys [89], and in Florida it occurs in hammock and floodplain forests (review by [66]). Growth is considered most vigorous at the edges of hammocks and in gaps in the forest canopy (Gordon and Putz 1992 personal communications cited in [66]). Chinese yam similarly tolerates full sun to partial shade but may be most common at intermediate light levels (review by [78]). In southern Illinois, Chinese yam occurred in closed-canopy woodlands, where canopy cover averaged 68% and light intensity averaged 8% of full sunlight [8]. In Great Smoky Mountains National Park, Chinese yam occurred primarily beneath partial canopies (350-350,000 lux-candles) and was rare beneath closed canopies [54].

Disturbed sites often provide yam habitat [94]. Given their often robust tubers and high reproductive output [21,30,41,55,77], yams are able to regenerate soon after disturbances [34]. A review reports that Chinese yam establishment is often associated with disturbed sites, including building sites and roads [78]. A little over 2 years after Hurricane Andrew hit subtropical hardwood hammock forests in southern Florida, air yam occurred in 22% of sampled plots and averaged 2.8% cover. Cover of air yams was greater than that of any native vine species [34]. For additional information on yam regeneration following disturbances, see Impacts and Control.

FIRE EFFECTS AND MANAGEMENT

SPECIES: Dioscorea spp.

FIRE EFFECTS:

Immediate fire effect on plant: Yams are likely only top-killed by fire (review by [66]).

Postfire regeneration strategy [71]:
Geophyte, growing points deep in soil
Ground residual colonizer (on site, initial community)
Secondary colonizer (on- or off-site bulbil sources)

Fire adaptations: Although fire effects studies on yams were uncommon in the literature (as of 2009), there are reports of sprouting from tubers after fire (review by [66]) and other top-killing disturbances [19,27,52].

While detailed reports on the survival of bulbils following fire were lacking, there was general agreement that bulbil size and fire severity affected survival potential. On the ground, large bulbils were less susceptible to fire damage than small bulbils. High-severity fires were most likely to damage bulbils of any size ([26], reviews by [51,66]).

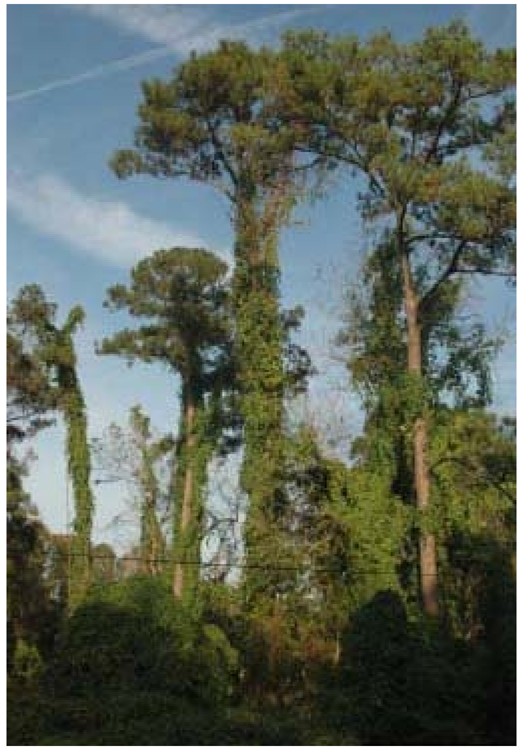
Surface fires that do not burn into the canopy may have little negative affect on bulbils still attached to the vine. Potential bulbil survival likely increases with increasing distance from the flames.

Plant response to fire: It is likely that the potential for postfire sprouting following high-severity fires increases with increasing tuber size and depth of burial, which vary for the nonnative yam species. Likewise the potential for survival of bulbils attached to the vine probably increases with increasing bulbil size and increasing vine height. Although directly related to vine length, actual vine height is also highly dependent on the height of the vegetation being used as a trellis. The information summarized below may help in predicting the likelihood of postfire sprouting and bulbil survival.

Summary of the appearance, size, depth, and/or height of yam tubers and bulbils				
Species	Tuber size	Depth of tuber	Bulbil size	Maximum vine length
Air yam (*D. bulbifera*)	5-10 cm in diameter; < 1 kg; when present, tuber is solitary [21,66,89,93]	Just below the soil surface, if present [21]	≥5 cm in diameter and 13 cm long; smooth [3,12,21,47]	≤30 m [21,89]
Chinese yam (*D. polystachya*)	Vertical tubers from long stalks; can weigh 3.5-4.5 kg; 1 to many tubers [21,24,55]	≤1 m below ground [24,55]	≤3 cm long and 2 cm in diameter; round and warty [21,47,61,69]	≥5 m [24,72].
Fiveleaf yam (*D. pentaphylla*)	2.5-17 cm long and equally as wide; large tubers may be 1.4 kg; tubers solitary [70]	Near the soil surface to ≥1 m under ground [70,89]	About 1 cm in diameter; horseshoe shaped [89]	≥10 m long [70,89]
Water yam (*D. alata*)	Branched, vertical tubers 10 to ≥50 kg; 1 to several tubers [3,21,46,93]	May be buried "deeply" [46]	≤10 cm long and 4 cm in diameter; rough with fleshy protrusions [12,21]	≥30 m [21,46,94]
Zanzibar yam (*D. sansibarensis*)	Irregularly lobed tuber; ≤40 cm in diameter [21,82]	≤15 cm [21,82]	≤6 cm in diameter; smooth [21,51,82]	≥25 m [82]

Because few fire studies are reported from habitats invaded by yams, the effects of fire season, fire severity, and fire frequency on postfire recovery and establishment of yams are largely unknown (as of 2009). According to the supervisory forester for Great Smoky Mountain National Park, the abundance of Chinese yam was reduced by a fall wildfire in the area (Johnson 2002 personal communication cited in [78]). Neither pre- or postfire abundance were reported. Air yam abundance increased following 3 years of annual fires in the sandhill uplands of the Janet Butterfield Brooks Preserve in Florida. Fires occurred in March, before the emergence of air yam vines. Although fire effects on air yam were not the focus of this study, researchers noted that fires significantly reduced the density of skunkvine (*Paederia foetida*) and "actually released air yam and exacerbated that problem" [28].

FUELS AND FIRE REGIMES:
Yams occur in a variety of habitats (see Habitat Types and Plant Communities). Altered fire frequency, severity, or behavior in habitats invaded by yams was not described in the available literature (2009). However, yams typically grow into tree canopies ([30], reviews by [51,66,78]). In areas where surface fires would have been common in the absence of yam vines, yam ladder fuels could encourage crown fires. Many field observations indicate that the weight of yams can break stems of supporting vegetation and cause mortality of trees and shrubs (reviews by [51,66,78]). Increased dead material in areas where yams have killed associated vegetation could increase fire frequency, intensity, or severity. Although these changes in fire regimes and behavior are speculative, they highlight the need for more information about how yams may affect the fire ecology of invaded habitats. For more information on the aggressive growth of yams and its effect on associated vegetation, see Impacts. See the Fire Regime Table for more information on fire regimes in vegetation communities in which yams may occur.



Water yam (*D. alata*) climbing slash or pond pine (*Pinus elliottii* or *P. serotina*) south of Tallahassee, FL. Photo © Chris Evans, River to River CWMA, Bugwood.org

FIRE MANAGEMENT CONSIDERATIONS:
Preventing postfire establishment and spread: Preventing invasive plants from establishing in weed-free burned areas is the most effective and least costly management method. Research has shown that vegetative and reproductive growth increased substantially once Chinese yam populations were established and growing from tubers [44]. Discouraging establishment and controlling yam populations soon after bulbils sprout can increase the chance of successful control. This may be accomplished through early detection and eradication, careful monitoring and follow-up, and limiting dispersal of yam bulbils into burned areas.

General recommendations for preventing postfire establishment and spread of invasive plants include:

- Incorporate cost of weed prevention and management into fire rehabilitation plans
- Acquire restoration funding
- Include weed prevention education in fire training
- Minimize soil disturbance and vegetation removal during fire suppression and rehabilitation activities
- Minimize the use of retardants that may alter soil nutrient availability, such as those containing nitrogen and phosphorus
- Avoid areas dominated by high priority invasive plants when locating firelines, monitoring camps, staging areas, and helibases

- Clean equipment and vehicles prior to entering burned areas
- Regulate or prevent human and livestock entry into burned areas until desirable site vegetation has recovered sufficiently to resist invasion by undesirable vegetation
- Monitor burned areas and areas of significant disturbance or traffic from management activity
- Detect weeds early and eradicate before vegetative spread and/or seed dispersal
- Eradicate small patches and contain or control large infestations within or adjacent to the burned area
- Reestablish vegetation on bare ground as soon as possible
- Avoid use of fertilizers in postfire rehabilitation and restoration
- Use only certified weed-free seed mixes when revegetation is necessary

For more detailed information on these topics see the following publications: [4,9,25,84].

Use of prescribed fire as a control agent: While fire alone is unlikely to control yam populations, it may improve the effectiveness of other control methods. Fire has been recommended to reduce the chance of bulbil survival ([77], review by [51]) and to increase the visibility of bulbils to be collected (Gordon 1992 personal communication cited in [66]). After a year beneath leaf litter, Chinese yam bulbils remained highly viable (see Bulbil banking). Periodic fires that reduce litter cover could decrease the potential for regeneration from bulbils [77].

Burning of collected yam bulbils has also been recommended, since on-site destruction of bulbils should decrease the potential for dispersal and spread (review by [51]). Fire may also be useful in disposing of cut vines, especially important because at least one yam species, Zanzibar yam, developed bulbils on stems cut 1 week earlier [62]. Yam bulbils can survive fire [26], so fire must be severe enough to cause vine and bulbil mortality.

Altered fuel characteristics: Because yam vines use other vegetation for support, they can damage or kill this vegetation as well as provide ladder fuels into the canopy. This topic is discussed in Fuels and Fire Regimes.

MANAGEMENT CONSIDERATIONS

SPECIES: Dioscorea spp.

- IMPORTANCE TO WILDLIFE AND LIVESTOCK
- OTHER USES
- IMPACTS AND CONTROL

IMPORTANCE TO WILDLIFE AND LIVESTOCK:
Several sources report evidence of small mammals feeding on yam bulbils ([8,77], review by [78]), but little to no predation of air yam bulbils was reported in Florida (Brinkley and Putz 1992 personal communications cited in [66]).

Palatability and/or nutritional value: Chemical composition and nutritional value of yams is reported in the following references: [13,45,45]. Although air yams have moderate protein levels, protein quality is generally low [45].

OTHER USES:
Yams are well known as an edible crop and as an attractive ornamental ([21,45], review by [51]), but yams also have many medicinal and other uses (reviews by [3,5,78]).

Dietary and social importance: Not all nonnative yam tubers are edible or palatable, yet some are of such dietary importance that they have achieved social and religious importance as well. Unpalatable or toxic forms of yams are used as fish poison and are sometimes planted within edible yam crops to discourage thieving [3,13,45].

Tubers and bulbils produced by Zanzibar yam are toxic [21]. According to the Center for Aquatic and Invasive Plants, nonnative yams are very toxic and should not be consumed. However, other sources indicate that air yam bulbils are edible when toxins are removed through proper preparation [13,17,21]. In Hawaii, air yam tubers are only eaten in times of famine [89]. Water yams are one of the most commonly cultivated yam crops. Both water yam tubers and bulbils are edible, but tubers are considered more palatable [21,45]. In Papua New Guinea, water yam cultivation holds religious and psychological importance for some. Water yam gardens are tended strictly by males. Gardens that produce giant plants and tubers are a source of male pride [46].

Medicinal importance: Yam leaves and tubers are used to treat a variety of ailments. The leaves of air yam, Chinese yam, and water yam are used as a poultice for pimples and tumors and in bath water to soothe skin irritations and stings (reviews by [5,78]). Air yam is also used to treat sores, swelling, hemorrhoids, sore throats, and diabetes. In northern Bangladesh, air yams are used to treat leprosy and tumors. Researchers have identified antitumor properties in air yams [3]. Chinese yams are used to treat poor appetite, diarrhea, asthma, coughs, frequent urination, diabetes, and emotional instability. Chinese yam tubers contain allantoin, which speeds the healing process. Diosgenin, which is used to manufacture progesterone and other steroids, is also produced in Chinese yam tubers (review by [78]).

IMPACTS AND CONTROL:
Yams grow rapidly, and the spread of yam populations can be extensive in a short time. Dense shading and sometimes eventual mortality of low-growing herbaceous vegetation, shrubs, and tree seedlings and saplings are the most commonly described impacts of yam populations.

Throughout their nonnative range, yams are often identified as aggressive, problematic species. As of 2005, Florida's Exotic Pest Plant Council ranked water yam and air yam Category 1 invasives: species that are "altering native plant communities by displacing native species and changing community structures or ecological functions" [22]. In 2001, the USDA Forest Service reported that air yam, Chinese yam, and water yam "pose a demonstrable threat to the integrity of the natural plant communities" in the Southern Region. The use of these yams is prohibited on National Forest Service lands, and they receive high priority for control funding [83]. Several eastern states consider Chinese yam a "highly invasive" species [88] that poses a "severe threat" to native plant communities [6,37].

Spread: Increases in Chinese yam population size and range are documented for southern Illinois and Great Smoky Mountains National Park. After conducting a survey of Chinese yam's distribution, habitats, and population biology, the Illinois Department of Natural Resources reported that Chinese yam "appears to be one of the fastest spreading exotics in southern Illinois" [90]. In southern Illinois, Chinese yam has spread from homesteads where it was planted as early as 1900. As of 2001, populations were "flourishing in pristine environments" [8]. As of 2003, Chinese yam was reported in "highly prized" natural areas of southern Illinois that included the Lusk Creek Wilderness Area and Giant City State Park (Gillespie 2003 cited in [76]). During surveys conducted in 1994 and 1995 in Great Smoky Mountains National Park, Chinese yam occurred at 77 of 78 visited sites. At 64% of visited sites, populations were expanding. In 69% of visited sites, the density of Chinese yam leaves was classified as moderate or heavy. Researchers found that the estimated area occupied by Chinese yam in 1995 was more than twice that occupied in 1988 [54].

Impacts: Climbing habits, rapid growth rates, and typically high levels of asexual regeneration of yams can negatively impact associated vegetation. Restricted woody regeneration and decreased species richness are reported in habitats invaded by air yam and Chinese yam.

Air yam: Dense leafy air yam vines have been referred to as "aggressive", "dangerous" (review by [3]), and "impenetrable" [55]. Reviews report that air yam can grow up to 8 inches (20 cm)/day and smother tree seedlings and understory vegetation (review by [51], Line 1992 personal communication cited in [66]). Hammer [30] suggests that air yam "is, indeed, one of the most aggressive weeds ever introduced" and is capable of growing over an entire tree canopy in a single season. Nehring, the first known grower of air yam in Florida, suggested that air yam's aggressive growth and regeneration was second only to that of kudzu (*Pueraria montana* var. *lobata*) [55].

Research conducted before and after Hurricane Andrew damaged subtropical hardwood hammock forests in southern Florida indicated that the presence of air yam may prevent normal regeneration of canopy vegetation. After the hurricane, the cover of nonnative vines was much greater on untreated than treated sites, where all nonnative species are intensely managed for their reduction. Two years following the hurricane, the cover of air yam was greater than that of any native vine species on untreated sites. Two to five years after the hurricane, native tree, shrub, and herb seedling recruitment was much lower on untreated than treated sites. During the same time period, the number of new native tree, shrub, and herb stems (>0.75-inch (1.9 cm) DBH) was also much lower on untreated than treated sites. Researchers proposed that nonnative vines could negatively impact forest regeneration [34]. Other researchers studying vegetation recovery in Florida hammocks following Hurricane Andrew similarly proposed that air yam limited the recovery of canopy vegetation, maintained canopy gaps, and reduced the resiliency of hammock vegetation [27].

Chinese yam: A review reports that Chinese yam climbs over other vegetation, forming a blanket of leaves that shade other plants and may bend or break branches (review by [78]). This smothering effect is also reported in the Oak Ridge National Environmental Research Park in Tennessee, where Chinese yam often forms large clumps that completely cover native vegetation [18]. A land manager for Ohio's Edge of Appalachia Preserve reported that Chinese yam growth completely covered shrubs and resulted in some shrub mortality (Whan 2002 personal communication cited in [78]).

Studies in southern Illinois documented negative impacts on native species in areas with Chinese yam. One researcher noted that Chinese yam could reach 13 feet (4 m) long by early June in an area where plant species richness was significantly lower (P=0.0001) in plots with Chinese yam than in plots without Chinese yam. Both density and cover of native species were lower in plots with Chinese yam [8]. Along a tributary in Illinois' Giant City State Park, species richness was not different between plots with and without Chinese yam, but percent cover of native species was significantly higher in uninvaded (91.2%) than invaded (70.3%) plots [77].

Control: Several sources indicate that control of yams is improved if populations are treated soon after establishment. Once yams are established and growing from tubers, vegetative and reproductive growth increase substantially ([8,44], reviews by [66,78]) and control becomes more difficult, more expensive, and is more likely to disrupt the native plant community. Monitoring near established populations could allow for earlier control of satellite populations (review by [66]).

Control method did not largely affect the abundance of Chinese yam in Great Smoky Mountains National Park. Mechanical (hand weeding, clipping) and chemical (herbicide) treatments applied soon after emergence and at flowering did not result in significant reductions in Chinese yam cover, density, stem height, or leaf production. However, in the next year, other vegetation was establishing in areas where Chinese yam had been treated [52]. If control is successful, the potential for other invasive species to fill the void left by yam removal must be considered [10]. Control is most effective when it employs a long-term, ecosystem-wide strategy rather than a tactical approach focused on battling individual invaders [42].

Fire: For information on the use of prescribed fire to control this species, see Fire Management Considerations.

Prevention: It is commonly argued that the most cost-efficient and effective method of managing invasive species is to prevent their establishment and spread by maintaining "healthy" natural communities [42,67] and by monitoring several times each year [35]. Maintaining the integrity of the native plant community and mitigating the factors that enhance ecosystem invasibility are likely to be more effective than managing solely to control the invader [32].

Education and legislation can also be used to prevent the establishment and spread of yams. A review suggests educating the public about the proper disposal of bulbils and underground tubers to reduce inadvertent spread [66]. The state of Florida has laws against the introduction, possession, and moving of air yam vines [3]; however, as of 1998, air yam seedlings were available from California mail-order catalogs [30]. As of 2006, Chinese yam was also still available for commercial sale [44].

Weed prevention and control can be incorporated into many types of management plans, including those for logging and site preparation, grazing allotments, recreation management, research projects, road building and maintenance, and fire management [84]. In greenhouse studies, Chinese yam growth and reproductive output were increased by fertilization [8], suggesting that fertilizers should be not be used in or around established populations and perhaps populations in fertile areas should receive treatment priority. See the Guide to noxious weed prevention practices [84] for specific guidelines in preventing the spread of weed seeds and propagules under different management conditions.

Physical or mechanical control: Collecting bulbils, hand-pulling, and digging are potentially useful control methods for small, newly established yam populations. Repeated cutting may provide control of larger, established populations. Proper disposal or destruction of bulbils and cut stems is important. When Zanzibar yam stems were left in a laboratory, they began producing bulbils within a week of detachment, although bulbil production and size were less than those of intact stems [62].

Although labor intensive, manual removal of tubers and bulbils can control yams when the entire belowground structure is removed (reviews by [66,78]). Hand-pulling has been effective on a small air yam population in Everglades National Park. Volunteers and park staff have logged 588 hours over 8 years but believe the population will be eradicated soon, though vigilant monitoring will continue (review by [3]).

Because yams sprout soon after cutting, repeated mowing or cutting are required to deplete tuber stores (review by [78]). Mowing or cutting before bulbil development is recommended ([69], Gann-Matzen and Line 1992 personal communications cited in [66]). When air yams were grown from bulbils in pots kept outdoors, vine growth averaged 1 inch (2.5 cm)/day for the first 81 days. After cutting stems to a 2-inch (5 cm) height, vine growth rates averaged 0.9 inch (2.3 cm)/day [19]. For the results of herbicide treatments on cut stems, see Integrated management.

Biological control: Currently (2009) there have been no insects or pathogens released to control nonnative yam species. Researchers have identified potential agents in Ghana, Malaysia, and Nepal, but no releases have occurred ([20], review by [3]). Presence of closely related native yam species in the eastern United States suggests that development of a biological control program requires "great caution" (review by [66])

Biological control of invasive species has a long history that indicates many factors must be considered before using biological controls. Refer to these sources: [86,91] and the Weed control methods handbook [79] for background information and important considerations for developing and implementing biological control programs.

Chemical control: Several sources suggest that timing of herbicide applications is important to successful yam control. Recommendations regarding effective timing vary, although most suggest growing season treatments are most effective [3,52,81]. Applying herbicides to cut yam stems may increase effectiveness (review by [51]).

Herbicide treatments made soon after yam emergence are generally considered ineffective, since vines often recover by the end of the growing season (reviews by [3,78]). Herbicides applied to Chinese yam "later" in the season may be translocated to tubers and may result in increased mortality (Johnson 2002 personal communication cited in [78]). Others reported that herbicides were most effective on Chinese yam when they were applied at full leaf expansion but prior to the maturity of bulbils [81]. In field studies, Chinese yam was controlled better with a single herbicide application at the time of flowering than 2 herbicide applications, one soon after emergence and another at flowering [52]. For air yams, herbicide treatments applied when vines were developing bulbils were considered most effective [3]. In Florida hammocks, several herbicide treatments were compared on air yam populations. In all treated areas, vines emerged in the year following treatments, although stem number and height were often reduced. Herbicide treatments just before or shortly after bulbil development may reduce subsequent bulbil production [53].

Herbicides are effective in gaining initial control of a new invasion or a severe infestation, but they are rarely a complete or long-term solution to weed management [11]. See the Weed control methods handbook [79] for considerations on the use of herbicides in natural areas and detailed information on specific chemicals. Guidelines for the use of herbicides to control yams are provided by Langeland and Stocker [40].

Integrated management: Sources often recommend collecting and removing yam bulbils and cutting yam vines prior to herbicide applications for improved effectiveness and coverage ([16,40], review by [66]). When air yams were grown from bulbils and kept outdoors in pots, vine growth averaged 1 inch (2.5 cm)/day for the first 81 days. When stems cut to a 2-inch (5 cm) height were treated with herbicides, growth rates were reduced by 34% to 100%, depending on type of herbicide used. Cutting alone only reduced growth rates by about 10% [19].

In southern Florida hammocks, herbicide treatments in areas where air yam was hand pulled were no more effective than hand pulling alone. However, treated and control sites were impacted by Hurricane Andrew soon after treatments. Control measures appeared to encourage sprouting from bulbils in the litter layer, and 3 years after treatments and the hurricane, air yam density in treated plots was 2 times that before the treatments and the hurricane. However, recovery of air yam was slower on treated than control plots [27].

APPENDIX: FIRE REGIME TABLE

SPECIES: Dioscorea spp.

The following table provides fire regime information that may be relevant to yam habitats. Follow the links in the table to documents that provide more detailed information on these fire regimes.

Fire regime information on vegetation communities in which yams may occur. This information is taken from the LANDFIRE Rapid Assessment Vegetation Models [39], which were developed by local experts using available literature, local data, and/or expert opinion. This table summarizes fire regime characteristics for each plant community listed. The PDF file linked from each plant community name describes the model and synthesizes the knowledge available on vegetation composition, structure, and dynamics in that community. Cells are blank where information is not available in the Rapid Assessment Vegetation Model.

Great Lakes	Northeast	South-central US
Southern Appalachians	Southeast	

Great Lakes

- Great Lakes Woodland
- Great Lakes Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Great Lakes Woodland					
Northern oak savanna	Replacement	4%	110	50	500
	Mixed	9%	50	15	150
	Surface or low	87%	5	1	20
Great Lakes Forested					
Great Lakes floodplain forest	Mixed	7%	833		
	Surface or low	93%	61		
Maple-basswood	Replacement	33%	≥1,000		
	Surface or low	67%	500		
Maple-basswood mesic hardwood forest					

(Great Lakes)	Replacement	100%	>1,000	≥1,000	>1,000
Maple-basswood-oak-aspen	Replacement	4%	769		
	Mixed	7%	476		
	Surface or low	89%	35		
Oak-hickory	Replacement	13%	66	1	
	Mixed	11%	77	5	
	Surface or low	76%	11	2	25

Northeast

- Northeast Woodland
- Northeast Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Northeast Woodland					
Eastern woodland mosaic	Replacement	2%	200	100	300
	Mixed	9%	40	20	60
	Surface or low	89%	4	1	7
Northeast Forested					
Northern hardwoods (Northeast)	Replacement	39%	≥1,000		
	Mixed	61%	650		
Eastern white pine-northern hardwoods	Replacement	72%	475		
	Surface or low	28%	>1,000		
Northern hardwoods-eastern hemlock	Replacement	50%	≥1,000		
	Surface or low	50%	≥1,000		
Northern hardwoods-spruce	Replacement	100%	≥1,000	400	>1,000
Appalachian oak forest (dry-mesic)	Replacement	2%	625	500	≥1,000
	Mixed	6%	250	200	500
	Surface or low	92%	15	7	26

South-central US

- South-central US Grassland
- South-central US Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
South-central US Grassland					
Oak savanna	Replacement	3%	100	5	110
	Mixed	5%	60	5	250
	Surface or low	93%	3	1	4
South-central US Forested					
Interior Highlands dry-mesic forest and woodland	Replacement	7%	250	50	300
	Mixed	18%	90	20	150
	Surface or low	75%	22	5	35
Southern floodplain	Replacement	42%	140		
	Surface or low	58%	100		

Southern Appalachians

- Southern Appalachians Grassland
- Southern Appalachians Woodland
- Southern Appalachians Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Southern Appalachians Grassland					
Eastern prairie-woodland mosaic	Replacement	50%	10		
	Mixed	1%	900		
	Surface or low	50%	10		
Southern Appalachians Woodland					
Appalachian shortleaf pine	Replacement	4%	125		
	Mixed	4%	155		
	Surface or low	92%	6		
Southern Appalachians Forested					

Bottomland hardwood forest	Replacement	25%	435	200	≥1,000
	Mixed	24%	455	150	500
	Surface or low	51%	210	50	250
Mixed mesophytic hardwood	Replacement	11%	665		
	Mixed	10%	715		
	Surface or low	79%	90		
Eastern hemlock-eastern white pine-hardwood	Replacement	17%	≥1,000	500	>1,000
	Surface or low	83%	210	100	>1,000
Appalachian oak forest (dry-mesic)	Replacement	6%	220		
	Mixed	15%	90		
	Surface or low	79%	17		

Southeast

- Southeast Woodland
- Southeast Forested

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)
Southeast Woodland					
Longleaf pine/bluestem	Replacement	3%	130		
	Surface or low	97%	4	1	5
Longleaf pine (mesic uplands)	Replacement	3%	110	40	200
	Surface or low	97%	3	1	5
Southeast Forested					
Coastal Plain pine-oak-hickory	Replacement	4%	200		
	Mixed	7%	100		
	Surface or low	89%	8		
Loess bluff and plain forest	Replacement	7%	476		
	Mixed	9%	385		
	Surface or low	85%	39		
Southern floodplain	Replacement	7%	900		
	Surface or	93%	63		

	low				

*Fire Severities—
Replacement: Any fire that causes greater than 75% top removal of a vegetation-fuel type, resulting in general replacement of existing vegetation; may or may not cause a lethal effect on the plants.
Mixed: Any fire burning more than 5% of an area that does not qualify as a replacement, surface, or low-severity fire; includes mosaic and other fires that are intermediate in effects.
Surface or low: Any fire that causes less than 25% upper layer replacement and/or removal in a vegetation-fuel class but burns 5% or more of the area [31,38].

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