Schinus terebinthifolius

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Photo by Shirley Denton, Atlas of Florida Vascular Plants

AUTHORSHIP AND CITATION:
Meyer, Rachelle. 2011. Schinus terebinthifolius. 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/ [2011, February 25].

FEIS ABBREVIATION:
SCHTER

NRCS PLANT CODE [190]:
SCTE

COMMON NAMES:
Brazilian pepper
Brazilian peppertree
Christmas berry
Florida holly
aroeira

TAXONOMY:
The scientific name for Brazilian pepper is *Schinus terebinthifolius* Raddi (Anacardiaceae) [12,94,95,190]. The following varieties are recognized:

*Schinus terebinthifolius*var. *terebinthifolius* Raddi [12,95]
Schinus terebinthifolius var. *raddianus* Engl. [12,94,95]
Schinus terebinthifolius var. *acutifolius* Engl
Schinus terebinthifolius var. *pohlianus* Engl. [12]
Schinus terebinthifolius var. *rhoifolius*Engl. [12,94]

SYNONYMS:
None

LIFE FORM:
Shrub-tree

DISTRIBUTION AND OCCURRENCE

SPECIES: Schinus terebinthifolius

- GENERAL DISTRIBUTION
- HABITAT TYPES AND PLANT COMMUNITIES

Photo by Vic Ramey, University of Florida, IFAS-Center for Aquatic and Invasive Plants

GENERAL DISTRIBUTION:
A native to Brazil, Argentina, and Paraguay [24,56,70], Brazilian pepper has established in many areas outside its native range, such as Australia [13,199], South Africa [83,137,199], Mediterranean Europe, southern Asia, and the United States [137,199], including Puerto Rico [56,188]. Although Brazilian pepper was introduced to the United States as an ornamental from the mid- to late 1800s [7,56,119,137,211], it did not establish outside of cultivation in Florida until the 1950s [3,56]. Brazilian pepper occurs throughout southern and central Florida, including islands off

its coast [77,103,137]. According to unpublished surveys performed in the mid-1990s, over 740,000 acres (300,000 ha) in Florida are inhabited by Brazilian pepper [59], as are 91% of preserves in southern Florida [17]. In Texas, sporadic occurrences have been reported since the 1950s in Cameron and Hidalgo Counties. More recently, establishment of Brazilian pepper in Texas has been reported in Aransas [113] and Galveston counties [73]. Brazilian pepper was introduced to Hawaii as an ornamental before 1911 [33,191]. By the late 1940s it was spreading and considered a range pest [214]. Brazilian pepper occurs on all of the major Hawaiian Islands [173,214], with moderate to dense stands covering an estimated 120,000 acres (50,000 ha) as of 1991, according to weed managers [214]. In the early 1990s, Brazilian pepper began establishing outside cultivation in southern California [2,39,47,154], and it may occur outside cultivation in central California [47,154]. Occurrence of Brazilian pepper in southern Arizona has been noted [56,109,137], but no further details are available. Plants database [190] provides a distributional map of Brazilian pepper that does not include Arizona.

Schinus terebinthifolius var. *raddianus* is reported throughout Brazilian pepper's United States distribution [95] and an occurrence of *S. terebinthifolius* var. *rhoifolis* was reported in Texas [113]. Barkley's [12] 1944 investigation of the *Schinus* genus reported cultivation of *S. terebinthifolius* var. *raddianus* in Florida, *S. terebinthifolius* var. *terebinthifolius* in California and Florida, and *S. terebinthifolius* var. *acutifolius* in California. Based on genetic analysis there are 2 haplotypes in Florida that hybridize extensively [203,204]. One is more common in southeastern Florida, and the other is more common in northwestern Florida [203]. The haplotypes suggest Brazilian pepper was introduced to Florida from 2 distinct source populations [204]. An unpublished report speculates that *S. terebinthifolius* var. *terebinthifolius* and *S. terebinthifolius* var. *raddianus* may hybridize in Florida (Campbell and others 1980 cited in [93]). Given the lack of distinction between varieties in the literature and the uncertainty of their relative importance across Brazilian pepper's range, variety will not be addressed further in this review.

HABITAT TYPES AND PLANT COMMUNITIES:

Although Brazilian pepper can establish in relatively undisturbed plant communities [3] and on undisturbed substrates [132], it is most often found in areas with some level of anthropogenic disturbance [43,56,64,65,73,101,201,214]. In these areas Brazilian pepper often forms dense thickets (e.g., see Plant architecture and stand structure) that include few other species [51,56,65,101,195]. For example, only 7 species were observed in six 1,100-ft² (100 m²) plots in a Brazilian pepper-dominated forest on abandoned farmland near Everglades National Park [195].

Species such as wax myrtle (*Morella cerifera*), silverling (*Baccharis glomeruliflora*), and grape (*Vitis* spp.) often cooccur with Brazilian pepper on abandoned farmland [3,51,56,101,132], roadsides [3,56], powerline rights-of-way, canal banks [56], levees, and berms [3]. Brazilian pepper is often associated with other nonnative species such as guava (*Psidium guajava*), Australian pine (*Casuarina equisetifolia*), and melaleuca (*Melaleuca quinquenervia*) on roadways [3,56], abandoned farmland [3,56,65,101,132], pastures [65,214], and areas with altered substrates [64,103] in Florida and Hawaii. Species that have been reported on abandoned farmland sites in southern Florida where Brazilian pepper reaches high cover (>75%) include Guianese colicwood (*Myrsine floridana*) [101,195], groundsel-tree (*Baccharis halimifolia*), and Virginia creeper (*Parthenocissus quinquefolia*) [101]. In Little Manatee River State Park in Florida, Brazilian pepper, groundsel-tree, common elderberry (*Sambucus nigra* ssp. *canadensis*), and dogfennel (*Eupatorium capillifolium*) dominated an area along a road near recently abandoned crop land [140]. Herbaceous species that may inhabit Brazilian pepper stands in Florida include blue mistflower (*Conoclinium coelestinum*), Florida Keys thoroughwort (*Koanophyllon villosum*), and ferns such as leatherfern (*Acrostichum* spp.) and Kunth's maiden fern (*Thelypteris kunthii*) [3,101,132,181].

In Florida, Brazilian pepper occurs in several plant community types including South Florida slash pine (*Pinus elliottii* var. *densa*) [4,51,118,197], hardwood hammock [3,34,140], cypress [131,197], and mangrove [3,68,69,77,162,198] forests, shrublands [3,62], and seasonally wet grassland and marsh communities [162,196,197]. Brazilian pepper frequently occurs with wax myrtle [3,51,56,101,129,196], saw-palmetto (*Serenoa repens*) [3,140,152], redbay (*Persea borbonia*), dahoon (*Ilex cassine*), cabbage palmetto (*Sabal palmetto*), and Florida poisontree (*Metopium toxiferum*) [3,51,56,101,181,209,212].

Brazilian pepper occurrence in South Florida slash pine forests is well documented. Brazilian pepper, wax myrtle, groundsel-tree, Florida poisontree, and Florida clover ash (*Tetrazygia bicolor*) formed a subcanopy under an open overstory of South Florida slash pine in the Everglades [51]. The understory on a site dominated by Brazilian pepper

with scattered south Florida slash pine included Guianese colicwood, Brazilian pepper, wild guava (*Guettarda scabra*), pineland fern (*Anemia adiantifolia*), and pineland milkberry (*Chiococca parvifolia*) [118]. In 1969, Brazilian pepper seedlings were present in a South Florida slash pineland that had not burned since 1951 [4]. Brazilian pepper occurred in 3% of 104 plots in a pine rockland in southern Florida comprised of South Florida slash pine, saw-palmetto (*Serenoa repens*), and perennial grasses and herbs [152].

Brazilian pepper occurs in several hardwood forest types in southern Florida. Wax myrtle and Brazilian pepper dominated forests on tree islands in the Everglades that were infrequently flooded [129]. Species associated with Brazilian pepper in hardwood forests include gumbo limbo (*Bursera simaruba*), tietongue (*Coccoloba diversifolia*) [3,34,201], sugarberry [116,201], laurel oak (*Quercus laurifolia*) [140,166], cabbage palmetto [131,166], and baldcypress (*Taxodium distichum*) [131,197]. On a site with baldcyprees, melaleuca, Peruvian primrose-willow (*Ludwigia peruviana*), and Guianese colicwood, Brazilian pepper occurred only as an epiphyte above high water on baldcypress knees and buttresses [131]. Brazilian pepper grew on root mounds of windthrown baldcypress trees on a site that also included icaco coco plum (*Chrysobalanus icaco*), toothed midsorus fern (*Blechnum serrulatum*), and leatherfern [3]. Common species of pond and river margin communities of southern Florida were Brazilian pepper, buttonbush (*Cephalanthus occidentalis*), Carolina ash (*Fraxinus caroliniana*), water hickory (*Carya aquatica*), sugarberry, redbay, and Virginia chain-fern (*Woodwardia virginica*) [116]. In the Indian River Lagoon of Florida's east coast, Brazilian pepper occurred in an area with a scattered canopy of cabbage palm (*Sabal palmetto*) and a graminoid layer of sand cordgrass (*Spartina bakeri*) and other grasses and forbs [162].

Brazilian pepper occupies mangrove swamps dominated by black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*), or red mangrove (*Rhizophora mangle*) [3,68,69,77]. In the Indian River Lagoon of Florida's east coast, Brazilian pepper occurred in mixed mangrove communities [162]. Saltgrass (*Distichlis spicata*) [3,68], cordgrass (*Spartina* spp.), melaleuca, and button mangrove (*Conocarpus erectus*) may also be present in these communities [3].

Brazilian pepper also inhabits shrub communities in Florida. Along the Atlantic Coast, Brazilian pepper occurred in scrub communities commonly comprised of saw-palmetto, sand live oak, cabbage palmetto, myrtle oak (*Quercus myrtifolia*), yaupon (*Ilex vomitoria*), and seagrape (*Coccoloba uvifera*) [62]. In southern Florida, species such as Brazilian pepper, button mangrove, buttonbush, and melaleuca may form "shrub islands" among graminoids like cordgrass, saltgrass (*Distichlis* spp.), and stout rush (*Juncus nodatus*) [3].

Brazilian pepper occurs in seasonally wet grasslands and marshes in Florida. Brazilian pepper seedlings (≤ 3 feet; (1 m) tall) established in a hairawn muhly (*Muhlenbergia capillaris*)-dominated site with scattered sawgrass, occasional cabbage palmetto, and small patches of saw-palmetto [3]. Shrubs such as Brazilian pepper, groundsel-tree, and wax myrtle occur in Jamaica swamp sawgrass (*Cladium mariscus* ssp. *jamaicense*)-dominated marshes of Sanibel Island [196]. In the Indian River Lagoon, Brazilian pepper occurred in sand cordgrass marsh [162]. At a site in the transition zone between hammock and marsh, Brazilian pepper was dominant and occurred with common elderberry, Florida strangler fig, silverling, and Peruvian primrose-willow [3]. Brazilian pepper seedlings occurred in the transition zone between a mangrove forest and a marsh in an area with Jamaica swamp sawgrass, white mangrove, button mangrove, and several epiphytes [198]. Brazilian pepper in a maritime forest was impacting the edges of a saltmarsh community on the Atlantic Coast in northern Florida comprised of black rush (*J. roemerianus*), Jesuit's bark (*Iva frutescens*), and patches of chickenclaws (*Sarcocornia perennis*), turtleweed (*Batis maritima*), and bushy seaside tansy (*Borrichia frutescens*) [177]. Dikes may facilitate Brazilian pepper invasion into marshes [162].

Although Brazilian pepper occurs in grasslands, shrublands, and forests of Hawaii, it is most common on disturbed sites with other nonnative species such as guava, melaleuca, strawberry guava (*Psidium cattleianum*), guineagrass (*Urochloa maxima*), octopus tree (*Schefflera actinophylla*) [209,212,214], Java plum (*Syzygium cumini*) [139,173], Australian pine [65,159], white leadtree (*Leucaena leucocephala*) [65,173,212], and klu (*Acacia farnesiana*) [65,173]. Brazilian pepper has been reported in native kawelu (*Eragrostis variabilis*) grassland and in a mixed-shrub grassland comprised of yellow ilima (*Sida fallax*) and the nonnative fingergrass (*Chloris* spp.) [65]. Brazilian pepper occurs in several native shrublands including those dominated by beach naupaka (*Scaevola sericea* var. *taccada*) [65,159] or false ohelo (*Wikstroemia* spp.) [65,139,187,209]. Uhaloa (*Waltheria indica*) [187,212] and alahe'e (*Psydrax odoratum*) occur with Brazilian pepper in lowlands [139,187]. Brazilian pepper establishes in haole koa (*Acacia koa*)

dry and mesic forests [65]. It has been reported in tall-scrub [139] and forests [65] with lama (*Diospyros sandwicensis*). Brazilian pepper was noted to occur with ‘ohi’a lehua (*Metrosideros polymorpha*) in the understory of a melaleuca stand [209], in ‘ohi’a lehua mesic forests, and in grassland-shrubland transitions [65].

Little is published about Brazilian pepper distribution in Texas and California. On a southeastern Texas site, Brazilian pepper occurred with honey mesquite (*Prosopis glandulosa*), agarito (*Mahonia trifoliolata*), Brazilian bluewood (*Condalia hookeri*), lime pricklyash (*Zanthoxylum fagara*), cactus apple (*Opuntia engelmannii*), Texas swampprivet (*Forestiera angustifolia*), and wax mallow (*Malvaviscus arboreus*) [113]. In southern California, Brazilian pepper was documented in 52% of canyon fragments studied, where vegetation was classified into 3 major types: chamise (*Adenostoma fasciculatum*) stands; stands dominated by California sagebrush (*Artemisia californica*), black sage (*Salvia mellifera*), and eastern Mojave buckwheat (*Eriogonum fasciculatum*); and stands dominated by Nuttall's scrub oak (*Quercus dumosa*), laurel sumac (*Malosma laurina*), and lemonade sumac (*Rhus integrifolia*). The extent to which Brazilian pepper occurred in each of these types was not reported [2]. According to a California invasive plant inventory, Brazilian pepper is invasive in riparian areas of southwestern California [21].

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Schinus terebinthifolius

- GENERAL BOTANICAL CHARACTERISTICS
- SEASONAL DEVELOPMENT
- REGENERATION PROCESSES
- SITE CHARACTERISTICS
- SUCCESSIONAL STATUS

Photo by Dan Busemeyer, Illinois Natural History Survey

GENERAL BOTANICAL CHARACTERISTICS:

- **Botanical description**
- **Raunkiaer life form**

Botanical description: This description provides characteristics that may be relevant to fire ecology and is not meant for identification. Keys for identification are available (e.g., [12,70,113]).

Brazilian pepper is a root-sprouting [56,108], nonnative, evergreen tree, shrub [56,70,108], and occasionally a liana [177] or epiphyte [131]. Brazilian pepper grows 10 to 43 feet (3-13 m) tall [56,70,84,113]. It typically has a multiple-stemmed trunk with most stems less than 4 inches (<10 cm) DBH [56], although Brazilian pepper up to 3 feet (1 m) DBH have been reported [137]. Young twigs are covered in smooth bark that becomes furrowed and somewhat scaly with age [108,113]. Brazilian pepper has alternate compound leaves with generally 7 (3-15) glabrous leaflets ranging from 1 to 4 inches (2-10 cm) long and 0.4 to 1.4 inches (1-3.5 cm) wide [70,84,113]. Brazilian pepper's tiny flowers occur in axillary panicles up to 5 inches (15 cm) long on the distal portion of branches [56,70,108,113,137]. The

globose fruits are drupes 3.5 to 6.0 mm wide and contain a single seed [70,113,137].

As of 2010, no infomation regarding Brazilian pepper root morphology is available. Mycorrhizal colonization of Brazilian pepper roots has been observed in southern Florida [8,132]. In a greenhouse experiment, mycorrhizae have been shown to significantly (P<0.05) increase the size of Brazilian pepper [24].

Plant architecture and stand structure: Brazilian pepper can form dense stands, and its architecture may vary with site conditions. Brazilian pepper comprised 80% of the trees present on abandoned farmland near Everglades National Park [195]; on abandoned farmland in southern Florida, Brazilian pepper densities ranged from 200 to 2,500 trees per hectare [56]. Brazilian pepper has dense, spreading to erect branches that, due to a lack of self-pruning, may form thickets to ground level [56,84,108,137]. Near the edge of saltmarsh and maritime forest in northern Florida, Brazilian pepper in a crowded habitat (neighboring crowns touching) grew like lianas, with neighboring trees supporting their weight. The ratio of height to diameter in crowded habitat (148.4) was significantly greater than that in more open habitat (63.5) (P<0.01) [177].

Raunkiaer [156] **life form:**
Phanerophyte

SEASONAL DEVELOPMENT:
In Florida, Brazilian pepper flowering is synchronous. The majority occurs in fall with a peak in October. Approximately 10% of Brazilian pepper flower again in April or May. Fruits typically ripen from December to March [56,184] and may remain on plants until May (Anderson personal communication cited in [11]). In mangrove communities along the east-central coast of Florida, timing of Brazilian pepper flowering, fruiting, and budding peaked about 2 months after the peak in annual temperature. Flowering peaked in October and November. Fruiting occurred on 2 sites from November to March and peaked in December and January. A second fruiting period in spring was not observed [112]. Based on observations from October to the end of January, leaf flush in Brazilian pepper is generally steady and decreases during the peak of reproductive activity, from about October to December [55]. Germination occurs from November to April, with the majority occurring in January and February [56,184].

REGENERATION PROCESSES:

- **Pollination and breeding system**
- **Seed production**
- **Seed dispersal**
- **Seed banking**
- **Germination**
- **Seedling establishment**
- **Plant growth**
- **Vegetative regeneration**

Brazilian pepper reproduces by seed and by root sprouting. It also sprouts from the stem, root crown, and roots following damage [207].

Pollination and breeding system: Brazilian pepper is mainly dioecious [56,108]. Of 395 flowering Brazilian pepper trees surveyed in Everglades National Park, 49.6% of trees were males and 50.4% were females. Fruiting trees that later produced male flowers were also observed. Whether the fruit originated from female or perfect flowers is unknown. However, perfect flowers [56,113] and monoecious trees [56] have been observed in Brazilian pepper.

Insects pollinate Brazilian pepper flowers. Ewel and others [56] found that an average of 34.7% of exposed flowers produced fruit while less than 3% of enclosed flowers did. The major pollinator was a syrphid fly but species of dipterans, hymenopterans, lepidopterans, a hemipteran, and a coleopteran were also netted at Brazilian pepper trees. In California, honey bee visits to Brazilian pepper ranged from 0.5 bees/3 minutes to 5 to 9 bees/3 minutes. The only

native bees observed visiting Brazilian pepper were from the genus *Ceratina* and visited at a rate of 0.5 to 1 bee/3 minutes [63]. Due to Brazilian pepper's sticky anthers and pollen, wind pollination rarely occurs even across short distances [56].

Seed production: Brazilian pepper generally produces large amounts of seed and reaches maturity within 3 years of germinating. Brazilian pepper seedlings that were 4 to 12 inches (10-30 cm) tall when transplanted into Everglades National Park reached reproductive maturity in approximately 2 years [56]. Ewel and others [56] determined the number of fruits on 2 inflorescences (1 from the outer canopy and 1 from the inner canopy) of 20 separate trees in Everglades National Park. Five trees were sampled early in the fruiting season, 5 late in the season, and 10 in the peak of the season. The total seed count for the 40 inflorescences was 10,415. Individual inflorescences produced 0 to 1,211 fruits. Each fruit contains 1 seed [56]. In southeastern Brazil, estimated Brazilian pepper fruit production averaged 8,373 fruits/plant [25]. Based on Brazilian pepper's age at maturity, its high seed production, and seed mass, Rejmanel and others [158] rated Brazilian pepper as "very likely invasive". Parasitism by the vine devil's gut (*Cassytha filiformis*) may reduce seed production (see Biological control).

Seed dispersal: Humans are the main disperser of Brazilian pepper. This occurs on many scales, including introduction into new areas as an ornamental, disturbances facilitating spread [13,102,119], and improper disposal of garden waste leading to spread into neighboring areas [13].

Animals including birds and reptiles disperse Brazilian pepper seed. Mockingbirds, cedar waxwings, American robins, red-whiskered bulbuls, and catbirds disperse Brazilian pepper seed by eating its fruit [56,137,183]. When American robins are abundant in southern Florida during the winter fruiting period, they may disperse more Brazilian pepper seeds than all other dispersers combined. Brazilian pepper's phenology may serve to enhance dispersal by frugivores in Florida, because few native species are fruiting when Brazilian pepper is fruiting [56]. Tassin and others [183] suggest that bird dispersal of Brazilian pepper seed on Reunion Island is often localized to Brazilian pepper communities, because no other plant species are fruiting when Brazilian pepper fruits, and Brazilian pepper seeds remain in the systems of red-whiskered bulbuls (an introduced bird involved in plant invasions on the island) for only short periods. Brazilian pepper fruit may be favored by alien frugivorous birds in Hawaii [173]. For information on bird species that disperse Brazilian pepper seed within its native range, see Cazetta and others [25]. Intact Brazilian pepper seed was found in the stomachs of black spiny-tailed iguanas in southwest Florida [89], and seed occurred in the scat of a box turtle on Egmont Key in Tampa bay [40]. In northeastern Brazil, ants were observed dispersing Brazilian pepper seeds [111].

Mammal dispersal may provide an advantage to Brazilian pepper seed due to the high nutrient content of mammal scat [56]. Raccoons are known to disperse Brazilian pepper seeds [56,67], and opossums, deer, and cattle may also disperse the seed [56,108]. In Hawaii Brazilian pepper seeds are dispersed by feral pigs [191].

Brazilian pepper seeds may be dispersed substantial distances by water. Brazilian pepper fruits remained buoyant for 6 to 7 days on average in saline water (15 and 30 ppt), significantly ($P<0.001$) longer than the average duration of buoyancy in freshwater (5 days). Seed viability decreased as the number of days the fruits floated increased ($P<0.001$). Estimated dispersal distances in a lagoon on Florida's east coast were 10.5 miles (16.9 km) in freshwater and over 13.7 miles (22.0 km) in saline water. Seed dispersal into drier, less saline habitats suitable for Brazilian pepper establishment may be facilitated by boat wakes, possibly followed by vertebrate dispersal [42]. Because Brazilian pepper germination occurs after soaking seeds in water and seedlings are abundant along riverbanks and in wetlands on Reunion Island, Tassin and others [183] concluded that Brazilian pepper seed is dispersed by water in this location.

Proximity to a seed source is likely an important factor influencing the spread of Brazilian pepper. For example, seed traps in Brazilian pepper-dominated forests captured more Brazilian pepper seeds than those in other habitats [56]. Observational evidence suggests that proximity to a seed source and/or seed bank composition were probably more important than several other site factors, such as differences in substrate or hydrology, in determining which species would dominate successional vegetation within the Hole-in-the-Donut area of Everglades National Park [101]. In Queensland, Australia, percent and number of weed species were much greater in areas near residences than those further away, and observations suggested that dumping of garden waste was a major source of weeds, including Brazilian pepper [13].

Seed banking: Brazilian pepper seeds are relatively short-lived. In seed introduction experiments in Florida, less than 0.05% of Brazilian pepper seeds placed in field plots were viable after 5 months, and after 6 months no Brazilian pepper seeds germinated [56]. In a field experiment in southeastern Queensland, 0% of seeds with their exocarp removed, 15% of seeds in buried fruits, and 2.9% of seeds in surface sown fruits were viable after 26 weeks. No Brazilian pepper seeds germinated from soil or litter samples taken from under female Brazilian pepper collected just before fruiting began [148]. Germination rate of Brazilian pepper seed from fruit collected on Reunion Island and stored in a laboratory was 94% after 32 days, 83% after 64 days, 72% after 128 days, and 0% after 256 days [183]. Brazilian pepper exhibited large declines in germination (≥50%) after about 6 months in cold storage (Anderson personal communication cited in [11]).

Germination: Brazilian pepper germination generally peaks within several weeks of sowing. Field studies in southern Florida indicate that germination of Brazilian pepper seeds begins to decline 30 days after planting on most sites [148]. In laboratory studies most Brazilian pepper germination takes place within 30 days [56,141,142,148], and no germination occurred after about 55 days in a greenhouse experiment [56]. Seeds buried in commercial potting mix and grown outdoors in southeast Queensland began emerging 8 weeks after sowing [148].

- Seed treatments
- Site conditions

Seed treatments: Treatments including exposure to heat, scarification or exocarp removal, and burial affect Brazilian pepper seed germination. In a laboratory study, Brazilian pepper seeds heated to 158 °F (70 °C) for 1 hour did not germinate [142]. It is unclear how heat from fire may affect Brazilian pepper germination and viability.

The Brazilian pepper exocarp inhibits germination. Several researchers found increased germination rates following exocarp removal [123,141,148,183]. Less than 5% emergence resulted from planting whole Brazilian pepper fruits, while extracted seeds sown on the soil surface had a mean total emergence of 39.2% and those buried to 0.3 inch (1 cm) depth had 17.7% emergence [148]. In a laboratory experiment, Brazilian pepper fruit attached to the peduncle did not germinate, while 22% of fruits without the peduncle germinated in 30 days. These germination rates were significantly (P<0.001) lower than those of Brazilian pepper fruits with the peduncle and exocarp removed (68% germination in 14 days). Brazilian pepper fruits with their exocarps and mesocarps removed exhibited even greater germination (100% germination in 18 days, P<0.001) [183]. Brazilian pepper seeds scarified with a metal sieve under running water had significantly (P<0.05) higher germination rates than unscarified seeds [141]. Acid scarification may also increase Brazilian pepper germination, although laboratory results do not report consistent increases (e.g., [56,142]). Seed source [56] and planting conditions [142] may affect germination rates of acid-scarified seeds.

Digestion of Brazilian pepper seed may increase germination compared to manually extracted seeds. Brazilian pepper seeds digested by red-whiskered bulbuls had significantly (P<0.001) higher germination rates (97%-100%) than seeds that were manually extracted from fruits (68%) [123] or seeds that had their exocarps, but not their mesocarps, manually removed (68%) [183]. In contrast, germination of seeds digested by silvereyes in southeastern Queensland did not differ significantly from germination of seeds with exocarps removed manually [148].

Site conditions: Many site conditions influence germination of Brazilian pepper including disturbance, soil type, soil salinity, moisture, and associated species.

Disturbance and/or successional stage may influence Brazilian pepper germination in the field. In an ecotone association in southern Florida, Brazilian pepper germination was 50% in plots where vegetation was removed and 13% in undisturbed plots after 4 months [141]. In Everglades National Park, Brazilian pepper germinated in all the habitat types investigated, though there was substantial variation within and between sites. Percent germination in the field varied from <1% to >30%, with early successional sites having generally higher germination rates. In mature communities, Brazilian pepper germination and subsequent survival was highest in pineland and lowest in hammock vegetation [56]. While Brazilian pepper seed germination was reduced by about 10% when exposed to Brazilian pepper exocarp extracts in the laboratory [142], inhibition was not evident in the field as over 100 Brazilian pepper

seedlings emerged/m²/15 days in associations dominated by Brazilian pepper [56].

Soil type may influence Brazilian pepper seed germination. For instance, Brazilian pepper germination was significantly (P=0.0002) higher on marl soil (36%) than on peat (13%), both collected from Everglades National Park [141]. However, germination rates of acid-treated Brazilian pepper seeds sown in greenhouse soil mix (10%) and those sown in soil collected from bare ground in a southern Californian chaparral community (7%) were similar [142].

Germination and viability of Brazilian pepper seeds decline with increasing salinity in both field and laboratory experiments. Scarified fruits sown on filter paper exhibited decreasing germination with increasing salinity (P=0.0001). Germination of Brazilian pepper seeds in 0% saline solution was 80%. Germination rate declined linearly with increasing salinity, and Brazilian pepper seeds in the 20% saline solution exhibited 12% germination. Brazilian pepper seeds sown in marl and peat soils from Everglades National Park did not germinate when watered with 5%, 10%, or 15% saline solution in the laboratory. Similarly, germination in the field occurred only in ecotone vegetation where salinities were from 2% to 5% [141].

Mesic conditions are likely to increase Brazilian pepper seed germination. In a laboratory experiment, Brazilian pepper germination was 37% when the soil was always moist but never saturated. This was significantly (P=0.0002) higher than the 20% germination rate observed when the soil was moist at time of watering but dry within 24 hours, or the 16% germination rate observed when water was maintained at the top of the soil surface [141]. In the field, heavy, dry-season, rainfall increased germination in drier areas but decreased germination in wetter, low-lying areas [56].

Seedling establishment: According to Ewel [55], Brazilian pepper seedlings are likely to survive once they reach about 4 to 6 inches (10-15 cm) tall and have well developed root systems. Factors likely to influence seedling establishment and survival include light levels, moisture availability, salinity, and plant community.

Brazilian pepper seedlings survive and grow in a wide range of light levels, but grow faster in full sunlight. In southern Florida, Brazilian pepper seedling survival over 22 months was >25% in dense habitats, and nearly 100% in open habitats. Brazilian pepper seedlings are capable of increased growth when light levels increase. In Everglades National Park, Brazilian pepper seedlings in canopy gaps were over twice the height of seedlings under the canopy after 2 years [56]. Two-week-old Brazilian pepper seedlings grew better at higher light levels; total dry weight of seedlings in the 300 µE/m²/sec treatment was over 3.0 grams after 6 weeks, and was less than 1.0 gram in the 60µE/m²/sec treatment [143]. In another greenhouse experiment, Brazilian pepper seedling relative growth rate, carbon dioxide assimilation, and light-saturated photosynthetic rates were significantly ($P \leq 0.05$) higher in 100% full sunlight than in 5% full sunlight, although Brazilian pepper survived and grew in 5% full sunlight. Relative growth of Brazilian pepper seedlings in both full sunlight and partial shade (31% full sunlight) was typically about twice that of native Hawaiian species in the same treatment group [149]. In a greenhouse experiment within the native range of Brazilian pepper, relative growth rate of Brazilian pepper seedlings increased from about 10 mg/g/day at 5% sunlight to just over 30 mg/g/day at 25% sunlight. Brazilian pepper also exhibited higher net photosynthetic rates under 25% sunlight than in more shaded conditions. However, it was considered stressed at all light levels tested (≤25%) [57].

Brazilian pepper seedlings grow on sites with varying water availability, from areas that are rarely inundated to those that are flooded for several weeks at a time [56]. Brazilian pepper seedlings (~1 year old) in treatments that were flooded to under 1 inch (1-2 cm) above soil level for 56 days exhibited 100% survival. After 20 days a 36% reduction in stomatal conductance and a 29% reduction in net photosynthesis were observed in flooded seedlings compared to control seedlings. In addition, flooded seedlings had significantly (P<0.01) smaller root biomass [135]. Brazilian pepper seedlings are more drought tolerant than Peruvian pepper (*Schinus molle*) seedlings [143]. In Florida, Brazilian pepper seedlings are susceptible to mortality during summer flooding and during the dry period, which ends in June. On wet sites, survival of outplanted seedlings ranged from 30% to 50%. Some of the seedlings that died were completely submerged during this period. Rapid changes in water levels may also cause seedling mortality [56].

Brazilian pepper seedlings require low salinity for survival in the field. Seedlings 3 to 4 inches (8-10 cm) tall were planted in 3 vegetation types: mangrove, herbaceous, and the transition between these types. All seedlings on sites with salinities of more than 5% died. The greatest survival over 9 months (89%) occurred on a disturbed ecotone plot where salinity ranged from 2% to 5% [141]. However, in a greenhouse experiment all Brazilian pepper seedlings exposed to

salinities up to 15% survived. Growth, resource allocation, and gas exchange parameters were not significantly ($P \leq 0.05$) affected by slowly increasing salinity to 8% or 15% and then maintaining these levels for 1 month [52].

Investigations of Brazilian pepper invasiveness suggest that young successional vegetation (less than 8 years old) on sites that were previously farmed provides optimum habitat for seedling survival and growth. Brazilian pepper seedlings from seeds experimentally planted in young successional vegetation had the highest survival rates (<5%) over a period of about 9 months compared to those in undisturbed or generally older successional communities. For example, no Brazilian pepper that germinated from experimentally planted seeds survived in undisturbed hammock vegetation, and survival was less than 1% in other undisturbed communities and some older Brazilian pepper stands. Across habitat types, seedlings that were transplanted when 4 to 12 inches (10-30 cm) tall had higher survival rates (≥50% on 8 of 10 sites) than those of experimentally planted seeds. Survival rates were generally higher in young successional vegetation than mature communities. For instance, survival of Brazilian pepper seedlings was about 50% or less in mature pineland and hammock communities [56].

Plant growth: In some circumstances, Brazilian pepper grows quickly. Brazilian pepper seedlings that were 4 to 12 inches (10-30 cm) tall when transplanted into Everglades National Park reached a height of about 7 feet (>2m) in approximately 2 years [56]. In another southern Florida site, seedlings planted on previously farmed land when 10 to 12 inches (25-30 cm) tall reached a mean height of 15 feet (4.6 m) after 20 months [160]. In a relatively open pineland habitat, which is a typically infertile type, 87% of Brazilian pepper seedlings had positive growth rates, and the average growth of seedlings was 0.41 cm/month. The highest growth rate observed was 0.8 inch (2 cm)/month [118]. Brazilian pepper planted on a site in southern Brazil grew to 11.8 feet (3.59 m) in 19 months [88]. Brazilian pepper seedlings grown in a greenhouse and adequately watered had relative growth rates of 1.12 g/g/week in the second month after germination [143]. Temperature may also influence Brazilian pepper growth rate [112].

Vegetative regeneration: Brazilian pepper forms root suckers which develop into new plants. Damage to the plant apparently does not need to occur to trigger root sprouting [207]. On abandoned dryland farm sites on Reunion Island, Brazilian peppers originating from suckers were significantly ($P=0.003$) more abundant than those originating from seeds. In contrast, riverbank sites had more seedlings than suckers [183].

Brazilian pepper also sprouts from aboveground stems and root crowns following top-kill or damage [175,207]. Growth of sprouts can be rapid and may be affected by timing of damage or top-kill. For example, in Everglades National Park, 2 years after cutting Brazilian pepper to less than 1 inch (1-2 cm) in February, aboveground biomass was 4 times more than before cutting. Sprouts from Brazilian pepper cut in February or March in Everglades National Park surpassed their original biomass in 2 years, while sprouts from individuals cut during any other month did not [175] (see below).

Timing of cutting influences survival and the subsequent growth rate of Brazilian pepper. On 2 sites in Florida, cutting from June to October resulted in the highest mortality rates for Brazilian pepper compared to cutting at other times of the year. Cutting a 2nd time after 2 years did not result in substantially higher mortality, except for trees in Big Cypress National Preserve cut twice in June, which had 60% cumulative mortality. The following table shows percent mortality of Brazilian pepper cut to less than an inch (1-2 cm) above ground in different months [175].

Percent mortality of Brazilian pepper following cutting in different months (1987) on 2 Florida sites [175]

Month	Everglades	Big Cypress National Preserve
January	0	0
February	0	0
March	8	0
April	0	0
May	0	0

June	25	18*
July	8	17
August	25	9*
September	33	0
October	17	33
November	0	0
December	0	8
*n=11; all others n=12		

SITE CHARACTERISTICS:

Brazilian pepper occurs on a wide range of sites but grows best in low-elevation, mesic areas [56,141]. In California, Brazilian pepper occurs in low-elevation canyons and washes [2,84]. It is most common in parts of Hawaii receiving from less than 20 inches (500 mm) [65,173] to 59 inches (1,500 mm) of annual precipitation. In areas receiving 39 to 59 inches (1,000-1,500 mm) of annual rainfall, Brazilian pepper was one of the most abundant weeds below 1,300 feet (400 m). It occurs in some areas of Hawaii receiving more than 59 inches of annual precipitation [173,214].

Although sensitive to freezing, Brazilian pepper sprouts after frost damage. Because it recovered 3 months after frost in Florida, Duever and others [48] concluded that Brazilian pepper was more cold tolerant than native species such as strangler fig and pond apple. A model suggested that increases in temperature would benefit Florida mangrove species to a greater extent than Brazilian pepper [112].

Disturbed sites are particularly susceptible to Brazilian pepper invasion [56,58,101]. In Hawaii, Brazilian pepper stands typically occur on disturbed sites at low elevation [33,65,214]. In southern Florida, Brazilian pepper is common along roads, canals, and power lines [56]. It may form dense thickets on abandoned farmland [56,101]. Altered soil characteristics are thought to contribute to Brazilian pepper's success on these sites [37].

- **Water**
- **Soil**
- **Elevation**

Water: Brazilian pepper occurs on a variety of sites, from seasonally flooded to mesic areas [56,108,149,182,213].

Brazilian pepper occurs on sites with variable water levels, but it commonly occurs on relatively dry sites in wet habitats. In mangrove habitats of east-central Florida, soil moisture content at sites with Brazilian pepper averaged 72%, significantly (P<0.01) less than the 88% average soil moisture on sites without Brazilian pepper [43]. In tree island vegetation in the Everglades, Brazilian pepper was most common on sites that were comparatively dry, with water tables consistently 12.6 to 20.5 inches (32-52 cm) lower than those in 2 other site types [201]. In southern Florida, the driest community Brazilian pepper occurred in was a hammock with a water table that was typically deeper than 16 inches (40 cm) below the soil surface. Large seasonal fluctuations in the water table occur on some southern Florida sites where Brazilian pepper occurs. For instance, on a site dominated by wax myrtle with clusters of Brazilian pepper, the water table in the dry season was 5.5 feet (1.7 m) below the soil surface, but rose to within 5 inches (12 cm) of the surface after a heavy rain [56]. At Hole-in-the-Donut in Everglades National Park, untreated Brazilian pepper stands had an average of 27% wetland species, compared to an average of 66% wetland species in adjacent natural vegetation [145].

Although Brazilian pepper tolerates some flooding, it typically does not occur in areas flooded for long periods, including areas where historical water levels have been restored [26,37]. Kruer and others [102] report that Brazilian pepper survived flooding for up to 6 weeks. In an investigation of seasonal water use by Brazilian pepper, Ewe and Sternberg [50] found evidence that it is more tolerant of wet season soil saturation than Florida native species such as wax myrtle, groundsel-tree, Guianese colicwood, and white indigoberry (*Randia aculeata*). However, in the Hole-in-

the-Donut region of Everglades National Park, Brazilian pepper has not shown any morphological adaptations to wetlands. Direct observation, ground elevation, and hydrological data suggest that untreated Brazilian pepper stands do not have surface water at any time during the year [145]. On Sanibel Island, some Brazilian pepper trees lost their leaves and died while others recovered after flooding to an average of 9.5 to 15 inches (24-38 cm) from mid-September to early December. Flooding levels of less than 9.5 inches created little or no stress. Soils in the lower areas (15 to 22 inches (38-56 cm) of inundation) had more organic matter and may have become anaerobic causing severe root stress [59]. In some areas of southern Florida small declines in elevation result in increased hydroperiods that may have detrimental effects on Brazilian pepper [37]. For example, a tree island with no Brazilian pepper was over 3 feet (1 m) lower in elevation than a tree island dominated by Brazilian pepper, although other factors were likely contributing to Brazilian pepper's occurrence or absence [129]. Brazilian pepper has been observed growing as an epiphyte above the high water level on cypress trees [131].

Brazilian pepper uses water more efficiently than several native species in Hawaii and Florida. In Florida, Brazilian pepper had higher water use efficiency in the wet seson than Florida natives wax myrtle, groundsel-tree, Guianese colicwood, and white indigoberry (*Randia aculeata*) [51]. In Hawaii, the increase observed in Brazilian pepper water-use efficiency from the wet to the dry season was much greater than that observed in native species such as lama, ‘ohi’a lehua, and Hawaii olive (*Nestegis sandwicensis*) [182]. Although Brazilian pepper used groundwater in wet and dry seasons, groundwater was used to a greater extent during the wet season in a southern Florida site [195]. Brazilian pepper resisted cavitation and had xylem specific conductivity similar to that of wax myrtle, suggesting that hydraulic traits are not contributing to Brazilian pepper's spread [153].

Despite Brazilian pepper's limited tolerance to salinity, it is widespread in and near saline coastal regions of Florida [43,93,198]. In east-central Florida, average salinity of mangrove habitats with Brazilian pepper was 1.3 ppt. Following Brazilian pepper declines in these habitats due to 3 hurricanes in 2004, increases in Brazilian pepper abundance were limited to the 33-foot (10 m) and 66-foot (20 m) intertidal zones of an open site [43]. Brazilian pepper did not occur in swamps where water salinity at 6 inches (15 cm) was 2.5 ppt or greater. Lower salinity in rotationally managed impoundments was suggested as a factor facilitating high Brazilian pepper density in these areas [134]. In the transition between mangrove and marsh ecosystems, Brazilian pepper established on a site with an average salinity of 10 ppt and maximum salinity of about 15 ppt. Sites closer to the mangrove forests that did not have Brazilian pepper had average salinities from 10 to 15 ppt and maximum salinities of 20 to 30 ppt [198]. In the transition between an upland pine and mangrove community, water uptake patterns suggested that during the dry season Brazilian pepper "was less of a salt excluder" than several native upland species [53]. Based on a simulation, increases in salinity from 20 to 35 ppt due to rising sea level would result in Brazilian pepper declines in mangrove habitats in Florida [112]. In Hawaii, Brazilian pepper occurs at the inland boundary of the beach naupaka shrublands were impacts of salt spray are minimal [65].

Effects of salinity on germination are discussed in Germination: site conditions, and effects of water level on seedlings are discussed in Seedling establishment.

Soil: Brazilian pepper is common in calcareous substrates. The pine rockland savannas invaded by Brazilian pepper in southern Florida occur on limestone soils that range from nearly pure calcium carbonate to sandy limestone [197]. Brazilian pepper occurred in a pineland community where the sparse soil consisted of limestone and organic debris [56]. In southern Florida the soil of a hammock community where Brazilian pepper occurred was comprised of a layer of organic matter approximately 8 inches (20 cm) thick over oolitic limestone. On the coast of Oahu, Brazilian pepper occurred in calcareous sand [159].

Soils on sites with Brazilian pepper were variable in Hawaii, including sites with thick fertile soils and those with lava flows less than 100 years old [214]. Brazilian pepper occurs in coastal dry mixed communities that are often found on talus slopes or in rocky clay soils and in beach naupaka shrublands found on dunes [65]. On the coast of Oahu, Brazilian pepper occurred about 203 feet (62 m) from the shoreline. On another transect in the same habitat, also 203 feet from the shoreline, pH was 5.5 and organic carbon was 27.07% in the top 1 inch (2.5 cm) of soil [159].

In Florida, Brazilian pepper may be less prone to invade acidic soils and peat soils than alkaline soils. Based on unpublished data, Schmalzer and others [163] note that coastal scrub on alkaline soil appears more susceptible to

Brazilian pepper establishment than coastal scrub on acidic soils, especially when soils are disturbed. Peat soils may provide a less suitable substrate for Brazilian pepper establishment than marl soils [141].

Cultivation results in changes to soil properties that favor Brazilian pepper. A soil removal experiment demonstrated that changes to soil due to farming facilitated Brazilian pepper colonization [37]. In addition to changes in elevation that influence the hydroperiod, cultivation and farming can increase soil nutrients, soil volume, macropore space, and percentage of rock fragments. These changes may increase fertility, aeration, and drainage [115,132]. Total concentrations of copper, zinc, and phosphorus are higher on previously farmed sites of Hole-in-the-Donut in Everglades National Park. The correlation between Brazilian pepper leaf phosphorus and plant available phosphorus in the soil implies that increased levels of phosphorus facilitated Brazilian pepper colonization of the area [115]. Addition of superphosphate resulted in significantly (P<0.05) larger Brazilian pepper in a greenhouse experiment [24].

On a site in southern Brazil, Brazilian pepper litter was estimated to return 5.1 g nitrogen/m²/year, 1.9 g phosphorus/m²/year, 2.9 g potassium/m²/year, 30.6 g calcium/m²/year, and 6.0 g magnesium/m²/year to the soil, which was less than 3 other species tested. The mineral content of Brazilian pepper litter was 1.11% nitrogen, 0.21% phosphorus, 0.33% potassium, 3.49% calcium, and 0.68% magnesium. These values were low to intermediate compared to the 3 other native Brazilian species tested [88].

For information on the effects of soil characteristics on germination or seedling establishment see those sections.

Elevation: Brazilian pepper occurs primarily at low elevations, from sea level to over 2,300 feet (700 m) [56]. On the southeastern coast of Florida, Brazilian pepper occurred on dunes from 20 to 190 feet (6-58 m) above high tide at one site and at 190 feet, 276 feet (84 m), 318 feet (97 m), and 361 feet (110 m) above the high tide on another [106]. In California it is typically found below 700 feet (200 m) [84]. Brazilian pepper is most abundant below 2,300 feet (700 m) in Hawaii, but scattered plants are found up to 3,000 feet (1,000 m) [149,173,212,214].

SUCCESSIONAL STATUS:
Brazilian pepper is primarily an early-successional species. It colonizes areas within a few years of disturbance [3,44], and it is considered a pioneer species in its native range [88]. Mid- to late-succssional native communities are generally less susceptible to Brazilian pepper colonization than early-successional communities [56]. In mangrove habitats of east-central Florida, Brazilian pepper was positively (P=0.006) correlated with the number of open areas along transects [43]. Of mature communities, pinelands are at higher risk of Brazilian pepper establishment than wet prairies, while hammocks had the smallest risk of colonization among the mature communities investigated (see Germination, and Seedling establishment for details) [56]. However, Brazilian pepper recruitment continues under a closed canopy, resulting in a self-maintaining stand [56,101]. In a disturbed area in southern Florida, Doren and Whiteaker [44] observed Brazilian pepper stands of varying ages and found that colonization progresses from low density, to high density of small stems (<4 inches (10 cm) basal diameter), to moderate density of large stems (>10 cm basal diameter). In Hawaii, white leadtree communities may succeed to Brazilian pepper [173] on moist sites [138]. Other nonnatives such as guava or java plum may follow Brazilian pepper in succession [65]. Brazilian pepper also occurs in relatively stable Hawaiian communities such as mixed mesophytic forests [138].

The effect of light on Brazilian pepper seedlings is discussed in the Seedling establishment section.

FIRE EFFECTS AND MANAGEMENT

SPECIES: Schinus terebinthifolius

- FIRE EFFECTS
- FUELS AND FIRE REGIMES
- FIRE MANAGEMENT CONSIDERATIONS

FIRE EFFECTS:

- **Immediate fire effect on plant**
- **Postfire regeneration strategy**
- **Fire adaptations and plant response to fire**

Immediate fire effect on plant: Brazilian pepper typically survives or is top-killed by fire [45,118], although small trees are often killed by fire. Based on observations in southern Florida, fire-induced mortality of Brazilian pepper less than 20 inches (50 cm) tall is nearly 100% [56,118]. In pine rockland savanna of southeastern Florida, mortality rates of unburned Brazilian pepper were 0% to 4%, while mortality rates of Brazilian pepper burned in late July were 30% to 45%. Mortality rates of individuals with a basal diameter <0.4 inch (1 cm) were 63% to 100%, while mortality rates of individuals with a basal diameter >1 inch (3 cm) ranged from 0% to 8% [178]. Based on these data, a model predicts the probability of postfire mortality for Brazilian pepper plants of various sizes [179]. More information regarding the influence of Brazilian pepper's size on its response to fire is described in Plant response to fire.

Modeled probability of Brazilian pepper mortality due to fire at various sizes [179]

Basal diameter (cm)	Probability of mortality
0.1	74% to 78%
1.0	50% to 56%
2.0	21% to 34%
4.0	2% to 7%

Brazilian pepper mortality from fire may be greater in areas with low densities of Brazilian pepper than in areas with high densities. In pine rockland savanna of southeastern Florida burned in July, fire killed 8 of 9 Brazilian pepper trees in areas with low Brazilian pepper densities (≤2/80 m²), but only killed 2 of 31 Brazilian pepper trees in areas with high Brazilian pepper densities (>3/80 m²) [178]. For information regarding the impact of Brazilian pepper on Fuels and Fire Regimes see those sections.

In a laboratory experiment, Brazilian pepper seeds heated to 158 °F (70 °C) for 1 hour did not germinate [142], suggesting a limited tolerance of Brazilian pepper seed to heat.

Postfire regeneration strategy [180]:
Tree with adventitious buds, a sprouting root crown, and/or root sprouts
Tall shrub, adventitious buds and/or a sprouting root crown
Small shrub, adventitious buds and/or a sprouting root crown
Initial off-site colonizer (off site, initial community)
Secondary colonizer (on- or off-site seed sources)

Fire adaptations and plant response to fire:

- Fire adaptations
- Plant response to fire

Fire adaptations: Brazilian pepper is adapted to survive fire and may produce rapidly growing sprouts from aboveground stems, the root crown, and/or roots following fire [56,118]. Plant size and stand density are important factors in determining its postfire response. See Plant response to fire below for more information.

Brazilian pepper is well known for its ability to establish in disturbed areas (see Site Characteristics), and is often

reported on burned sites, although the origin of these plants is not always discussed. For example, Brazilian pepper was found in a severely burned hardwood stand in Big Cypress National Preserve during a survey of nonnative plants during the early 1970s (Alexander and Crook 1975 cited in [78]). Wade and others [197] report Brazilian pepper on recently burned sites in southern Florida, and small Brazilian pepper plants have been reported on pineland sites burned approximately every 5 years in the Everglades [118]. In tree island vegetation of the Everglades, Brazilian pepper was most common on sites where recent, severe fire was common (50% of sites) [201]. In the eastern region of Everglades National Park, Brazilian pepper occurred in several "burned-out" hammocks and had cover from 10% to 50% on hammocks that had been burned during the period of investigation. However, Brazilian pepper did not occur in all burned hammocks and occurred in mature, comparatively undisturbed, hammocks as well [117]. The timing of Brazilian pepper establishment on these sites relative to the fires is not known.

Given the lack of Brazilian pepper germination in a laboratory experiment in which seeds were heated to 158 °F (70 °C) for an hour [142] and Brazilian pepper's short-lived seed bank, the source of postfire recruitment is more likely from sprouts, seeds from on-site trees that survived the fire, and/or seeds from trees in neighboring areas rather than from seeds in the soil seed bank. More research is needed on the degree to which Brazilian pepper's establishment and persistance on burned sites is affected by fire season and severity, site and plant community characteristics, and the abundance of Brazilian pepper in and around the site.

Plant response to fire: Brazilian pepper may establish, persist, or spread on burned sites, and fire may influence seed production in Brazilian pepper. Factors influencing Brazilian pepper's response to fire include stand density (see Immediate fire effect on plant), plant size, and timing, severity, and frequency of fire (see below).

Plant size is an important factor influencing Brazilian pepper's response to fire. Larger Brazilian pepper are more likely than smaller individuals to survive and sprout following fire [45,118,178]. On a site with experimentally planted Brazilian pepper, 20% of seedlings less than 24 inches (≤60 cm) tall survived and sprouted after a fall prescribed fire. The smallest surviving Brazilian pepper was 12 inches (30 cm) tall. On a pine forest site about a mile (≈3 km) to the east, the shortest Brazilian pepper to sprout after a fall prescribed fire was 23 inches (58 cm) tall before the fire. After this site was burned, 30% of Brazilian pepper under 3 feet (<1 m) tall survived and sprouted, while at least 85% of Brazilian pepper in larger size classes survived and sprouted. Similarly, Brazilian pepper in size classes larger than 6.5 feet (>2 m) had greater survival rates, as well as basal and top sprouting, following a fall prescribed fire in a pineland-Brazilian pepper ecotone at Long Key Pine Campground [118]:

Number (%) of Brazilian pepper sprouting after a fall prescribed fire in Long Key Pine Campground in Everglades National Park [118]

Size class (m)	*n*	Number with no green leaves	Number with some branches not fire killed	Number only top sprouting	Number only basal sprouting	Number both top and basal sprouting
<2	7	2 (28.6)	1 (14.3)	0	4 (57.1)	1 (14.3)
2.5	35	0	7 (20.0)	1 (2.9)	22 (62.9)	8 (22.9)
5	13	2 (15.4)	3 (23.1)	1 (7.7)	5 (38.5)	5 (38.5)
Total	55	4 (7.3)	11 (20)	2 (3.6)	31 (56.4)	14 (25.5)

Sprouts of fire-damaged Brazilian pepper can grow rapidly. Some sprouts grew to over 3 feet (1 m) tall within 6 months of a fall prescribed fire in a pineland community. Average shoot growth was over 5 inches (14 cm) per month [118]. Growth rates of burned Brazilian pepper in a pine rockland community in Everglades National park averaged 0.69 cm/year, which was faster than the average growth rate of 0.33 cm/year observed in unburned Brazilian pepper [179].

There is evidence that Brazilian pepper seed production decreases following fire. Brazilian pepper individuals that survived a July prescribed fire in pine rockland savanna of southeastern Florida produced less fruit than unburned individuals for at least 1.5 years after fire. Increased fruit production with increased size was not observed after fire, although this relationship was observed in unburned individuals. Most burned individuals started bearing seed at 0.3-

to 0.4-inch (0.8-1.0 cm) diameter; this was a narrower size range for maturation than observed in unburned individuals [179]. No Brazilian pepper seed rain occurred in a pineland site during the first 30 days after a fall prescribed fire [56].

Time of burning may influence the response of Brazilian pepper to fire. Snyder [175] demonstrated a seasonal trend in sprouting response for Brazilian pepper top-killed by cutting to less than an inch (<2.5 cm) above ground. Most mortality occurred in Brazilian pepper cut from June to October (see Vegetative regeneration for more details). The majority of wildfires in Florida are ignited by lightning during the wet season from May to September [184]. Few Brazilian pepper seeds are available (see Seasonal Development) to colonize recently burned areas at this time of year. Additionally, the wet conditions at this time of year may increase fire damage to established Brazilian pepper. Brazilian pepper trees in a pine rockland in a Miami-Dade County park were killed by a slow backfire performed in winter following an extended wet season (Memo cited in [155]). Direct investigation of the effect of seasonal burning on Brazilian pepper is needed to clarify the importance of factors affecting Brazilian pepper's postfire response, such as physiological activity, prevailing site conditions, and abundance of Brazilian pepper seed.

In eastern coastal lowlands of Hawaii, 5 of 7 Brazilian pepper sprouted following high-severity fires and 18 of 21 sprouted following low-severity fires [187].

Influence of fire frequency: Frequent fire in pinelands may limit Brazilian pepper establishment. In pine savannas in Everglades National Park, Brazilian pepper invasion was less likely and less severe on sites burned at least once within the previous 20 years. More than 50% of sites that had not been burned in 20 years were "severely" invaded by Brazilian pepper. Although the sample size was small, Brazilian pepper had not invaded any of the areas that had burned more than twice and had not severely invaded any site burned more than once in the previous 20 years [178]. Model simulations based on data from a study on Brazilian pepper in pine rockland savanna suggested that a 4-year fire-return interval would eliminate an initial population of 100 Brazilian pepper females within 25 years [179]. However, small Brazilian pepper plants have been reported on pineland sites burned approximately every 5 years [118]. Loope and Dunevitz [118] suggest the lack of Brazilian pepper on pinelands of Everglades National Park is due to a combination of burning about every 5 years and poor growing conditions that slow Brazilian pepper growth so plants rarely reach a fire resistant size between burns. In contrast, Brazilian pepper was abundant in pineland sites outside of Everglades National Park that were not regularly burned [118]. Frequent burning of pineland in Big Cypress Natural Preserve was thought to be a factor in maintaining low abundance of Brazilian pepper there [78].

In highly disturbed communities it is unlikely that fire has substantial negative effects on Brazilian pepper. In a previously farmed area within Everglades National Park, Brazilian pepper stem densities increased [46] and recruitment into larger size classes continued [45] despite successful burning 2 to 4 times in a 5-year period. Brazilian pepper density declined on 1 site, but this was most likely due to a long hydroperiod. Brazilian pepper density increased linearly on sites that were burned 4 times during the 5-year period, and exponentially on sites burned less frequently and/or less completely. Higher fuel production by associated plant species may account for some sites burning more frequently and/or completely [46]. The slowed colonization by Brazilian pepper on these fuel-rich sites may not be due to burning, but rather to increased competition with associated, fuel-producing species or to site conditions that allowed for persistence of these species.

FUELS AND FIRE REGIMES:

- **Fuels**
- **Fire regimes**

Fuels: Brazilian pepper may reduce fuel loads on invaded sites. In a salt marsh community in Florida, the average biomass of plants, mainly black rush, under Brazilian pepper was 0.0512 kg/m², significantly (P=0.03) less than the 0.588 kg/m² average biomass occurring in adjacent areas [177]. Several references assert that the dense shade of Brazilian pepper stands displaces other plants (see Impacts), suggesting potential decreases in understory fuels wiht Brazilian pepper invasion.

Several sources assert that Brazilian pepper stands lack fine fuels [45,54,197], and some data support this. In the southern portion of Everglades National Park, cover of herbaceous plants was low in Brazilian pepper stands more

than 20 years old, with paragrass, native grass, and other herbaceous species each having 0% to 5% cover in all plots. Herbaceous species in Brazilian pepper stands that were 11 to 20 years old rarely had more than 50% cover, and in most plots paragrass, native grass, and other herbaceous species each had 0% to 5% cover. Herbaceous cover in stands of Brazilian pepper less than 11 years old was more variable [44]. Brazilian pepper trees on sites that burned completely were smaller and had more herbaceous fuel around them than in partially burned and unburned areas [45]. According to Doren and Whiteaker [45], stands of Brazilian pepper with occational individuals of other hardwood species in Hole-in-the-Donut have "high" live fuel moisture.

Brazilian pepper litter apparently contributes little to fuel loads, although litter production may be higher than that in some native community types. Ewel [54] suggests the year-round dense shade and quick decomposition of Brazilian pepper litter (J.R. Synder unpublished cited in [54]) results in almost no litter in the understory. In its native range, Brazilian pepper litterfall was below 50 g/m² in most months. Brazilian pepper litterfall was less than that of 3 other species native to Brazil investigated from January to July. However, litterfall peaked at about 120 g/m² in October, which was greater than that of the other species [88]. In mangrove communities along the east-central coast of Florida, Brazilian pepper leaf production was greater than that of red or black mangrove and similar to or greater than that of white mangrove on 3 of 4 sites [112].

Brazilian pepper stands inhibit the spread of fire under some conditions. In pine savanna in Everglades National Park, areas with intermediate density (<4 trees /78.5 m²) of Brazilian pepper burned often, while areas with high density (>6 Brazilian pepper /78.5 m²) did not burn. Unpublished remote sensing data also suggest that fire did not penetrate savannas with high Brazilian pepper abundance [178]. In a pine savanna, areas that were not burned had a dense Brazilian pepper shrub layer, while an area that burned apparently lacked a dense, woody shrub layer [151]. Observers described a decrease in intensity when an"extremely hot" prescribed fire in a pineland reached the ecotone with a Brazilian pepper stand [118]. Wade and others [197] note that intense wildfires do not commonly penetrate dense stands of Brazilian pepper. Because of this, Brazilian pepper hedgerows are often used as firebreaks [197]. Attempts to burn Brazilian pepper using delayed aerial incendiary devices resulted in a patchy burn. There was little fire spread in a Brazilian pepper stand even under dry conditions and with the addition of gasoline [98]. It is likely that the lack of herbaceous cover (see above) in stands dominated by Brazilian pepper contributes to their lack of flammability [44,197].

In a pine savanna in the Long Pine Key area of Everglades National Park, fire temperature under isolated Brazilian pepper trees averaged 225 °F (107 °C), while a control 10 feet (3 m) away averaged 309 °F (154 °C). Dense stands had lower fire temperatures than open stands. The average temperature of fires in areas with no Brazilian pepper within 6.6 feet (2 m) ranged from 262 to 444 °F (128-229 °C), while in areas with dense Brazilian pepper (3 within 6.6 feet) the maximum temperature of the fire was 154 °F (68 °C). In some instances, dense stands apparently did not burn [178].

Fire regimes: Information on fire regimes in which Brazilian pepper evolved is lacking. In North America, there is a wide range of fire regime characteristics among habitats where Brazilian pepper occurs. Most naturally occurring fires in Florida are ignited by lightning during the wet season from May to September [184]. In many areas where Brazilian pepper occurs, presettlement fire regimes have been dramatically altered due to fire exclusion and massive disturbances resulting from human settlement. For example, depletion of aquifers in South Florida has shortened hydroperiods and increased occurrence of severe, peat-consuming fires. Invasion by Brazilian pepper and other nonnative invasive species accompanied these changes [72]. It is unclear how presettlement fire regimes in invaded communities would affect Brazilian pepper establishment, persistence, and spread. See the Fire Regime Table for further information on fire regimes of vegetation communities in which Brazilian pepper may occur.

Fire exclusion from communities that historically experienced frequent, low-severity fires may promote invasion by Brazilian pepper. The likely reduction in fire frequency due to increased hydroperiod associated with impoundments may have facilitated invasion of marsh communities by Brazilian pepper and other woody species [162]. Gange and Cuddihy [65] note that Brazilian pepper and firetree (*Morella faya*) may establish in fire excluded areas that were previously lowland mesic grassland. Frequent fire in pinelands may slow or prevent Brazilian pepper establishment on some sites (see Plant response to fire).

Invasive populations of Brazilian pepper may reduce fine fuel loads, inhibit fire spread, and decrease fire intensity,

especially in plant communities with historically frequent fire (see Fuels). These changes may result in increased fire-return intervals and/or reduced fire severity.

FIRE MANAGEMENT CONSIDERATIONS:

Potential for postfire establishment and spread: Brazilian pepper establishes on some recently burned sites [118,197]. This is most pronounced in areas where invasive populations of Brazilian pepper are well established [45,46]. Research is needed to examine the factors that influence Brazilian pepper's ability to establish in burned areas. See the Fire adaptations and Plant response to fire sections for more detail.

Preventing postfire establishment and spread: Preventing invasive plants from establishing in weed-free burned areas is the most effective and least costly management method. This may be accomplished through early detection and eradication, careful monitoring and follow-up, and limiting dispersal of invasive plant propagules 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: [5,18,74,189].

Use of prescribed fire as a control agent: The low flammability of Brazilian pepper stands [98,118,178], the high likelihood of sprouting following fire [56,118,178], the potential for rapid sprout growth [118], and the ability of Brazilian pepper to establish and persist on some burned sites [45,46,118,197] seriously limit the use of fire as a tool for managing Brazilian pepper in southern Florida. For plant communities with presettlement fire regimes characterized by short fire-return intervals and without abundant Brazilian pepper, repeated burning may limit or prevent Brazilian pepper establishment and spread [98,118,178]. Stevens and Beckage [179] suggest that fire every 4 years is likely to control the early stages of Brazilian pepper invasion in pine rockland savannas of Florida. Although details regarding effects on Brazilian pepper were lacking, prescribed fire in marshes of Sanibel Island was reported to decrease woody species [196]. Koepp [98] also mentions use of fire to reduce Brazilian pepper in marshes and pinelands as "partially successful." Combinations of mechanical treatment and prescribed burning were used to restore coastal scrub on a barrier island in east-central Florida. Brazilian pepper only occurred on some alkaline sites in this study area, and the extent to which treatments impacted Brazilian pepper were not described [163]. Given the descriptive and circumstantial nature of these data, more research on the use of prescribed fire to prevent Brazilian pepper establishment and spread in specific habitats, particularly those outside of Florida, is needed.

A regime of frequent burning may conflict with other management objectives. For example, in Everglades National Park pinelands, pine regeneration may require less frequent but more severe fires than the 5-year prescribed burn interval used to maintain Brazilian pepper at low levels [118]. Simulations suggest that increased length of fire-return intervals or increased propagule pressure may result in conversion from pine savanna to a Brazilian pepper-dominated community [178].

Altered fuel characteristics: Dense Brazilian pepper may alter fuel characteristics on invaded sites. Brazilian pepper stands appear to have low flammability due to a lack of fine fuels and potentially moist conditions. See the Fuels section for more details on this topic.

MANAGEMENT CONSIDERATIONS

SPECIES: Schinus terebinthifolius

- FEDERAL LEGAL STATUS
- OTHER STATUS
- IMPORTANCE TO WILDLIFE AND LIVESTOCK
- OTHER USES
- IMPACTS
- CONTROL

FEDERAL LEGAL STATUS:
None

OTHER STATUS:
Brazilian pepper is considered a noxious weed by Florida Department of Agriculture and Consumer Services [61,66]. Information on state-level noxious weed status of plants in the United States is available at Plants Database.

IMPORTANCE TO WILDLIFE AND LIVESTOCK:
Birds and raccoons eat Brazilian pepper fruits [56] and insects eat Brazilian pepper leaves, seeds, and nectar [85,211,214]. Otherwise it is not widely eaten and may be toxic to some animals [137,205]. Although many animals may use Brazilian pepper stands for cover, they are not considered optimal habitat for many native taxa.

Palatability and nutritional value: Brazilian pepper fruits and leaves may be toxic to humans, young cows, and horses [137,205]. It commonly causes an allergic reaction in people, including an itchy rash and swelling of the face [29,80,137,205]. Domestic goats appear to eat Brazilian pepper without consequence [137] as do a variety of insects [85,211,214]. Brazilian pepper is a nectar source for the atala butterfly, a rare species native to southern Florida [99]. Several bird species are known to eat the fruit regularly [56,123] (see Seed dispersal), and some apparently become intoxicated from consuming Brazilian pepper fruits [137,211]. Raccoons in Florida eat Brazilian pepper fruits [56]. In its native range, Brazilina pepper fruits occurred infrequently in the scat of crab-eating fox and crab-eating raccoon [67]. Brazilian pepper leaves and berries are secondary or seasonal food for gopher tortoises [6]. Box turtles [40] and introduced black spiny-tailed iguanas also eat Brazilian pepper seeds. Brazilian pepper may be especially important for black spiny-tailed iguanas in winter when other foods are scarce [89].

Cover value: Brazilian pepper stands are used by many types of animals. Curnutt [35] reported 6 bird species nesting in Brazilian pepper in Everglades National Park. Red-winged blackbird, common yellowthroat, and eastern towhee densities were higher in a Brazilian pepper stand than densities previously reported for pineland or forest-edge habitats [35]. Use of a cabbage palmetto-Brazilian pepper forest by box turtles on Egmont Key in Tampa Bay was highest in winter. Juveniles used it almost exclusively [40,90], and males generally used it more than females [40]. Black spiny-tailed iguanas use Brazilian pepper thickets for cover and dig their burrows within them [89]. In the Everglades, reptile and amphibian species occurrence was influenced by moisture more than vegetation association. On dry Brazilian pepper sites amphibians and reptiles trapped per check day was low (0.2) and similar to dry sites in hammocks, while on wet Brazilian pepper sites animals trapped per check day was higher (2.3) than most wet sites in other habitats. Species common to disturbed habitats include the southern toad and the eastern narrow-mouthed toad [36]. Cotton mice and cotton rats were common in a roadside area dominated by Brazilian pepper [146]. Florida panthers have

even been observed in Brazilian pepper stands [121].

Despite use by a wide range of animals, Brazilian pepper communities are less suitable than native communities for many taxa. For example, a short-term investigation of breeding birds in a Brazilian pepper stand found total bird density and diversity less than those typically found in other habitats. Difference in methodology between studies may explain at least some of this discrepancy [35]. Brazilian pepper is likely to replace species used as food by white-tailed deer, which are important in the diet of Florida panthers [122]. A positive correlation between gopher tortoise density and grass basal cover (Auffenberg and Iverson cited in [181]) implies that dense stands of Brazilian pepper, with their low herbaceous cover [44] and potential to negatively impact important gopher tortoise forage species [6], are poor habitat for gopher tortoises. Some reptile and amphibian species, including the Florida chorus frog and the ground skink, were rarely or never captured in previously farmed areas in the Everglades, which are commonly dominated by Brazilian pepper. Nonnatives such as the brown anole lizard and the Cuban tree frog were most common in previously farmed areas [36]. Native insects have also been shown to occur in smaller numbers in Brazilian pepper stands. Although a Brazilian pepper stand in Everglades National Park had high diversity of ant species in leaf litter, 55% were nonnative and only 16 individuals of native ants were collected [27]. Gould and Hammer [76] assert that butterflies native to pineland and hammock communities are threatened by the spread of Brazilian pepper due to replacement of host plants. Brazilian pepper may provide poor habitat for mites [202].

OTHER USES:
Brazilian pepper has a variety of uses. In the United States it was originally introduced as an ornamental plant and is still sold for this purpose in some areas [7,56,119,137,211]. Brazilian pepper leaves and berries are used in decorations including Christmas wreaths. A resin of Brazilian pepper is reportedly used to preserve fishing lines and nets [137]. In addition, Brazilian pepper alkaloids [1] and essential oils [172] have shown promise as a mosquito larvicide. In contrast, larvae of an invasive mosquito, *Aedes albopictus*, were positively associated with Brazilian pepper in the field (P=0.0023) and in the lab (P<0.0005) [157]. The 2006 Brazilian pepper management plan [29] provides a review of its uses.

Brazilian pepper is a honey plant in Florida and Hawaii [9,214]. Although the honey is not considered table grade, it is used by bakers and its peppery flavor is appreciated in some areas [9,137]. The nectar and pollen of Brazilian pepper are considered an important fall food source for honeybees by Hawaiian apiarists [214].

In many areas, extracts of Brazilian pepper are used as medicine. Morton [137] lists many possible medicinal uses of Brazilian pepper including use as an antiseptic, relief of respiratory problems, and treatment of arthritis and muscular and tendon complaints. Several investigations have shown Brazilian pepper to have antibacterial [28,79,170], antifungal [79,91,161,165], and antioxidant [14,79,194] properties. The 'elepaio, a native Hawaiian bird, was observed wiping Brazilian pepper fruits on its feathers before preening, potentially controlling parasites or pathogens [193]. Brazilian pepper essential oils exhibited anticancer properties [14], and extracts exhibited antiulcer effects in rats [23]. Silva and others [171] determined that the essential oil of Brazilian pepper leaves "was not remarkably toxic" and recommended its use as an antimicrobial for veterinarian practices. In contrast, de Carvalho and others [38] found that extract from the bark of Brazilian pepper stems had positive mutagenic responses and they do not recommend its use for topical wounds. Several studies have investigated the chemical composition of various parts of Brazilian pepper (e.g., see [10,14,79,171]).

Wood Products: Although Brazilian pepper is not useful as a pulp wood, it is used in toothpicks, posts, railway ties, and construction [137].

IMPACTS:
In Florida, Brazilian pepper is a serious pest and its sale is prohibited [60,61,66,188]. Although statewide impacts are considered limited, the California Invasive Plant Council notes Brazilian pepper has significant local impacts [21].

There is evidence for reduced diversity [145] and negative associations between native plant species and Brazilian pepper [43,144], although the cause of these associations has not been investigated. It is often asserted that dense Brazilian pepper stands displace [65] and shade out [54,80,173] native plants. In mangroves of east-central Florida, sites with Brazilian pepper had significantly (P<0.01) lower abundance of native mangrove species including white

mangrove, red mangrove, black mangrove, chickenclaws, and saltwort (*Batis maritima*) compared to sites where Brazilian pepper was absent [43]. Densities of 2 rare pine rockland species, pineland milkpea (*Galactia pinetorum*) (P=0.008) and wedge sandmat (*Chamaesyce deltoidea* ssp. *adhaerens*) (P=0.048), are negatively correlated with Brazilian pepper densities in pine rockland dominated by south Florida slash pine [144]. On the southeastern coast of Florida on a site where Brazilian pepper was distributed from 20 to 190 feet (6-58 m) above high tide, increases in woody cover (including Brazilian pepper) were negatively (P=0.001) correlated with the number of species per plot [106]. Based on data collected from Hole-in-the-Donut in Everglades National Park from mid-2004 to mid-2005, areas with native vegetation had 105 species compared to 62 species in untreated Brazilian pepper stands. Only sites that underwent complete soil removal (treated sites) 6 months previously had fewer species on average than untreated Brazilian pepper stands. Brazilian pepper stands had greater cover than native vegetation and treated sites. Native and treated vegetation had similar cover of nonnative species, typically less than 5%. In contrast, nonnative species comprised an average of 44% of the ground cover and Brazilian pepper comprised 77% of aerial cover in untreated Brazilian pepper stands [145]. The pattern of reduced diversity is not consistent in all habitats. Brazilian pepper was associated with greater species richness in mangrove swamps of east Florida. This is likely due to the low salinities, low soil moisture, and open canopies allowing for establishment of species that did not occur in less disturbed mangroves, including wax myrtle, yaupon, groundsel-tree, and Brazilian pepper [43].

In Hawaii Brazilian pepper may displace several endangered species including 'awiwi (*Centaurium sebaeoides*) [133], opuhe (*Urera kaalae*) (Obata 1986, cited in [33]), Hawaii lady's nightcap (*Bonamiz menziesii*), erect island spleenwort (*Diellia erecta*), and mehamehame (*Flueggea neowawraea*). Information on several endangered Hawaiian species impacted by Brazilian pepper is included in the recovery plan for multi-island plants [191].

Alterations to litter fall and nutrient cycling may have detrimental impacts to sites invaded by Brazilian pepper. The turnover rate of Brazilian pepper litter was 0.44 years, faster than that of southern cattail (*Typha domingensis*) and black bogrush (*Schoenus nigricans*) in Hole-in-the-Donut, Everglades National Park. Phosphorus and nitrogen mineralization in Brazilian pepper litter was also greater than that in southern cattail and black bogrush litter. Farming and Brazilian pepper invasion have "increased phosphorus availability, altered microbial activities and reduced nitrogen transformation rates" [96]. Reduction in mangrove leaf fall due to Brazilian pepper invasion may be detrimental to estuarine waters [112], as could the potential allelopathic effects of Brazilian pepper litter on mangroves [41] and microalgae in coastal areas [82].

Hydrological feedbacks between different vegetation types and surrounding water bodies in Everglades National Park suggest a potential for invasion of nonnative species, such as Brazilian pepper, to alter regional ecosystem dynamics [195].

Laboratory studies suggest that Brazilian pepper extracts have allelopathic effects [71,136,142], although field tests are not available. Height growth (P=0.001) and leaf production (P<0.001) were reduced in red mangroves exposed to crushed Brazilian pepper fruit for 16 weeks compared to controls. Height growth and biomass of black mangrove were significantly reduced by exposure to high densities of intact Brazilian pepper fruit in water with a salinity of 30 ppt [41]. High concentrations (1:10) of Brazilian pepper leaf extract resulted in reduced growth of 3 of 4 microalgae tested, while low concentrations (1:1,000) resulted in enhanced growth for 2 of these species when compared with controls [82]. Lettuce (*Lactuca sativa*) [142], ripgut brome (*Bromus rigidus*) [71], and romerillo (*Bidens alba*) [136] germination were reduced when exposed to Brazilian pepper fruit or leaf extracts. Lettuce and cucumber (*Cucumis sativus*) exhibited significant (P<0.05) reductions in radicle growth when exposed to oil extracted from Brazilian pepper leaves or fruit at a concentration of 10,000 µg/mL [10].

Other impacts associated with Brazilian pepper invasion are addressed in other sections of this review: the wide range of community types where it can establish (see Habitat Types and Plant Communities), its impacts on animals (see Cover value), and its potential to alter fuel characteristics and possibly fire regimes in invaded communities. Based on Brazilian pepper's regeneration, life form, and impacts in native communities on 3 South Florida sites impacted by Hurricane Andrew, Brazilian pepper was categorized in the "seed-rain-of-terror" functional group [87]. Given these potential impacts and the already limited distribution of many invaded communities, including pine rocklands in Florida [144], invasion by Brazilian pepper is a major concern.

CONTROL:
Reviews on various control methods for Brazilian pepper are available [29,59,154]. Smith [173] provides general weed management recommendations for Brazilian pepper in Hawaii. Removal should be performed carefully, since direct contact with the sap may cause serious rashes and people who are sensitive have respiratory reactions to chemicals emitted by Brazilian pepper blooms [137]. It is important that results of control efforts are monitored [59] and soil disturbances and thinning of the canopy are minimized, especially during January and February when Brazilian pepper typically germinates [56,98,184]. Regardless of the method used follow-up treatments are likely needed prevent reestablishment of Brazilian pepper [80].

Education and public participation have been important to several Brazilian pepper control initiatives. Zarillo [215] describes the creation of "pepper busting days," and Clark [26] acknowledges the importance of collaboration between public and private groups to form an effective Brazilian pepper control program on Sanibel Island.

Kruer and others [102] describe mapping Brazilian pepper using field surveys, Lass and Prather [110] used a hyperspectral sensor to detect Brazilian pepper stands, and Pearlstine [150] describes a technique for detecting Brazilian pepper using low altitude digital images.

Prevention: The most effective method for managing invasive species is to prevent their establishment and spread. Some methods of prevention include monitoring several times each year [92], limiting seed dispersal, containing local infestations, detecting and eradicating weed introductions early, establishing and encouraging desirable competitive plants [167], minimizing disturbances [43,167], and maintaining "healthy" natural communities [120,167]. Managing to maintain the integrity of the native plant community and mitigate the factors enhancing ecosystem invasibility is likely more effective than managing solely to control the invader [86]. To decrease the seed source, commercial sale of Brazilian pepper was banned in Florida in 1990 [59]. Specific recommendations to prevent spread of invasive species in Florida include strengthening legislation that prohibits their sale or trade, requiring quarantine of livestock or other animals being moved from infested areas until propagules have been cleared from their systems, and development of educational programs to increase public awareness of the costs associated with invasive species [75]. Fire may prevent and/or slow Brazilian pepper establishment in some communities (see Use of prescibed fire as a control agent).

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 [189]. See the Guide to noxious weed prevention practices [189] for specific guidelines in preventing the spread of weed seeds and propagules under different management conditions.

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

Cultural control: Successful control of Brazilian pepper and other nonnative species was reported after removal efforts were followed by planting of native hardwood swamp species in Boyd Hill Nature Trail, a park in St. Petersburg, Florida [22].

Physical or mechanical control: Manual removal of Brazilian pepper seedlings is recommended in natural areas, since use of heavy machinery creates an environment favorable to Brazilian pepper establishment. Heavy equipment is used in already disturbed areas, such as ditch banks [59]. Mechanical operations that disrupt the vegetation while placing large volumes of Brazilian pepper seed on the soil will likely lead to reinvasion, perhaps at greater density than the original population [55]. Whether removed manually or with machinery, Brazilian pepper roots must be removed or the plant will sprout [98,154]. Leaving chipped Brazilian pepper as a mulch and planting native species was successful in restoring a pine rockland community in southern Florida, possibly due to the mulch suppressing Brazilian pepper germination [200]. Use of herbicide to reduce sprouting is common [34,59,108].

It is likely that restoration of historic water regimes of southern Florida would be effective in controlling Brazilian pepper, given its intolerance of prolonged flooding (see Site Characteristics: Water). In a previously farmed area within Everglades National Park, complete soil removal resulted in minimal reestablishment of Brazilian pepper. Removal of the disturbed substrate and slightly longer hydroperiod allowed for wetland plants to establish [37,145]. By June 2005 about 63% of the Hole-in-the-Donut region had been restored, 2.4% had been converted to soil disposal

mounds, and 35% remained as Brazilian pepper forest. It was estimated that the entire region would be restored by 2010 using this method [145]. Success of hydro-leveling spoil mounds dominated by Brazilian pepper to restore a mangrove community requires lowering mounds to the same level as the surrounding wetland, distributing the mound spoil well into adjacent wetlands to prevent burial of native vegetation, and, in some instances, planting native species to speed revegetation [174]. Since this method is appropriate for low lying areas with disturbed soil and is likely costly, these methods will only be useful in a narrow range of circumstances.

Biological control: Considerable research investigating insect biological control agents for Brazilian pepper is available. They have been studied in Hawaii since the 1950s [100,210] and in Florida since the late 1980s [15]. Releases in Hawaii do not appear to have resulted in substantial effects on Brazilian pepper [100,173,214]. As of 2010, biological control agents have not been released in Florida, although release has been recommended for a thrips species (*Pseudophilotrips ichini*) and a sawfly (*Heteroperreyia hubrichi*), and an application has been submitted for release of a leaflet roller (*Episimus unguiculus*). Release of the sawfly was not granted a permit by APHIS due to concerns about toxins present in the larvae that could harm native fauna if ingested [32]. See Cuda and others [30,31] and Manrique and others [126] for more detailed information on the thrips, and see Manrique and others [124,125,127] and Martin and others [128] for information on the leaflet roller. Several other species have been suggested as possible biological control agents (e.g., [29,130,164]) but are much less studied. A brief summary of initial surveys of insects associated with Brazilian pepper in Florida is included in Florida's Brazilian Peppertree Management Plan [29]. Reviews of Brazilian pepper biological control are also available: [29,85,214].

Brazilian pepper trees that were defoliated 5 times in 3 years had significantly fewer berries than Brazilian pepper trees that were not defoliated or were defoliated less frequently. The authors suggest that targeting biological control efforts on juveniles may be more effective [185].

Some plants and fungi have detrimental impacts on Brazilian pepper. For instance, in a laboratory experiment Brazilian pepper given nutrient solution drained through pots containing wax myrtle had significantly ($P<0.01$) lower leaf production and stem weights than Brazilian pepper in the control, which were given nutrient solution drained through pots containing kidney beans (*Phaseolus vulgaris*). The experiment also provided circumstantial evidence that the Brazilian pepper in the wax myrtle treatment were more susceptible to disease [49]. Brazilian pepper seeds exposed to a compound found in the roots of annual ragweed (*Ambrosia artemisiifolia*) had significantly ($P<0.05$) lower germination than controls [168]. In Florida field sites, Brazilian pepper parasitized by devil's gut had significantly ($P\leq0.001$) lower leaf area and fruit production than Brazilian pepper nearby that were not parasitized. Parasitized Brazilian pepper had an average of 321.9 fruits in a 2.7 ft² (0.25 m²) area on the canopy, while the same area on nonparasitized trees averaged 1,119.8 fruits [19]. In a greenhouse, Brazilian pepper parasitized by devil's gut for 1 month had lower leaflet biomass ($P=0.02$) and relative growth rate ($P=0.002$), and those parasitized for 3 months produced fewer ($P<0.05$) flowers than Brazilian pepper plants that were not parasitized [125]. Brazilian pepper is also host to several fungi, including root rot, *Verticillium* wilt [176], and *Neofusicoccum batangarum* [169]. Wiggers [202] suggested that the success of pathogen-based biological control efforts may be limited due to the abundance of fungivorous mites found on Brazilian pepper in southern Florida.

Biological control of invasive species has a long history that indicates many factors must be considered before using biological controls. Refer to these sources: [192,206] and the Weed control methods handbook [186] for background information and important considerations for developing and implementing biological control programs.

Chemical control: Several investigations of herbicide effectiveness for Brazilian pepper control have been undertaken. Some of the most extensive investigations include a study of various herbicides and application times and methods in Queensland, Australia [147], and experiments addressing the most cost effective way to control Brazilian pepper stands with minimal impacts on neighboring mangroves in southern Florida [114]. Preliminary results of several herbicides and application techniques is provided by Woodall [208]. Recommended herbicides for basal and cut surface applications, and information regarding the effectiveness of foliar applications of 3 herbicides are discussed by Kline and Duquesnel [97].

Herbicides are frequently used following cutting Brazilian pepper [34,59,108]. Herbicide application after fire has also been suggested, but not tested [207]. Langeland and others [107] list herbicides by application method and note that

glyphosate alone is less effective in spring and early summer than at other times of the year. The effect of season of application was demonstrated by a reduction in the effectiveness of basal bark applications from March to May, presumably due to inefficient translocation of the herbicide due to dry conditions [46]. On a mangrove site in east-central Florida, areas 33 to 66 feet (10-20 m) above the intertidal zone that were chemically treated had higher densities of Brazilian pepper approximately 11 months following treatment than areas in this zone that were not chemically treated. It is suggested that chemical treatment opened the canopy, resulting in increased Brazilian pepper recruitment [43]. Reviews that provide information on chemical control are available (e.g. [29,59,154]).

The effectiveness and efficiency of matricide using chemical control was initially investigated by Ewel and others [56], and Langeland and others [107] recommend focusing on female plants when resources are limited. However, due to similar time requirements for treatment of females only and treatment of an entire stand and the regular occurrence of male trees producing female flowers and viable fruit, Doren and Whiteaker [44] concluded this method would not improve control of Brazilian pepper.

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 [20] and may have negative impacts on nontarget species. For instance, Ashton and others recommend considering gopher tortoises and the retention of herbicides in plant tissue, water, and soil when using herbicides [6]. See the Weed control methods handbook [186] for considerations on the use of herbicides in natural areas and detailed information on specific chemicals.

Integrated management: Details of an integrated management plan for Florida, including biological control, are included in [29].

APPENDIX: FIRE REGIME TABLE

SPECIES: Schinus terebinthifolius

The following table provides fire regime information for plant communities and ecosystems where Brazilian pepper is likely to occur. Follow the links in the table to documents that provide more detailed information on these fire regimes. This list may not be inclusive for all plant communities in which Brazilian pepper occurs. For information on fire regimes in plant communities not listed here, see the Expanded Fire Regime Table.

Fire regime information on vegetation communities in which Brazilian pepper may occur. This information is taken from the LANDFIRE Rapid Assessment Vegetation Models [105], 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.

California | South-central US | Southeast

California

- California Grassland
- California Shrubland

Vegetation Community (Potential Natural Vegetation Group)	Fire severity*	Fire regime characteristics			
		Percent of fires	Mean interval (years)	Minimum interval (years)	Maximum interval (years)

California Grassland					
California grassland	Replacement	100%	2	1	3
California Shrubland					
Coastal sage scrub	Replacement	100%	50	20	150
Coastal sage scrub-coastal prairie	Replacement	8%	40	8	900
	Mixed	31%	10	1	900
	Surface or low	62%	5	1	6
Chaparral	Replacement	100%	50	30	125

South-central US

- South-central US Grassland
- South-central US Woodland

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					
Bluestem-sacahuista	Replacement	70%	3.6	1	
	Mixed	30%	7.7	2	
South-central US Woodland					
Mesquite savanna	Replacement	5%	100		
	Mixed	4%	150		
	Surface or low	91%	6		

Southeast

- Southeast Grassland
- 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 Grassland					
Everglades sawgrass	Replacement	96%	3	2	15
	Surface or low	4%	70		
Floodplain marsh	Replacement	100%	4	3	30
Everglades (marl prairie)	Replacement	45%	16	10	20
	Mixed	55%	13	10	
Palmetto prairie	Replacement	87%	2	1	4
	Mixed	4%	40		
	Surface or low	9%	20		
Pondcypress savanna	Replacement	17%	120		
	Mixed	27%	75		
	Surface or low	57%	35		
Southern tidal brackish to freshwater marsh	Replacement	100%	5		
Southeast Woodland					
Longleaf pine (mesic uplands)	Replacement	3%	110	40	200
	Surface or low	97%	3	1	5
Pine rocklands	Mixed	1%	330		
	Surface or low	99%	3	1	5
South Florida slash pine flatwoods	Replacement	6%	50	50	90
	Surface or low	94%	3	1	6
Southeast Forested					
Maritime forest	Replacement	18%	40		500
	Mixed	2%	310	100	500
	Surface or low	80%	9	3	50
Mesic-dry flatwoods	Replacement	3%	65	5	150
	Surface or low	97%	2	1	8
South Florida coastal prairie-mangrove swamp	Replacement	76%	25		
	Mixed	24%	80		

Southern floodplain	Replacement	7%	900		
	Surface or low	93%	63		

*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 [81,104].

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