Imperata brasiliensis, I. cylindrica

INTRODUCTORY

Cogon grass stand. Photo by Kazuo Yamasaki.

AUTHORSHIP AND CITATION:
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FEIS ABBREVIATION:
IMPBRA
IMPCYL
IMPSPP

SYNONYMS:
Imparata brasiliensis Trin. [163]

NRCS PLANT CODE [151]:
IMBR
IMCY

COMMON NAMES:
Brazilian satintail

cogon grass
alang-alang
Japanese bloodgrass
spear grass

TAXONOMY:
The scientific name of **Brazilian satintail** is *Imperata brasiliensis* Trin. (Poaceae) [24,41,43,64,173].

The scientific name of **cogon grass** is *I. cylindrica* (L.) Beauv. (Poaceae) [24,41,43,64,72,105,173]. Some authorities recognize 5 varieties of cogon grass; according to that treatment, *I. c.* var. *major* (Nees) CE Hubb. is the entity found in North America [64,133]. Gabel [43] does not recognize varieties of cogon grass.

Brazilian satintail and cogon grass are morphologically and genetically very similar, and their hybrids produce fertile offspring [57,133,165]. Hybridization, introgression, and overlapping morphological characters often cause taxonomic confusion between the 2 species, especially in North America. Some systematists consider the 2 species synonymous [24,57]. Hall [57] suggests that Brazilian satintail be classified as an infrataxon within *I. cylindrica*. Gabel [43] separates the taxa as 2 distinct species based upon continents of origin and morphological, cytological, and genetic attributes. This review treats Brazilian satintail and cogon grass as 2 distinct species.

Because there is little English-language literature currently available on Brazilian satintail, this review provides information mostly on cogon grass. Pertinent information on Brazilian satintail is included whenever possible. Given the taxonomic status of *Imperata*
in North America, information included in this review may apply equally to both species; however, further research is needed to be certain the 2 taxa respond similarly to fire and control treatments.

LIFE FORM:
Graminoid

FEDERAL LEGAL STATUS:
Noxious weeds [149]

OTHER STATUS:
Brazilian satintail and cogon grass were on these state and Forest Service weed lists as of 2005:

Area	Rank	
	Brazilian satintail	Cogon grass
Alabama	Class A noxious weed	Class A noxious weed
California	Quarantined	Quarantined
Florida	Noxious weed	Noxious weed
Georgia	----	Noxious weed
Hawaii	----	Noxious weed
Massachusetts	Noxious weed	----
Minnesota	Prohibited noxious weed	Prohibited noxious weed

North Carolina	Class A noxious weed	Class A noxious weed
Oregon	Quarantined	Quarantined
South Carolina	Plant pest	Plant pest
Vermont	Class A noxious weed	Class A noxious weed [151]
Virginia	----	Highly invasive [157]
U.S. Forest Service, Southern Region	Category 1	Category 1 [150]

DISTRIBUTION AND OCCURRENCE

SPECIES: Imperata brasiliensis, I. cylindrica

- GENERAL DISTRIBUTION
- ECOSYSTEMS
- STATES/PROVINCES
- BLM PHYSIOGRAPHIC REGIONS
- KUCHLER PLANT ASSOCIATIONS
- SAF COVER TYPES
- SRM (RANGELAND) COVER TYPES
- HABITAT TYPES AND PLANT COMMUNITIES

GENERAL DISTRIBUTION:
Brazilian satintail
is native to southern North America, Central America, and South America. Its native distribution extends from the Cape Region of Baja California Sur, Mexico, south to Brazil and Argentina [64,163,165]. Elsewhere in North America, it is present but nonnative in the Gulf Coast states from eastern Louisiana to South Carolina (excluding Georgia, where it does not occur) [3,24,72,173]. It is most common in coastal counties of the Southeast, although it has scattered inland occurrences [41]. Brazilian satintail also occurs in Puerto Rico and the West Indies [44,72]. Its distribution overlaps with cogon grass in Florida [64] and possibly elsewhere in the Southeast [57,133,165].

Cogon grass is native to Korea, Japan, China, India, and tropical eastern Africa [36,64,105]. It is nonnative and invasive throughout other tropical regions of the world. In North America it occurs along the Gulf Coast from Mexico east to South Carolina [4,72]. In the United States it is most common in Mississippi, coastal Alabama, and Florida [41]. Hitchcock [61] listed cogon grass as present in Oregon in 1950, although it has not been collected in Oregon for decades. There were 2 known locations of cogon grass introduction in the United States: 1 from Japan to Alabama in 1912, as packing material in a shipment of Unshu orange (*Citrus reticulata*) trees; and another from the Philippines to Mississippi in 1921, as a possible forage grass [32,44,142,143]. More than 1,000 acres (400 ha) of cogon grass were planted for livestock forage and soil stabilization in Florida the late 1930s and 1940s [31,133].

Grass Manual on the Web provides distributional maps of **Brazilian satintail** and **cogon grass**. It is commonly assumed that cogon grass is the more common of the 2 species; however Brazilian satintail or Brazilian satintail × cogon grass hybrid swarms may be misidentified as cogon grass [86,142]. Distributions of Brazilian satintail and Brazilian satintail × cogon grass hybrids may be more extensive in the Southeast than is currently known [44]. The 2 species occur in similar habitats in the Southeast [36,64]. The following lists give biogeographic classifications where Brazilian satintail and cogon grass are known to be present or invasive. These lists may not be exhaustive.

Brazilian satintail and **cogon grass:**
ECOSYSTEMS [45]:
FRES12 Longleaf-slash pine
FRES13 Loblolly-shortleaf pine
FRES14 Oak-pine

STATES/PROVINCES: (key to state/province abbreviations)
Brazilian satintail:
UNITED STATES

AL	FL	LA	MS	SC	PR

Cogon grass:
UNITED STATES

AL	FL	GA	LA	MS	SC	TX

MEXICO

Brazilian satintail and **cogon grass:**
BLM PHYSIOGRAPHIC REGIONS [10]:
None

KUCHLER [79] PLANT ASSOCIATIONS:
K111 Oak-hickory-pine
K112 Southern mixed forest
K114 Pocosin
K115 Sand pine scrub
K116 Subtropical pine forest

SAF COVER TYPES [38]:
69 Sand pine
70 Longleaf pine
71 Longleaf pine-scrub oak
74 Cabbage palmetto
75 Shortleaf pine
76 Shortleaf pine-oak
80 Loblolly pine-shortleaf pine
81 Loblolly pine
82 Loblolly pine-hardwood
83 Longleaf pine-slash pine
84 Slash pine
85 Slash pine-hardwood
98 Pond pine
111 South Florida slash pine

SRM (RANGELAND) COVER TYPES [132]:
808 Sand pine scrub
809 Mixed hardwood and pine
810 Longleaf pine-turkey oak hills
811 South Florida flatwoods

812 North Florida flatwoods
813 Cutthroat seeps
814 Cabbage palm flatwoods
816 Cabbage palm hammocks
817 Oak hammocks
820 Everglades flatwoods

HABITAT TYPES AND PLANT COMMUNITIES:
Brazilian satintail occupies pine (*Pinus* spp.) and oak (*Quercus* spp.)-pine communities of the Southeast. Descriptions of southeastern plant communities infested with Brazilian satintail were not found in the literature. Studies to determine if and how Brazilian satintail affects composition and diversity of such plant communities are needed.

Details of Brazilian satintail communities of South America are also limited. In Peru, Brazilian satintail dominates montane savannas. Copperleaf (*Acalypha* spp.), muttonwood (*Rapanea* spp.), speedwell (*Veronica spp.),* and false-willow (*Baccharis* spp.) are dominant woody genera; bracken fern (*Pteridium aquilinum*) often codominates on Brazilian satintail grassland areas. Scott [128] lists associated plant species on Brazilian satintail-dominated savannas of eastern Peru.

Cogon grass occurs in southeastern pine and oak-pine communities that experience frequent fire (see Cogon grass in North America for further details). It is most common in the ground layer of mesic longleaf pine (*Pinus palustris*) savannas [13]. Oaks including blackjack oak (*Q. marilandica*), turkey oak (*Q. laevis*), and southern red oak (*Q. falcata*) are often frequent in the overstory. Common shrub associates of cogon grass include persimmon (*Diospyros virginiana*), black highbush blueberry (*Vaccinium fuscatum*), dwarf huckleberry (*Gaylussacia dumosa*), and bitter gallberry (*Ilex glabra*). Common groundlayer associates include big bluestem (*Andropogon gerardii*), paintbrush (*A. tenerius*), Beyrich threeawn (*Aristida beyrichiana*), golden colicroot (*Aletris aurea*), and roundleaf thoroughroot (*Eupatorium rotundifolium*) [109]. Cogon grass occurs in south Florida slash pine/firegrass (*Pinus elliottii* var. *densa/Andropogon cabanisii*) savannas of Everglades National Park. Brazilian peppertree (*Schinus terebinthifolius*) and silkreed (*Neyraudia reynaudiana*) are other nonnative invasive associates inventoried on Everglades savannas. Cogon grass dominates some grassland sites in the Everglades [113].

In Puerto Rico, cogon grass occurs in early seral bracatinga (*Mimosa scabrella*) forests. Leandra (*Leandra australis*) and cappel (*Palicourea*
spp.) also occur in the overstory. Groundlayer associates include hemlock-rosette grass (*Dichanthelium sabulorum*) and flatsedge (*Cyperus hermaphroditus*) [54].

In Southeast Asia, cogon grass dominates extensive grassland areas. It also dominates the ground layers of Khasia pine (*Pinus kesiya*), Chir pine (*Pinus roxburghii*), and other pine forests that experience frequent surface fires [36,97]. Sticky snakeroot (*Eupatorium adenophorum*), which is native to Southeast Asia, is commonly associated with cogon grass in both the Old and New Worlds [97]. Jack-in-the-bush (*Eupatorium odoratum*) and broadleaf carpet grass (*Axonopus compressus*) are other common associates on Asian grasslands subject to frequent fire that also co-occur with cogon grass in the southeastern United States [80,82,103,144,172]. Cogon grasslands in Asia can become increasingly diverse with time since last fire [36]. Eussen [36] and Tanimoto [144] provide further descriptions of cogon grassland associations of Southeast Asia.

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Imperata brasiliensis, I. cylindrica

- GENERAL BOTANICAL CHARACTERISTICS

GENERAL BOTANICAL CHARACTERISTICS:
This description provides characteristics that may be relevant to fire ecology, and is not meant for identification. Keys for identification of Brazilian satintail and cogon grass are available (e.g. [24,43,64,163,173]). Gabel [43] and Hubbard [64] provide detailed morphological and cytological descriptions of Brazilian satintail, cogon grass, and other *Imperata* species.

Brazilian satintail is lesser known, and hence more poorly described, in the United States. It has slender, erect culms from 14 to 29 inches (36-74 cm) tall. Leaves are mostly basal and about 5 to 13 mm wide. The inflorescence is a 3- to 8-inch (7-20 cm), terminal panicle [163]; the fruit is a caryopsis. Brazilian satintail is rhizomatous, with a mat-like growth form [43,163].

Cogon grass grows to 3 feet (1 m) in height [24,105]. Leaves are mostly basal, growing from the rhizomes. Basal leaves are 0.4 to 0.8 inch (1-2 cm) wide [43]. A few small upper leaves occur on the pedestal [24,105]. The leaves have a characteristic white midrib that is set off-center. Being high in silica [25], cogon grass leaves are coarse in texture [25,160]. The inflorescence is a dense, 4- to 8-inch (10-20 cm) panicle of paired spikelets. Spikelets are unawned with long (~12 mm), silky hairs [24,105]. The seeds are small (1-1.3 mm long) [74,75].

The root system is fibrous. Cogon grass rhizomes are "tough and scaly," with short internodes forming a dense underground mat. Cogon grass rhizomes develop in 2 stages: primary seedling rhizomes, and secondary rhizomes that sprout from seedling rhizomes [43]. Rhizome and root depths vary with substrate. In central Florida, Gaffney [43] found cogon grass rhizomes were restricted to the top 4 to 6 inches (10-15 cm) of soil on a phosphate mine site, but grew down to 30 inches (80 cm) below ground on a clay settling pond site [43]. In Southeast Asia, rhizomes typically occur 4 to 20 inches (10-40 cm) below ground and form dense, extensive layers. Some rhizomes grow as deep as 3 feet (1 m) [8,100]. Cogon grass's growth habit is loose to clumped, compacted aerial stems arising from the dense rhizome mat [34,43]. Dense stands may form monocultures [43,87].

Brazilian satintail and **cogon grass**
are both nonnative, rhizomatous perennial grasses that are similar in appearance. They are primarily distinguished between 1 another by stamen numbers: Brazilian satintail usually has 1 stamen/flower, and cogon grass has 2 stamens/flower [43,64,106]. Other distinguishing characteristics include Brazilian satintail's relatively shorter spikelets (<3.5 mm) and narrower culm leaves (<5 mm) compared to cogon grass's spikelets and leaves [3]. These characteristics overlap [43,86], however, and it is likely that the 2 grasses have been misidentified in the Southeast [86]. Identification is further confounded by Brazilian satintail × cogon grass hybridization in the Southeast, the extent of which is unknown [165].

RAUNKIAER [119] LIFE FORM:
Both species are geophytes.

REGENERATION PROCESSES:
Brazilian satintail regenerates from rhizomes and seed [64]. It is pollinated by wind [133]. To date (2005), English-based literature does not provide many details on Brazilian satintail reproduction; such studies are needed for best Brazilian satintail management. Since they are closely related, the information given below for cogon grass may also apply to Brazilian satintail.

Cogon grass reproduces from seed, rhizome expansion, and rhizome fragments [43,86]. Both seed and rhizome regeneration are important in its spread. Seed reproduction allows for long-distance dispersal and colonization, whereas rhizome spread is the primary means of population expansion [56,64]. Transported rhizome fragments also contribute to its long-distance dispersal and colonization [86].

Breeding system: Cogon grass is outcrossing [43,50,125,133]. Clonal populations show low or no fertility [94]. *Imperata cylindrica* var. *major*
shows considerable diversity in reproductive morphology and physiology in Asia ([14] and references therein),[124,146]. A central and northern Florida study suggested a high degree of genetic variability among cogon grass populations. Populations with low genetic diversity tended to have low seed viability, while populations with high genetic diversity had high seed viability. It is not known whether low seed viability was due to inability to outcross, poor environmental conditions, or other factors. The authors concluded that successful outcrossing was low in most cogon grass populations, but higher rates of genetic diversity and fecundity could be expected as southeastern populations expand and outcross [133].

Pollination: Cogon grass is pollinated by wind [94,133].

Flower production:
Cogon grass flower production is highly variable. Some researchers report cogon grass as highly productive [43], but flowering is often sporadic, ranging from none to frequent flowering within and among populations [33,43,106,170]. In a common garden study using Malaysian collections, some cogon grass populations frequently produced flowers; others never produced flowers (but spread vegetatively); while most produced flowers only after mowing disturbance [125]. Disturbances including nitrogen amendment, slashing, burning, defoliation, and grazing may trigger cogon grass flowering [43,63]. However, Shilling and others [133] found consistent flowering in 11 Florida cogon grass populations, none of which were disturbed. Field and greenhouse studies suggest that cogon grass flowering is not photoperiod dependent [133].

Seed production
and seed viability likewise vary widely among populations. A Florida study found that geographically isolated cogon grass populations did not produce seed, but plants within the population produced fertile seeds when cross-pollinated with pollen from another population [94]. Saijise [124] found a mean of 700 seeds/panicle on cogon grass plants in the Philippines. A spikelet count in Florida showed a mean of 363 ± 47.5 spikelets/panicle. Actual production was higher because some spikelets had shattered prior to data collection [133]. A Malaysian study found heavy flower production followed by low seed set [125]. Preliminary investigations in Florida found flowers growing under stressful conditions rarely produced seed, so cogon grass has sometimes been labeled as a poor seed producer [36,124]. However, later research showed cogon grass can produce seed prolifically, even after disturbance [94,133]. Fire, tillage, mowing, and cold stress may stimulate cogon grass flower and seed production [124].

Seed/rhizome dispersal:
Cogon grass seed is spread by wind. The seeds are small and light weight, with long, hairy plumes aiding wind carriage [43,94,133,164]. Cogon grass seeds may drift 15 miles (20 km) in open country [64]. Shilling and others [133] showed that wind can disperse cogon grass spikelets up to 360 feet (110 m) from the parent plant. Cogon grass spread in Alabama from 1973 to 1985 was apparently due to northeasterly prevailing winds from the Gulf of Mexico blowing seeds up Interstate 65 [164,165].

Roads and road construction are important corridors for cogon grass dispersal [16,169]. Rhizomes are transported by machinery and fill dirt during construction [43,107]. Most long-distance dispersal of cogon grass is probably from inadvertent human transport of rhizomes and seeds [86]. Willard and others [169,170] speculated that cogon grass spread in Florida was mostly from transporting soil contaminated with cogon grass propagules.

Seed banking: Cogon grass seed is short lived, generally remaining viable in the soil for about 1 year [50]. Viability of seeds stored in a laboratory steadily decreased over 13 months [33]. Field studies in Asia show a maximum seed life of 16 months [124,125].

Germination:

Cogon grass seeds are not dormant and do not require stratification. They germinate 1 to 4 weeks after ripening [8,33,124,125,133]. Shilling and others [133] found that with 11 Florida cogon grass populations, seeds began germinating within 7 days of harvest, with 94% germination by day 14. Seed viability is variable. Seed collected from 9 sites in central Florida showed high variability in germination rate between sites, with viability ranging from 0% to 100% [133]. An Alabama study found 80% to 95% seed viability [33]; another study found 0% germination in Mississippi and 20% in Florida in the same year [64]. Across years in a single population, an Alabama study found 4% germination in 1970 and 70% germination in 1972 [31].

In the laboratory, cogon grass seed collected in Alabama germinated at temperatures from 77 °F to 95 °F (25 °C-35 °C), with best germination at 86 °F (30 °C). Light increased germination time and rate [33]. A Philippine study also found high germination (>80%) in open areas [124]. Light and soil fertility interactions may affect germination. In Florida, seeds germinated with light did not show an increased germination rate when fertilized with potassium nitrate solution; however, seed germinated in the dark had highest germination rate with addition of potassium nitrate [33].

Seedling establishment: Seedlings establish best on open, disturbed areas [8]. In a greenhouse study conducted on seed bank samples collected over 2 years in Polk County, Florida, cogon grass seed emerged over a 3-month period. Seedling density averaged 1.9 ± 0.48 seedlings/m². There was no significant difference (p=0.78) in seedling emergence between collection years, but emergence differed significantly (p=0.001) with month of soil collection. Best emergence occurred in samples collected from April to June, particularly samples collected in May. Another emergence spike occurred in samples collected in December and January. Seedlings did not emerge from soil samples colleted in other months [133]. Cogon grass seedlings tend to emerge in clumps, reflecting the tendency of spikelets to disperse in clumps [34]. Seedling mortality is generally high, with about 20% of emergents surviving to produce seed. Risk of mortality probably lessens when seedlings sprout rhizomes [133].

For established populations, **asexual regeneration** from rhizomes is cogon grass's primary method of expansion [7,43]. Kushwaha and others [82] reported that on old fields in India, cogon grass regenerated from mostly seed on recently burned, clipped, or abandoned plots, but regenerated only from rhizomes on 3- to 5-year-old fallows. On 2 study sites in Mississippi, cogon grass spread into longleaf pine savannas from infested roadsides. Spread was almost entirely from rhizomes. Rhizome spread slowed, but did not stop, as the populations expanded into interior savannas [165]. Eussen [36] reported that cogon grass can produce 350 rhizomes in 6 weeks, and cover 4 m² in 11 weeks.

Regenerative capacity of cogon grass rhizomes is linked to stem age, length, thickness, and number of large buds. Only old ("2nd generation" or rhizomes arising from rhizome buds) rhizomes can sprout and grow roots [43]. Rhizomes sprout readily after mowing, grazing, or burning removes top-growth [8]. A low root:rhizome ratio aids in rapid regrowth after fire or mowing [124]. In a growth chamber study, Ayeni and Duke [8] found old, large rhizome segments showed best stem sprouting and biomass gain compared to small, younger rhizome segments. Soerjani [136] found rhizome sprouting ability was not restricted by bud size, position on the node, internode length, or node diameter. In greenhouse and laboratory experiments, potted rhizomes buried deeper than 3 to 8 inches (8-20 cm) below the soil surface show poor sprouting ability [36,165].

Possibly because of low intrapopulation genetic diversity and inability to outcross, isolated cogon grass populations reproduce mostly or entirely by clonal expansion from rhizomes. Although rhizome growth is rapid, populations that reproduce mostly by cloning probably have lower overall rates of expansion compared to populations that reproduce from both seed and rhizomes. Overall rates of invasion probably increase when seed-reproducing cogon grass populations expand into and cross-pollinate with previously rhizome-expanding populations [86].

Growth: Ramet growth is considerably faster than seedling growth. In the greenhouse, Shilling and others [133] found plant height, leaf number, and biomass were significantly greater ($p<0.001$) in plants grown from broken rhizome fragments compared to seedlings. Rhizome fragments produced new secondary rhizomes within 4 weeks, while seedlings took 12 weeks to produce primary rhizomes. Cogon grass rhizomes can produce 350 shoots in 6 weeks and cover 4 m^2 in 11 weeks [36]. In the greenhouse, cogon grass seedlings produced primary rhizomes 4 weeks after emergence [125]. In Marion County, Florida, 3- to 4-month-old, wild seedlings were observed in the 5-leaf stage in October, and seedlings had formed roots and primary rhizomes. Secondary rhizomes were not yet present [133].

Growth may vary among cogon grass populations. In a greenhouse experiment, plants grown from rhizomes collected in Mississippi (2 populations of Philippine origin) were significantly smaller ($p<0.05$) than plants grown from Alabama rhizomes (2 populations of Japanese origin). In the growth chamber, ideal day/night temperatures and photoperiod across cogon grass populations were 84/73 °F (29/22 °C) and 16 hours, respectively [106].

Biomass of fully developed cogon grass stands is considerable. A New Guinea study found cogon grass's annual dry-matter production averaged 23 Mg/ha [58]. In a Java field study, Soerjani [136] determined that undisturbed cogon grasslands contained approximately 3 to 6 million shoots/ha, 7 to 18 tonnes of leaves/ha, and 3 to 11 tonnes of rhizomes/ha.

SITE CHARACTERISTICS:
Brazilian satintail occurs on rocky pineland sites in Florida [173]. In its native Peru, Brazilian satintail grows on montane savannas that average 80 inches (2,000 mm) annual precipitation. The dry season lasts from June to September. Temperatures average 73 °F (23 °C) and vary little between seasons. Soils are reddish-brown Latosols on dry upper slopes and reddish-yellow Podosols on moister, low slopes. Brazilian satintail grasslands generally have acidic soils with poor infiltration and drainage [128].

Cogon grass
tolerates a wide range of site conditions across its worldwide range. It is drought tolerant, and somewhat shade and salt tolerant [70]. In its native lands of Asia and Africa, it grows on arid desert sands, river margins, and swamps [134]. Describing cogon grass in Indonesia, Terry and others [146] wrote "unlike most other plants ... *I. cylindrica* can tolerate drought, waterlogging, fire, cultivation and short-term shade ... at a single site." *Imperata cylindrica* var. *major*, the variety in North America, commonly occupies a wide variety of habitats in Asia including grasslands, deforested areas, old fields, cultivated fields, riparian areas, and disturbed sites such as roadsides. Other varieties have narrower habitat requirements and are less ubiquitous in their native ranges [36]. Hubbard [64] speculated that when Southeast Asian lands were still pristine, cogon grass may have been restricted to arid, relatively sterile, or heavy clay soils. In the United States, cogon grass is common on disturbed sites such as roadsides, mine spoils, pastures, agricultural lands, plantations, and early seral pine forests [43,90,173]. It also occurs on relatively undisturbed sites including wet and dry bottomland [137] and old-growth longleaf pine forests [155].

Soils:

Cogon grass is sometime mistaken as an indicator of "degraded" lands with nutrient-poor soils. Although common on nutrient-poor soils (Ultisols and Oxisols) that native southeastern grasses cannot tolerate, it also occurs on soils of moderate to high fertility (Inceptisols and Andisols) [43,46,100]. Cogon grass tolerates a wide range of soil textures from coarse sands to heavy clays [43]. Soils in cogon grass's native Asia are often highly leached, with low pH, fertility, and organic matter [124]; however, cogon grass is not limited to nutrient-poor soils in Asia [100]. About 65% of cogon grass in Asia grows on strongly acidic soils ($pH \leq 5.0$) with a topsoil layer of 4 to 6 inches (10-15 cm) [18]. Nigerian researchers report cogon grass growing on slightly acid to neutral soils [130]. Best growth in North America occurs on moist, very strongly acid (pH 3.0-4.7) clay soils [43,64,124]; however, cogon grass often grows on clay soils of neutral pH in Florida [43,64]. On poor soils, cogon grass's ability to form monotypic stands in the southeastern United States is due in part to its ability to outcompete native herbs for space, light, water, and nutrients [11,25,37,48,86]. Cogon grass forms thick swards that cover thousands of hectares on abandoned phosphate mines dug in the heavy clay soils of Polk County, Florida [86].

Elevation:

Worldwide, cogon grass is most common at elevations from sea level to 3,000 feet (1,000 m) elevation [18]. Elevational ranges for cogon grass in the United States are not reported as of this writing (2005).

Climate:

Cogon grass is native to regions of wet-tropical and subtropical Asia and Africa where annual rainfall averages between 40 to 100 inches (1,000-2,500 mm) ([100] and references therein),[134]. Worldwide, cogon grass is most invasive in wet tropical and subtropical areas receiving 30 to 200 inches (750-5,000 mm) of annual rainfall [16]. It tolerates hot temperatures but is sensitive to cold [164,165]. It is limited to latitudes below 45° in both hemispheres ([16] and references therein). Rhizomes cannot recover when subject to temperatures of approximately 14 °F (-10 °C). Cogon grass survived winter temperatures that dropped to 7 °F (-14 °C) in Alabama [165], but did not survive winter temperatures of 18 °F (-8 °C) in Mississippi [64].

Moisture regime:

Cogon grass tolerates both xeric and flooded soils, but cannot tolerate soils that are waterlogged for long periods of time [116]. Along the Nile River in Egypt, cogon grass is associated with high-moisture, high-salinity sites [129]. It grows up to the edges of standing water in Florida [70], but does not invade continually flooded sites [27]. In a greenhouse experiment, cogon grass germinants were intolerant of soil inundation and became increasingly tolerant of saturated soils as the plants matured. The authors concluded that soil inundation in early spring could limit cogon grass seedling establishment [74].

SUCCESSIONAL STATUS:

Little information is available on the successional role of **Brazilian satintail**, either in North America or in its native South America. One report suggests that like cogon grass, it is adapted to frequent disturbance. Scott [128] described old-field succession in montane eastern Peru, where Native Campa practice frequent burning to maintain their croplands. There, Brazilian satintail occurs early in postfire succession (about postfire month 4). It becomes dominant on relatively dry sites within 2 to 3 postfire years. Bracken fern tends to dominate on wet sites; the 2 species may codominate on mesic sites. Bracken fern may shade Brazilian satintail out in the absence of further burning; however, Brazilian satintail becomes dominant on sites that are burned annually. Sprouting woody genera including muttonwood and copperleaf become important by postfire year 3. Woody species grow rapidly, reaching 20 feet (6 m) in less than 2 years. Brazilian satintail and other herbaceous species become shaded out in the absence of further disturbance. Sites without woody species may succeed to grasslands dominated by bluestems (*Andropogon lanatum, A. leucostachyus*) and other bunchgrasses. These bunchgrasslands can survive frequent fire, and Brazilian satintail becomes less important except under annual or other very frequent burning regimes [128].

Cogon grass is an early seral species. In both native and nonnative habitats, it depends on fire or other frequent disturbance to maintain dominance [36,82]. In tropical and subtropical ecosystems of Asia, cogon grass ordinarily declines and disappears with postdisturbance canopy closure [36,81,144]. It does best in full sun. Cogon grass cannot tolerate deep shade [14,100], but can survive in the moderate shade of savannas [63,64]. It establishes in forest gaps of all sizes. In longleaf pine/wiregrass (*Aristida* spp.) wet savannas of Grand Bay National Wildlife Refuge, Mississippi, cogon grass was experimentally seeded-in on small- (10 cm in diameter; 66% of full sunlight) to large-diameter (100 cm; 89% full sunlight) gaps created by herbicide spraying. Cogon grass germination averaged 40% across treatments. Seedling survivorship did not differ among gap sizes ($p>0.05$) [75]. For information on cogon grass succession in fire-created gaps, see Discussion and Qualification of Plant Response.

In its native Southeast Asia, cogon grasslands are an early successional stage that develops following a stand-replacement event, usually fire [36,104,114]. Cogon grass is common in tropical old-field succession, with or without fire, but shifting (slash-and-burn) agriculture has greatly increased its occurrence in Asia and Africa. In its native lands, cogon grass has formed extensive swards in areas that were once forested [85,174]. In Asia, cogon grasslands succeed to tropical forest if succession is not interrupted by slash-and-burn agriculture [9,42,104]. Postdisturbance tropical forest development can be blocked by lack of sprouting trees, seed bank depletion, lack of off-site seed dispersal, and/or depletion of soil nutrients [42,100]. Several cycles of sand-replacement disturbance are usually needed for tropical forest-to-grassland conversion [36,100]. In northeastern India, cogon grass colonized burned fields for up to 6 years after burning. Importance value of cogon grass peaked at 74.5 in study plots at postfire year 3, when cogon grass was the most important plant species present. After 6 postfire years, Kashia pine and broadleaved trees began establishing and shading out cogon grass, sticky snakeroot, and other early successional herbs [97]. Without frequent disturbances, cogon grass usually becomes less important as succession advances. On old fields in India, cogon grass was successionally eliminated on plots undisturbed for more than 5 years [82]

Cogon grass also occurs after nonanthropogenic disturbances. It was recorded as a pioneering species on Krakatau, Indonesia, 14 years after the 1883 volcanic eruption. The nearest point of possible seed dispersal was 25 miles (40 km) away (references in [64]). On coastal Japan, cogon grass dominates stabilizing sand dunes, becoming less common on either unstable or stable dunes [89]. In Puerto Rico, cogon grass was 1 of the most frequent pioneering herbaceous species in bracatinga forests disturbed by hurricanes [54].

SEASONAL DEVELOPMENT:
Little information is available on **Brazilian satintail** phenology. In Florida, Brazilian satintail flowers from late winter to spring (March-May) [24,173].

Worldwide, **cogon grass**
shows variable phenological development depending upon climate and population genetics. Cogon grass flowers from May to June in its native Japan [105]. Generally, populations growing in mediterranean climates tend to flower in spring and summer, while populations in tropical and subtropical areas (including Florida) tend to flower year-round [16]. On foothill slopes of the western Himalayas in India, cogon grass germinated in March to April; grew vegetatively from May to June; flowered from July to mid-August; fruited from late August to early September; produced ripe fruit through September; and was dormant from October-December [1].

In Florida, cogon grass flowering peaks in late winter to spring (March-May) [24,173]. In a Polk County study, cogon grass flowered in November and December and again in March and April in both years of a 2-year study. Flowering time was consistent within a population, but varied across populations [133].

Cogon grass rhizomes develop in spring at about 4 weeks of age, or the 3rd or 4th leaf stage of seedlings. Seedling rhizomes are initially vertical, growing horizontally by the 5th leaf stage [16,43].

FIRE ECOLOGY

SPECIES: Imperata brasiliensis, I. cylindrica

FIRE ECOLOGY OR ADAPTATIONS:
Fire adaptations: Both Brazilian satintail and cogon grass are adapted to very frequent fires [55,63,93,97,128,160].

Brazilian satintail sprouts from the rhizomes after top-kill [128]. Postfire seedling establishment is also likely. Mass flowering has been noted in Brazilian satintail following fires in Brazil [55,93].

Cogon grass sprouts from the rhizomes after top-kill by fire [64,97]. It also establishes from seed, usually blown in from off-site [97]. Postfire regrowth is rapid [8,124], and frequent fire favors cogon grass over associated species worldwide [14,97,160]. Fire is so important to cogon grass's ecology that relative response to fire is 1 of the characteristics used to distinguish between its varieties [64].

Fuels: Descriptions of fuel characteristics and loads of **Brazilian satintail** grasslands were not available as of 2005.

Cogon grass
changes fuel properties in pinelands of the Southeast. As a tall, rhizomatous grass on sites historically dominated by bunchgrasses, cogon grass produces more standing biomass and litter than native bunchgrasses. Thus, it increases fuel loads and horizontal and vertical continuity. There is no evidence that there are differences in fuel chemistry between cogon grass and native bunchgrasses [15,87].

Fuel load estimates are needed for cogon grass-dominated sites in the United States. Fuel load measurements in native cogon grasslands may serve as a 1st-step basis for estimating fuel loads in the southeastern United States. Pickford and others [111] conducted fuel sampling in burned and unburned forest-mangrove (*Acacia mangium*)/cogon grass stands in Indonesia. They provide fuel loading and fire behavior information (based upon the BEHAVE fire behavior prediction system) for that community. Wibowo and others [162] provide fire behavior and severity information for a forest-mangrove/cogon grass community in West Java, Indonesia.

Fine fuels are the most important factor in ignition and spread of fire in Florida longleaf pine ecosystems [159], and cogon grass contributes a large fine fuel load. Live cogon grass plants ignite and burn easily while still relatively green [110], and cogon grass becomes very dry and flammable during the tropical dry season (June-October) [100]. Cogon grass's abundant litter may alter fire behavior on invaded sites [74,75,97]. Cogon grass is high in silica content, so the litter decays relatively slowly. In an Australian study, cogon grass had the slowest decay rate of 3 grass species studied. Its half-life rate of decay exceeded the study period of 24 weeks [59].

On Florida sandhill longleaf pine savannas, Lippencott [86,87] compared fine fuel loads on uninvaded and cogon grass-invaded sites. Cogon grass produced significantly ($p<0.05$) more persistent, standing dead biomass compared to sites with native understory vegetation, resulting in a greater fuel load on invaded sites. Fire mortality of young longleaf pines was greater on cogon grass sites, and postfire fuel accumulations were also greater on cogon grass sites. Fire temperatures reached 842 °F (450 °C) [86]. Such fires are severe enough to kill longleaf pine seedlings and saplings [71]. See the Fire Case Study for further details on fuel loads on cogon grass-dominated sites Florida.

Even in frequently burned communities, cogon grass reduces fire return intervals by increasing fine fuel loads. Platt and Gottschalk [113] investigated the effects of cogon grass and silkreed (*Neyraudia reynaudiana*), another nonnative tropical grass, on fine fuel loads in south Florida slash pine savanna in Everglades National Park. Historic fire regime of the area is frequent- (5- to 10-year) interval surface fire. Fuels are almost all fine: woody debris is rarely present except after hurricanes. Firegrass (*Andropogon cabanisii*) and other bunchgrasses native to the area tend to produce greatest biomass the 1st year following a fire; they also mass flower at that time. Productivity of native bunchgrasses decreases with time since last fire. In contrast, cogon grass produces prodigious biomass nearly every year. Study plots were on prescribed underburn rotations of 10 years or less. Study design compared plots with a native ground cover of firegrass, tropical nonnative grasses, or nonnative-firegrass mixes. Fuel biomass on nonnative and mixed sites averaged 1.7 more (measured as g biomass/cm^2 on 22×22 cm^2 plots) than on native grassland sites: a significant ($p=0.995$) difference. Biomass of firegrass was similar on mixed plots and uninvaded sites; however, litter biomass was significantly greater ($p=0.111$) on mixed plots due to fine fuels from the nonnatives [113].

Fire regimes: Little information is available on historic fire regimes of **Brazilian satintail.** Scott [128] investigated its occurrence in mixed muttonwood-copperleaf-Brazilian satintail-bracken fern savannas of montane eastern Peru. The study site was a tropical-humid forest area inhabited by Native Campa. He noted that the Campa practiced annual, dry-season burning around their village to maintain Brazilian satintail grassland. Areas where Native burning was abandoned succeeded to either bunchgrasses (in areas without sprouting woody species) or tropical forest. The origin of South American tropical savannas is unclear. Anthropogenic burning may be responsible. Hardpan soils over high water tables, wet climate, and a combination of anthropogenic burning, edaphic, and climatic factors are also suggested (numerous references cited in [128]). All researchers concede that regardless of their origins, South American savannas are currently maintained by frequent, intentional burning [128]. For information on postfire succession on Brazilian satintail old fields of Peru, see Successional Status.

No information is currently available on how Brazilian satintail affects fire intervals and behavior in southeastern pinelands. Information is needed on the fire ecology of Brazilian satintail in the United States and elsewhere.

Worldwide, cogon grass is favored by frequent surface fire in pine (*Pinus* spp.) and other savannas and by very frequent (<10-year rotation) stand-replacement fire in grasslands [15,127]. In its native Southeast Asia, cogon grass occurs in systems that experience frequent fire including farmlands, grasslands, and the understories of tropical and subtropical forests, especially pine forests [42,97,141]. Fire every 4 to 6 years tends to exclude other species, while succession to woody species occurs with 10- to 20-year fire cycles [127]. Cogon grass can tolerate even annual fires, dominating such sites to the near exclusion of other species [115,141]. Frequent fire is required to maintain cogon grasslands, which are successionally replaced by tropical forest [144,161]. Small-scale fires within subtropical and tropical forest of Nepal maintain uneven-aged forest-grassland mosaics [108,114]. Shifting agriculture, long practiced by Native peoples, probably helps maintain these mosaics.

Cogon grass fuels help maintain subtropical and tropical savannas and forest-grassland mosaics of Asia [108,144,161]. In subtropical Chir pine/cogon grass communities of Nepal and Pakistan, frequent surface fire maintains the open pine forests. Several other grass species co-occur with cogon grass in the understory, and shrubs are scarce (Shrestha and Joshi 1997, cited in [120]). Frequent fire slows succession to tropical forest and maintains the grassy understory [100,141].

Fire in conjunction with other disturbances encourages cogon grass expansion. Fires in Borneo and other tropical areas tend to occur during El Nino-induced droughts, and cogon grasslands expand during these drought-fire cycles [114,172]. The drought-fire cycles of 1983 and 1994 in Indonesia rapidly increased rate of forest-to-cogon grassland conversion there [46]. Logged areas tend to be more susceptible to fire, and when it occurs, fire is more severe in logged areas. In Malaysia, logged forests showed less understory diversity after fire compared to unlogged forest. Logged and burned forests were mostly dominated by cogon grass and/or Jack-in-the-bush [172]. Native burning undoubtedly increases fire and cogon grass occurrence, and it is unclear what fire regimes would have been if Native burning was not practiced. Charcoal evidence of fires in Borneo date back to the Holocene [114], but knowledge of natural fire regimes where cogon grass is native is largely unknown.

Shifting agriculture has shortened fire intervals in many tropical areas to the point that warm-wet-climate pines and other overstory trees can no longer regenerate, creating large-acreage swards of cogon grassland where cogon grass had formerly occupied only small mosaics within forestlands [122]. Its spread in its native range in Southeast Asia is largely due to human clearing of tropical rain forests followed by frequent burning [37,46]. In northeastern India, for example, intervals between fires in Khasia pine forests have been shortened from 20- to 30-year intervals to 5-year intervals due to shifting agriculture. This has resulted in cogon grass dominance in fallow fields and cogon grass invasion into crops on cultivated lands [97]. Cogon grass is successionally replaced by woody species in the absence of further fire [174]. Cogon grass has increased fire occurrence in shrublands, grasslands, and agricultural regions of Nigeria, causing great economic losses in that country [21].

Repeated short-interval fires on cogon grasslands reduce soil fertility and increase soil erosion, ultimately making restoration more difficult [51,52,53]. Where it is nonnative, cogon grass has likewise spread into tropical and subtropical regions where shifting agriculture or frequent prescribed burning is practiced [12,14]. It has, for example, invaded eucalypt (*Eucalyptus*
spp.) forests of northern Australia where Aborigines conduct frequent underburning [12].

Cogon grass in North America:
There is a large and dangerous potential for cogon grass to spread rapidly in warm-wet-climate regions of the Southeast [46,90]. Its rapid invasion in peninsular Florida and edges of the northern Gulf of Mexico has increased fire hazard on infested sites. Cogon grass populations are expected to expand in the Gulf Coast region in coming years, further increasing fire hazard [4,43]. Because it is native to pine ecosystems of subtropical Asia that have frequent surface fire regimes, cogon grass has readily adapted to subtropical pine ecosystems of North America that have similar fire regimes [15]. Cogon grass may invade before or after fire, increasing rapidly after the next fire [86,87].

Prior to the 20th Century, wildfires in the Southeast were most common in summer. Lightning strikes occur during the rainy season (May-October), with most lightning-ignited fires occurring in June [86,135]. Peninsular Florida's longleaf pine communities experienced frequent surface fires at 2- to 8-year intervals. These frequent fires maintained the savannas [23,101,123,140]. Southern Florida's slash pine forests probably had similar, but slightly longer (up to 15-year) intervals between surface fires. Reconstructing past fire regimes from fire scars has not been possible for southern Florida's pinelands [145]. Florida was inhabited by Aboriginals for thousands of years, and seasonality and extent of Aboriginal burning in the area is uncertain [135].

Fire behavior:
Cogon grass invasion in pinelands of the Southeast has shortened fire return intervals and increased fire severity over prehistoric conditions [4,15,43,86,87]. A study commissioned by the Mississippi Exotic Pest Plant Council reported cogon grass as 1 of the 4 most serious nonnative invasives in the Southeast, based upon its ability to alter natural fire regimes [90].

Cogon grass can increase fire's rate of spread and intensity [4,86,87]. Compared to native bunchgrasses, cogon grass produces a more continuous bed of fine fuels that is highly flammable when dry. In southern Florida pine sandhills, cogon grass fuelbeds are more evenly distributed, resulting in more horizontally continuous fire [86]. On sites where cogon grass reaches maximum heights (see General Botanical Characteristics), it also increases vertical continuity of fuels, which can change the fire regime from surface to crown fire [15,87]. In Mississippi, Grace and others [50] found flame heights in cogon grass sites were nearly twice those of sites dominated by wiregrass. Rates of fire spread were higher on cogon grass sites; however, maximum temperatures were lower. Ironically, cogon grass was once planted in firebreaks on the Withlacoochee State Forest, Florida [142].

The following table provides fire return intervals for plant communities and ecosystems where **Brazilian satintail** and **cogon grass**
are important. For further information, see the FEIS review of the dominant species listed below. This list may not be inclusive for all plant communities in which Brazilian satintail and cogon grass occur. If you are interested in plant communities or ecosystems that are not listed below, see the complete FEIS fire regime table.

Community or Ecosystem	Dominant Species	Fire Return Interval Range (years)
shortleaf pine	*Pinus echinata*	2-15
shortleaf pine-oak	*P. echinata-Quercus* spp.	<10
slash pine	*P. elliottii*	3-8
slash pine-hardwood	*P. elliottii*-variable	<35

sand pine	*Pinus elliottii* var. *elliottii*	25-45 [158]
South Florida slash pine	*P. elliottii* var. *densa*	1-15 [102,135,158]
longleaf-slash pine	*P. palustris-P. elliottii*	1-4 [102,158]
longleaf pine-scrub oak	*P. palustris-Quercus* spp.	6-10
pocosin	*P. serotina*	3-8
pond pine	*P. serotina*	3-8
loblolly pine	*P. taeda*	3-8
loblolly-shortleaf pine	*P. taeda-P. echinata*	10 to <35 [158]
cabbage palmetto-slash pine	*Sabal palmetto-P. elliottii*	<10 [102,158]

POSTFIRE REGENERATION STRATEGY [138]:
Brazilian satintail and **cogon grass:**
Rhizomatous herbs, rhizomes in soil
Ground residual colonizers (on-site, initial community)
Initial off-site colonizers (off-site, initial community)
Secondary colonizers (on-site or off-site seed sources)

FIRE EFFECTS

SPECIES: Imperata brasiliensis, I. cylindrica

- IMMEDIATE FIRE EFFECT ON PLANT
- DISCUSSION AND QUALIFICATION OF FIRE EFFECT
- PLANT RESPONSE TO FIRE
- DISCUSSION AND QUALIFICATION OF PLANT RESPONSE
- FIRE MANAGEMENT CONSIDERATIONS

IMMEDIATE FIRE EFFECT ON PLANT:
Fire top-kills **Brazilian satintail** [55].

Fire also top-kills **cogon grass**, and removes its litter layer [43,64,133,160].

DISCUSSION AND QUALIFICATION OF FIRE EFFECT:
No additional information is available on this topic.

PLANT RESPONSE TO FIRE:
Brazilian satintail sprouts from rhizomes after top-kill by fire [128]. There is also a postfire flowering response. Brazilian satintail has shown mass flowering after fire in Brazil. Mowing or clipping does not produce a similar mass flowering response [93]. Scott [128] found that under annual burning in Peru, Brazilian satintail usually produced seed the December following dry-season (Aug.-Sept.) fire. Snyder and others [135] report that in slash pine (*Pinus elliottii* var. *densa*) communities of southern Florida, Brazilian satintail rarely flowers except in early in postfire succession.

Cogon grass sprouts from the rhizomes after top-kill by fire [64]. Studies in Southeast Asia and Australia show that burning increases cogon grass sprouting [49,97,136,160]. Postfire mass flowering has been noted in cogon grass in Thailand (Paisooksantivantana as cited in [43]).

Cogon grass also establishes from wind-blown, off-site seed after fire [97]. Since it has a short-term seed bank

[50], seedling establishment from soil-stored seed is possible.

Cogon grass is favored by frequent fires [64]. Garrity and others [46] stated the "real distinguishing factor for its persistence is the intermittent occurrence of fire." Coster [27] called fire "the greatest help" to cogon grass spread in Asia. In northeastern India, cogon grass colonizes burned fields for up to 6 years after burning [97]. Hubbard [64] stated that cogon grasslands remain stable even under annual burning.

Fire increases nutritional value of cogon grass in the short term. For 3 months after fire in central Florida, cogon grass on burned sites had significantly higher nitrogen and phosphorus content, and lower fiber content, compared to unburned cogon grass [86].

In natural postfire succession in tropical ecosystems, cogon grass is initially important, then declines with canopy closure. The 1982-1983 drought in Indonesia caused widespread wildfires across Borneo. Nykvist [103] found that cogon grass, hilo grass (*Paspalum conjugatum*), and Jack-in-the-bush usually formed early seral grasslands by postfire year 2. Without further disturbances, the grasslands succeeded to woody vegetation, reducing from mean biomass of 20 kg/ha at postfire year 5 to 3 kg/ha at postfire year 8.

DISCUSSION AND QUALIFICATION OF PLANT RESPONSE:
In central Florida, Lippincott [86] measured rates of **cogon grass** rhizome invasion into longleaf pine sandhill communities. Cogon grass expansion differed significantly (p<0.01) by treatment and was greatest in clearcuts and frequently burned stands:

Treatment	Time since last fire	Rate of expansion ± (*s*)
no treatment in plug-planted stands	5 years	0.5 ± 0.4 m/year
fire exclusion in self-established stands	15 years	0.5 ± 0.4 m/year
uncut plantation, self-established stands	4 years	0.6 ± 0.1 m/year
prescribed burning, self-established stands	5 years	1.9 ± 0.9 m/year
prescribed burning, self-established stands	1.5 years	2.6 ± 0.9 m/year
clear-cut plantation, self-established stands	4 years	2.7 ± 0.4 m/year

Cogon grass can establish in both large and small gaps, growing best if gaps are created by fire [86]. On the Grand Bay National Wildlife Refuge, Mississippi, six 10 × 10-m areas of longleaf pine savanna were burned under prescription on 6 April 1998. Cogon grass was transplanted onto transplant study plots 2 days after burning or seeded into seed study plots 3 days after burning. Percentage photosynthetically active radiation was 78% and 30% on burned and unburned plots, respectively. At postfire month 2, survivorship did not differ between cogon grass transplants on burned and unburned plots (p=0.72), but growth (mean shoot length) of transplants was greater on burned vs. unburned plots (p=0.0007). For seedlings, emergence did not differ between burned and unburned plots; however, survival of germinants at postfire months 1 and 2 was significantly greater (p<0.05) on burned vs. unburned plots [75].

Early in its postfire recovery, cogon grass may allocate most of its biomass to rhizomes. Following mowing and prescribed burning in an old field in India, cogon grass regenerated entirely from rhizome sprouts. At postfire year 1, aboveground:belowground biomass ratio of cogon grass was 1:4, which was the lowest ratio of the 4 grasses present on burned plots [127].

The Fire Case Study Imperata cylindrica in a Florida sandhill longleaf pine community provides information on fuel loads, prescribed fire use, and postfire response of juvenile longleaf pines on cogon grass-infested sites and uninfested sites.

FIRE MANAGEMENT CONSIDERATIONS:
There is currently not enough information on **Brazilian satintail** to provide fire management summaries or recommendations. Because Brazilian satintail's and cogon grass's growth forms and postfire growth responses are similar, the following information may also apply to Brazilian satintail. If Brazilian satintail is found to be a serious threat to pineland ecosystems in the Southeast, fire and other studies are needed to determine how to best control it.

Cogon grass
is extremely problematic for fire managers. It invades fire-adapted, warm-wet-climate ecosystems, reducing species diversity and ecosystem function. Cogon grass has the potential to shorten already short fire-return intervals to the point that native plant species cannot recover. Yet excluding fire from these fire-adapted ecosystems also results in loss of ecosystem diversity and function [28]. Rapid accumulation of dense cogon grass litter, along with its spreading rhizome mass, makes unassisted recruitment of native warm-climate plant species unlikely on infested sites [86,87].

Fire alone cannot control cogon grass; in fact, burning with no further treatments will promote it [86,87]. Burning can help control cogon grass when it is part of an integrated control plan, however [62,160]. By removing cogon grass top-growth, the rhizomes are forced to utilize stored carbohydrates to produce new growth, thereby weakening the rhizomes. Removing cogon grass litter and standing dead biomass prior to other treatment often improves the success of other control measures. For example, tillage is more effective, and herbicide application to growing tissues more precise, if biomass is 1st removed [70]. Johnson and Shilling [70] provide a contact list of managers and academics with experience using fire to control cogon grass.

Burning and allowing cogon grass regrowth, followed by tillage and herbicide treatment, is the most effective control measure for large, established infestations of cogon grass [34,133]. In a Florida study, burning was used to remove aboveground cogon grass biomass and prepare a bare soil study area on all plots. Postfire treatments were 2 herbicide sprayings, 2 diskings, or spraying/disking combinations. Imazapyr was applied 44 and 90 days after burning. Disking was done the day after burning and at postfire day 90. Measured 18 months after treatment, the most effective treatment was a 1st disking on postfire day 1, followed by spraying at postfire day 44, and a 2nd disking at postfire day 90. Compared to untreated plots, spraying alone provided 82% control, and disking alone provided 53% control. Disking followed by spraying without a 2nd disking resulted in 86% control [69].

After cogon grass suppression, establishment of native herbaceous species is needed for long-term control [170]. Shilling and others [133] stated "if a replacement species does not fill the niche occupied by cogon grass after suppression then cogon grass will simply refill the niche."

Studies in southeast Asia show that although slash-and-burn treatments reduce rhizome biomass, they also encourage sprouting. Slashing alone produces more sprouts than slashing and burning [124,136]. A combination of prescribed burning and mowing reduced cogon grass in infested pastures in Australia. In heavily infested pastures, burning was followed by reseeding to pasture grasses, then mowing [160]. A Malaysian manager reports that burning cogon grass early in the dry season reduces next-year fuel loads, while late dry-season fires tend to increase next-year fuel loads [121].

Extensive, fire-created cogon grasslands can lower habitat quality and diversity in southeastern pinelands. Frequent fire on cogon grasslands in tropical Asia has reduced soil nitrogen and increased run-off [49]. In Florida longleaf pine stands, gopher tortoise mounds provide fire refugia and disturbed seedbed sites for early seral herbs. Gopher tortoises have difficulty digging in cogon grass, preferring more open sites. Fewer gopher tortoise mounds in cogon grass-infested sites may affect postfire plant community succession [86].

FIRE CASE STUDIES

SPECIES: Imperata brasiliensis, I. cylindrica

FIRE CASE STUDY CITATION:
Howard, Janet L. 2005. Imperata cylindrica in a Florida sandhill longleaf pine community 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/ (2007, February 06).

SPECIES INCLUDED IN THE SUMMARY:
This Fire Case Study contains information on the following species:

Common name	Scientific name
cogon grass	*Imperata cylindrica*
longleaf pine	*Pinus palustris*

FIRE CASE STUDY REFERENCES:
The summary is based on the following research papers:

Lippincott, Carol L. 2000. Effects of Imperata cylindrica (L.) Beauv. (Cogongrass) invasion on fire regime in Florida Sandhill (USA). Natural Areas Journal. 20(2): 140-149.

Lippincott, Carol L. 1997. Ecological consequences of Imperata cylindrica (cogongrass) invasion in Florida sandhill. Gainesville, FL: University of Florida. 165 p. Dissertation.

STUDY LOCATION:
The study was conducted in the 16,000 ha Citrus Tract of the Withlacoochee State Forest in west-central peninsular Florida (28°65'N, 82°36'W).Withlacoochee State Forest is in Citrus County near the city of Brooksville. The study period was from 1995 to 1996 [87].

SITE DESCRIPTION:
Soils on the study site are low-nutrient Entisols derived from marine sand deposits that lack profile development. Mean annual precipitation on Florida sandhills ranges from 1,190 to 1,630 mm/year, with rains mostly occurring from June to September (references in [86]).

PREFIRE PLANT COMMUNITY:
Study sites were in a longleaf pine savanna with a subcanopy of bluejack oak (*Quercus incana*), turkey oak (*Q.*

laevis), and sand live oak (*Q. geminata*). Wax myrtle (*Myrica cerifera*) and saw-palmetto (*Serenoa repens*) also occurred in the subcanopy. There were 4 study sites, each with 2 treatment plots (invaded and uninvaded). Invaded and uninvaded plots were adjacent to each other on each of the 4 sites [86,87]..

Groundlayer vegetation differed on invaded and uninvaded plots. The ground layer on invaded sites was mostly nonnative cogon grass. Groundlayer vegetation on uninvaded sites was dominated by native bunchgrasses including pineland threeawn (*Aristida stricta*), pineywoods dropseed (*Sporobolus junceus*), narrowleaf silkgrass (*Pityopsis graminifolia*), and lopsided Indiangrass (*Sorghastrum secundum*). Summer farewell (*Dalea pinnata*) was a common forb associate [86].

Cogon grass was intentionally introduced into the Brooksville area in the early 1990s as a forage crop [143]. It was probably introduced in the Citrus Tract from seed-contaminted road fill (Blanchard, as cited in [87]). During the study period, cogon grass occurred in scattered swards in the Citrus Tract. Cogon grass patch size ranged from a few square meters to several hectares [87].

PLANT PHENOLOGY
Plant phenology was not described; however, the fire was conducted as a growing-season burn.

FIRE SEASON/SEVERITY CLASSIFICATION:
Early spring/Moderate severity

FIRE DESCRIPTION:
The objective of the study was to determine if fuel loads and fire behavior on longleaf pine sandhill sites invaded by cogon grass differed compared to uninvaded longleaf pine sandhill sites. Before burning, fuel load, vertical distribution, horizontal continuity, moisture content, and heat of combustion were compared on invaded and uninvaded sites. After fire, rates of accumulation of postfire fuels were compared on invaded and uninvaded plots.

Longleaf pine juveniles were randomly tagged on burn and no-burn plots before prescribed burning. Fire spread was measured during burning. Fire severity was determined by measuring mortality of tagged juvenile longleaf pines and postfire growth rate of tagged juvenile longleaf pines that survived the fire. Mortality and height and basal area of surviving pines were measured at postfire month 1. Height and basal area of surviving pines were measured again at postfire year 1 [87].

The natural fire regime of longleaf pine forests on Citrus Tract is surface fire at 2- to 8-year intervals, fueled primarily by pine needles, oak leaves, and perennial bunchgrasses including threeawns (*Aristida* spp.) and pineywoods dropseed (*Sporobolus junceus*). Lightning-ignited fires were most common during the spring and summer thunderstorm season [86].

The Florida Division of Forestry conducts regular prescribed burning on the Citrus Tract for forest and game management. The area in which study plots were located was last burned 4 years prior to study initiation [87]. Just before this study's prescribed burn, mean moisture contents of live and dead fuels were similar on invaded and uninvaded plots (46.2% ± 10.7 and 42.3% ±
12.3, respectively). Mean heat of combustion was slightly higher for native grasses (18.40 kJ/g ± 0.20) compared to cogon grass (18.77 kJ/g ±
0.22). Prescribed fires were conducted early in the growing season (March and April) and ignited in mid-morning as backing fires. Midway through burning, wind shifts caused the 3rd and 4th fires to head. Treatment plot sizes and weather parameters were [87]:

Site	Plot size (m)	Season	Fire type	Wind speed (km/hr)	Relative humidity (%)	Ambient temperature (°C)

1	35 × 130	April 1995	backing	8	32	25
2	35 × 145	April 1995	backing	13	56-68	29
3	35 × 40	April 1995	backing/head	16	44-56	24
4	35 × 35	March 1996	backing/head	8	63	22

Prefire fine fuel load was significantly less (p=0.04) on native sandhill sites compared to cogon grass sites. From 0 to 0.49 m in height, fine fuel mass did not differ between uninvaded and cogon grass-invaded sites; however, fine mass of fine fuels from 0.50 to 1.50 m was higher (p<0.01) on cogon grass sites [86]. Prefire fuel loads at 3 heights were [87]:

Aboveground height (m)	Fine fuel biomass (g/m²)	
	Invaded	Uninvaded
0 - 0.49	800	630
0.50 - 0.99	275	75
1.00 - 1.50	25	----

Mean heat of combustion was slightly higher for native fuels (p<0.01). Instantaneous maximum fire temperature at 3 heights was measured with temperature-indicating paints on steel poles. There was a significant difference (p<0.05) in mean maximum temperature between prescribed fires in cogon grass (260.9 ±13.7 °C) and native sandhill (218.3 ± 14.5 °C) sites [86]. Fuel load ratios and fire temperatures by height were [87]:

Aboveground fuel height	Fuel biomass ratio (Invaded:Uninvaded)	Maximum temperature (°C)	
		Invaded	Uninvaded
ground level	----	275	250
0.5 m	4.5:1	245	195
1.5 m	6:1	250	175

Fire rate of spread was similar on invaded and uninvaded plots (p=0.75). Fireline intensity was also similar on invaded vs. uninvaded plots (p=0.22) [87]:

Site	Fire type	Rate of spread (m/s)		Intensity (kW/m)	
		Invaded	Uninvaded	Invaded	Uninvaded
1	backing	0.0185	0.0235	395.95	341.41
2	backing	0.0208	0.0195	445.18	283.30
3	head	0.1300	0.1300	2782.37	1888.64
4	head	0.1458	0.0280	3120.54	406.78

FIRE EFFECTS ON PLANT COMMUNITY:
Cogon grass changed fine fuel characteristics that determine the fire regime of Florida sandhill plant communities. At postfire month 5, significantly more (p<0.01) fine fuels had accumulated on cogon grass sites compared to native sandhill sites. Cogon grass sites had 90% less bare ground, so fine fuels were more evenly

distributed than fuels on uninvaded sites. At time of burning, cogon grass had 50% more fine fuel by weight compared to native herbaceous fuels, so cogon grass reached higher temperatures than native herbs. Cogon grass fuels averaged 50 °C hotter at 0.5 m above ground, and 73 °C hotter at 1.5 m, compared to native sandhill herbaceous fuels. Cogon grass recovered quickly after fire. At postfire month 3, cogon grass sites had 100% more fine fuels than native sandhill sites; 86% more at postfire month 6; and 50% more at postfire month 14. With twice as much fuel after only a few months' growth, fire in cogon grass-infested sites could ignite and spread frequently in the absence of fire management [86].

Fire mortality of longleaf pine juveniles was higher on cogon grass-invaded plots, and the postfire growth rate of surviving longleaf pine juveniles was decreased on invaded plots. Juvenile longleaf pine size classes were indicated by height. Longleaf pine mortality on invaded and uninvaded plots was [86,87]:

Juvenile size class	Height (m)	Mortality (%)	
		Invaded	Uninvaded
Small	0-0.49	32	23
Medium	0.50-0.99	80	49
Large	1.00-1.50	84	76

At postfire year 1, growth of surviving small juvenile longleaf pines was significantly less ($p<0.01$) on invaded vs. uninvaded plots. Median increase of pines in the smallest size class was 21% vs. 50%, respectively [87]. Poor growth in small longleaf pine juveniles was probably due to competitive interference by cogon grass, rather than direct fire effects to small longleaf pines [86]. (See longleaf pine's Fire Ecology section for discussion on fire effects to longleaf pine juveniles). Height gains for medium- and large-sized longleaf pine juveniles were similar ($p=0.86$) on invaded and uninvaded plots. For all size classes, stem diameter growth of longleaf pine juveniles was not significantly different on invaded and uninvaded plots [87].

Although cogon grass increases fire mortality of longleaf pine seedlings, mature longleaf pines may not be directly affected by cogon grass presence. In this study, growth of longleaf pines greater than 10.4 cm dbh was not slowed by cogon grass [86].

FIRE MANAGEMENT IMPLICATIONS:
Without management, fire in longleaf pine sandhill communities has the potential to ignite and spread more quickly on cogon grass-invaded sites compared to uninvaded sites. Presence of cogon grass significantly ($p<0.05$) affected fine-fuel load, changed fuel structure, and increased fire temperatures.

Cogon grass-invaded plots had 50% more fine fuel biomass than uninvaded plots prior to burning. Before burning, invaded plots had a significantly greater ($p<0.01$) fine-fuel load (μ=1,163 g/m² ± 285 g/m²) compared to uninvaded plots (μ=177 g/m² ± 297 g/m²). Structurally, fine fuels on invaded plots were generally taller than on uninvaded plots. Fine-fuel loads between 0.4 and 1.51 m in height were significantly greater ($p<0.01$) on invaded plots. In contrast, fine-fuel loads less than 0.50 m in height were similar on invaded and uninvaded plots (μ=795 g/m² and 668 g/m², respectively; $p<0.07$). Horizontally, fine fuels were significantly ($p=0.04$) more continuous on invaded vs. uninvaded plots, with 3.0% bare ground on invaded plots and 0.3% bare ground on uninvaded plots. Fuels on invaded plots were distributed significantly higher above ground: 27% of total fuels were ≥0.5 m high on invaded plots compared to only 8% on uninvaded plots. Consequently, invaded plots produced significantly higher maximum fire temperatures compared to uninvaded plots (260.9 °C vs. 218.3 °C, $p=0.40$), and fires were more patchy on uninvaded plots. Fire temperatures in cogon grass reached a maximum of 458 °C on some strips at all aboveground heights measured. After fire, fine fuels accumulated more quickly on invaded plots [86,87].

These mortality data and instantaneous maximum temperature measurements at given points suggest that longleaf pine juveniles may succumb to cogon grass-fueled fires [87]. Additional data on fire duration (e.g., Jacoby and others [68]) will help determine direct fire effects of cogon grass fuels on longleaf pine juveniles. Rapid growth out of the "grass stage" of growth gives juvenile longleaf pines protection from fire. However, this study showed that young longleaf pines in the 0.5-1 m height class are vulnerable to fire damage on cogon grass sites, which have more fuels and higher fire temperatures compared to sites with native bunchgrass fuels [87]. Koskela and others [78] had similar findings in a Sumatran pine (*Pinus merkusii*)/cogon grassland of northern Thailand. As a juvenile, Sumatran pine has a "grass growth" stage similar to that of longleaf pine. Juvenile Sumatran pines were killed by frequent fires fueled by cogon grass [78].

Cogon grass can alter longleaf pine community structure and consequently, its fire regime and level of diversity. As a fast-growing, rhizomatous grass that is supplanting slow-growing native bunchgrasses, cogon grass-invaded sites have higher fuels loads, greater horizontal and vertical fuel continuity, and potentially greater flame heights compared to sites with native herbaceous ground layers. In this study, overall understory plant diversity was lower on cogon grass-infested sites compared to uninfested sandhill sites [86]. At postfire month 3, cogon grass sites had over 100% more fine fuels compared to uninvaded sites ($p<0.01$). Fuel accumulations at 6 and 14 postfire months were 86% and 50% more, respectively, on invaded compared to uninvaded plots. Rapid growth and nonbunching habit of cogon grass can increase fire severity, continuity, spread, and frequency in longleaf pine sandhill habitats, thereby increasing fire mortality of young longleaf pines and reducing habitat quality for native organisms adapted to longleaf pine/bunchgrass habitats [87].

MANAGEMENT CONSIDERATIONS

SPECIES: Imperata brasiliensis, I. cylindrica

IMPORTANCE TO LIVESTOCK AND WILDLIFE:
As of 2005, management information on **Brazilian satintail**
was lacking. In terms of stand structure and fuel characteristics, Brazilian satintail and cogon grass may be functional equivalents in southeastern ecosystems [86]. Although their impacts may be similar, that does not imply that their responses to control measures are identical. The following information discusses cogon grass. Information on Brazilian satintail palatability, nutritional value, cover value, control methods, and other pertinent management issues is needed.

Cogon grass
is generally detrimental in wildlands and pastures in North America. It reduces habitat quality for wildlife that have evolved in pine/bunchgrass ecosystems [43,86]. It is little used as forage in the United States even though it was originally planted for that purpose. Pendleton [110] warned against cogon grass introduction in 1948:

Cogon grass "is anything but nutritious. Certainly its hazard as a potential weed for upland crops in the tropical and subtropical portions of the western hemisphere is a very much more serious threat to agriculture than the small amount of benefit it can possibly be as a forage. The writer feels very strongly that *steps should be taken at once to completely eradicate this noxious weed from the western hemisphere*" [110] (italics are Pendleton's).

Although cogon grass is weedy in wildlands where it is nonnative and in agricultural systems worldwide, it has a valuable ecological role as fuel and forage in grasslands where it is native. In Royal Bardia National Park, Nepal, for example, cured cogon grass helps fuel the natural fire cycle that maintains tropical forest-grassland mosaics. Live cogon grass provides cover for ground-nesting birds and forage for grazing animals. Cogon grass is an important component of the food web for threatened [152] animals in the Park including hispid hares, swamp deer, and tigers [108]. In Borneo, the Banjarese historically burned open fields with cogon grass to create deer habitat and forage [114]. Asian and African ranchers use cogon grass as cattle forage [29,34]. Cogon grass is expected to become less important forage in developing countries as it is replaced by plantings of more nutritious grass species [64].

Palatability:

Cogon grass is relatively unpalatable and unnutritious for livestock and North American wildlife [39,40,43,58,86]. It is lower in nitrogen and higher in fiber and silica compared to native wiregrasses (*Aristida* spp.) of the Southeast [23,25,86]. The leaf blades are sharp and rough at the edges, discouraging animals from grazing [25]. New spring growth and postfire sprouts are palatable to livestock for 3 to 4 weeks; however, plants become coarse and fibrous after that [160]. In a rangeland study in subtropical Australia, cogon grass cover increased in response to cattle grazing at the expense of common carpet grass (*Axonopus fissifolius*), which is more palatable and nutritious [60]. Stober [139] described cogon grass as unpalatable to domestic sheep in Malaysia; however, domestic sheep can learn to graze cogon grass [156].

As it becomes more common in the Southeast, cogon grass will affect grazing wildlife. Gopher tortoises, a federally threatened species [152], prefer native grasses and forbs to cogon grass [86]. Three North American skipper butterflies graze cogon grass as caterpillars [16].

Nutritional value: Nutritional studies of cogon grass in the Southeast are few. Lippencott [86] found that compared to native Florida sandhill herbs, cogon grass was higher in nitrogen and phosphorus and lower in fiber for the first 3 months after fire. By 6 postfire months, cogon grass provided less nitrogen and phosphorus, and by postfire month 14, it was higher in fiber compared to native herbs. Studies conducted on cogon grass in Asia are reported below.

Most sources claim that cogon grass forage quality declines quickly, is low in minerals (particularly phosphorus), and that cattle require nutritional supplements when grazing cogon grass ([18] and references therein, but see [39] for a contrasting viewpoint). In India, domestic goats on a native grassland mixture that included cogon grass showed poor weight gain [175]. Asian ranchers have successfully raised cattle on cogon grass-legume pastures [18]. Nutritional content of cogon grass from Asian sources (country not reported) was [73]:

	Dry matter (%)	Crude protein (%)	Digestible protein (%)	Metabolizable energy (Mcal/kg)
1-14 days growth	27	10.4	6.7	2.36
85-98 days growth	35	8.5	5.1	2.18
Mature	61	4.9	2.0	1.99

Analysis of cogon grass in Malaysia showed (as cited in [64]):

	Dry matter	Crude protein	Crude fat	Crude fiber	N-free extract	Ash
Composition (%)	25.3	3.7	0.5	8.7	10.8	1.6
Digestible nutrients (%)	----	2.5	0.2	5.6	7.6	----

A Thailand study suggests fire and repeated grazing reduce forage quality of cogon grass. A cogon grass sward was burned on 23 March 1978, then harvested every 3 weeks from April through October 1978. Mean dry-matter nitrogen content was 2.93% in April, declining to 0.56% in October. Phosphorus content declined from 0.90% to 0.37%, and in-vitro digestibility declined from 71% to 39% in the same time period. Nutrient values on an undisturbed 5-year-old cogon grass sward were generally lower: 0.66% nitrogen, 0.12% phosphorus, and 31.4% in-vitro digestibility [39].

Cover value: Cogon grass stands are poor habitat for most southeastern wildlife species [43]. Cogon grass is about 3 times the height of native Florida grasses. Its height probably impedes movement of small animals. Ground-dwelling species can be displaced by cogon grass's dense cover [70]. In central Florida, habitat quality of 2 keystone fossorial animals, gopher tortoises and scarab beetles, was reduced on cogon grass-invaded sites compared to uninvaded sites. Beetle populations were reduced approximately 76% on invaded sites. Threatened [152] gopher tortoise populations were too low to allow quantitative assessment; however, thick rhizome growth that deters burrowing, reduces the number of open areas for egg laying, and reduces herbaceous forage species, lowers gopher tortoise habitat quality. Southeastern pocket gophers, another keystone fossorial animal, were not affected by cogon grass presence [86].

OTHER USES:
Cogon grass is used as a forage plant, for short-term soil stabilization, and as roofing thatch in Asia and Africa [21,34,133]. It is occasionally used to make paper (references in reviews by [34,64,98]. The rhizomes were once used to make beer in Malaysia and Uganda [64].

In traditional Asian folk medicine, cogon grass is used as a tonic, an emollient, an anti-inflammitory, and a fever-reducing agent (references in reviews by [48,90,91,92]). Chemical and pharmacological studies are underway to assess potential uses of cogon grass in modern medicine [90,91,92,112]. A cogon grass extract shows anti-insecticide properties against mosquitoes [99].

'Red Baron,' a cultivar of cogon grass with red leaves, is commercially available and planted as an ornamental despite cogon grass's federal and state listings as a noxious weed [26,171] an laws against its use [149]. 'Red Baron' is usually described as infertile and nonspreading, but data are lacking to support the claim [25]. Greenhouse studies suggest 'Red Baron' is at least capable of vegetative spread. After 3 months in the greenhouse, 'Red Baron' rhizomes produced a similar number of secondary rhizomes compared to Brazilian satintail rhizomes (μ=5.7 and 5.1 rhizomes for 'Red Baron' and Brazilian satintail, respectively), and significantly more secondary rhizomes than *Imperata cylindrica* var. *major*, the "wild type" cogon grass (μ=3.9 *I. c.* var. *m.* secondary rhizomes, p=0.05). Growth rates of the 2 cogon grass types and Brazilian satintail were similar [133]. 'Red Baron' may be more shade tolerant than the wild type [26]. Use of 'Red Baron' is not recommended in the United States for ecological reasons [147].

IMPACTS AND CONTROL:

IMPACTS:

Cogon grass has potential to alter function, structure, and diversity in southeastern warm-wet-climate ecosystems. As a rhizomatous grass, it cannot functionally replace native southeastern bunchgrasses like wiregrass [86,87]. It can shorten fire return intervals to the point that native species cannot recover (see Fire Ecology and Fire Management Considerations. Holm and others [63] rated cogon grass as the world's 7th worst weed. Cogon grass causes physical injury when its rhizome tips, which are as sharp as its leaves, penetrate the roots of other herbaceous species, sometimes forming a parasitic relationship with the injured plant [11,25,48]. Cogon grass rhizomes and roots extract water from shallow soil layers, outcompeting native grasses for space, light, nutrients, and water [37,43,86]. Cogon grass is noted for outcompeting native herbs on poor soils [37,86]. Its abundant litter and rhizome mat may physically exclude establishment of other plant species [50,71,87]. Herbs that compete successfully with cogon grass usually have deeper roots and/or taller crowns than cogon grass [37].

Cogon grass is identified as a large potential hazard to remnant old-growth longleaf pine stands due to its ability to invade undisturbed old-growth forests of the Southeast [155]. In central Florida, Lippencott [86] found cover and diversity of native herbs, shrubs, palms, and small longleaf pines and oaks (*Quercus incana, Q. laevis, Q. geminata*) were significantly reduced ($p< 0.01$) on cogon grass sites compared to uninfested sites (see The Fire

Case Study Imperata cylindrica in a Florida sandhill longleaf pine community. Yager [176] is conducting research on cogon grass rate of invasion into longleaf pine/bluestem and longleaf pine/shrublands in Mississippi. Preliminary data show an expansion rate ranging from 0 to 1.6 feet (0.5 m) over a 6-month period (April-Oct. 2002). Expansion rate is not significantly different between habitats [176]. Spread of cogon grass outside the lower Coastal Plains states is unlikely because of cogon grass's poor tolerance to low temperatures [106,165].

Cogon grass allelopathy has been implicated in laboratory experiments [19,25,65,76,77,117]; however, such claims are based upon research using cogon grass extracts at concentrations that do not occur under field conditions. Reputed allelopathy of cogon grass awaits reciprocal transplant experiments in the field and/or greenhouse.

Silvicultural:

Cogon grass competes with hardwood species for light, water, and nutrients. Cogon grass grows so tall and thick that it decreases growth and increases mortality of young trees [90]. Allen and others [4] describe cogon grass as particularly problematic in peninsular Florida pinewoods. Lippencott's [86] Florida study suggests that pine and oak regeneration is reduced in cogon grass swards; however, she found that median basal area of mature pines was greater on cogon grass sites compared to uninfested sites. Basal area of oaks did not differ between sites ($p<0.01$). She postulated that mature longleaf pine was unaffected by understory cogon grass cover once longleaf pine reached a critical size (10.4 cm dbh or 85.1 cm^2 basal area in her study), but that longleaf pine regeneration would not occur until cogon grass was controlled [86].

Because cogon grass increases fire severity, wildfires in pine plantations infested with cogon grass may kill pine seedlings that are normally fire resistant [90].

Tropical ecosystems:

Cogon grass is invasive in tropical and subtropical regions worldwide. Cogon grass is a troublesome agricultural weed in Asia and Africa [2,6,9,20,21]. Repeated agricultural burning has converted millions of acres of tropical forest to cogon grasslands [14]. In a 1997 survey, Garrity and others [46] estimated that about 35 million acres (14 million ha) were dominated by cogon grass in Asia, mostly as a result of frequent fire on shifting agricultural lands. In Indonesia, for example, shifting agriculture has resulted in a type conversion of tropical forest to coarse tropical grasslands dominated by cogon grass and/or wild sugarcane (*Saccharum spontaneum*) [42,100]. Cogon grass coverage increased in Indonesia from 31.3 million acres (12.5 million ha) in 1996-1997 to 58 million acres (23.2 million ha) in 2000. Cogon grass coverage also increased in tropical forest understories [100]. Van der Wall [154] demonstrated that it takes about 4 or 5 slash-and-burn cycles to effect a type conversion from tropical forest to cogon grassland.

Control:

Cogon grass is not easy to kill. Its extensive rhizome system requires several treatments before control is effective [43,133]. Long-term control of cogon grass only works if the cogon grass monoculture is changed to a competitive, diverse plant community [43]. Postcontrol revegetation needs to be accomplished quickly in order for a stable plant community to establish. Posttreatment inventory and spot-control treatments are needed to control new cogon grass infestations [70].

Prevention:

The most efficient and effective method of managing invasive species is to prevent their invasion and spread [131]. Preventing the establishment of nonnative invasive plants in wildlands is achieved by maintaining native communities and conducting aggressive surveying, monitoring, and any needed control measures several times each year. Preventing the introduction of cogon grass into uninfested areas, and early control of small infestations, should be a priority [70]. Monitoring efforts are best concentrated on the most likely sites of cogon grass invasion: disturbed soil, roadsides, old fields, pine savannas, and burns. Uninvaded sites should be periodically surveyed to detect new invasions. The Center for Invasive Plant Management provides an online guide to noxious weed prevention practices.

Limiting seed and rhizome dispersal reduces chances for cogon grass spread. Regular cleaning of road equipment, and restrictions on long-range movement of equipment, can limit cogon grass spread. Removal of 'Red Baron' cultivars from the market may also reduce cogon grass spread [90].

Integrated management

including burning, mowing, tillage, chemical, and/or cultural control will increase the likelihood of cogon grass control [34,69,133,166]. Successful control in Florida employs a combination of mechanical, chemical, and/or burning treatments. Johnson and Shilling [70] recommend beginning an integrated control program in late spring or summer, when cogon grass growth is peaking. Some treatments, like mowing and spot herbicide spraying, should be implemented year-round [70].

Physical/mechanical:

Cogon grass can be controlled by mowing, disking, pressing, or a combination of these methods [146]. Cogon grass is difficult to remove by hand cultivation due to its rhizomatous habit [116]. Mechanical treatments may not be possible or practical on some wildland sites.

Mowing treatments alone cannot control cogon grass. In the Philippines, Sajise [124] found cutting treatments increased cogon grass sprouting compared to uncut control plots. Plants cut every 2 months produced more sprouts compared to plants cut monthly [124]. Frequent, repeated mowing treatments, or mowing followed by reseeding and further mowing treatments, can reduce cogon grass [166]. An Australian review recommends removing before cogon grass flowers or reaches 12 inches (30 cm) in height [160].

Disking, or a combination of disking and other treatments, helps control cogon grass. Testing 11 populations in northern and central Florida, Shilling and others [133] found disking alone provided short-term control of cogon grass; however, disking and imazapyr application provided 96% control of cogon grass 1 year after treatments. Mowing in late spring to remove old growth and thatch, followed by disking 6 to 8 weeks later, when plants are 6 to 12 inches (20-30 cm) tall, was also effective [133]. Plants should be disked before they reach 30 inches (75 cm) in height. A second disking is needed 2 to 3 weeks later if disking is the only control method used [116].

Another northern Florida study illustrates the importance of multiple treatments. One year after mechanical or mechanical/chemical treatments, 1 summer mowing and disking treatment had increased cogon grass density; 2 mowing and disking treatments provided "moderate" control; summer mowing and disking, fall imazapyr or glyphosate treatment, and a 2nd summer mowing and disking provided 100% control [170]. In an Alabama study, Wilcut and others [165] found tilling cogon grass rhizomes to depths of 2 to 3 inches (5-8 cm) greatly reduced cogon grass sprouts. Rhizomes exposed to 23 °F to 25 °F (-5 °C to -4 °C) temperatures for 24 hours were also killed, suggesting that cold-weather tillage can maximize rhizome kill.

Small-farm operations in Asia commonly press or drum roll cogon grass stands, which breaks and lodges stems and leaves. In Indonesia, mechanical lodging is more effective than fire, mowing, or disking measures because cogon grass rhizomes are forced to grow through their own, artificially compacted, dense litter. Legume species tend to be better competitors for light after compaction treatments [116] (see Cultural control). Using roller/compactors, mechanical lodging may be effective as a part of an integrated control program on some sites.

Fire: See the Fire Management Considerations section of this summary.

Biological: There are no biological control agents currently approved for cogon grass control [116,134,148]. Cogon grass has several insects and fungal pathogens that infest it in Asia [35]. Two fungal pathogens (*Bipolaria sacchari* and *Drechslera gigantea*) have shown potential as cogon grass control agents in greenhouse trials [177,178].

Cogon grass is widely used as livestock forage in Asia and Africa [39,40]. Domestic sheep grazing has been successfully used as a control measure in Malaysia [156]; however, there are no studies on using livestock to help control Brazilian satintail or cogon grass in the United States. Some ranchers in the Southeast use cogon grass swards as winter cattle range [143]. Cattle weight gain is not as good on cogon grass compared to pasture grasses [39,40]; however, livestock grazing may be a useful part of an integrated Brazilian satintail/cogon grass control program if the primary management objective is weed control and not meat or milk production. Studies on how livestock use affects Brazilian satintail and cogon grass cover and reproduction are needed.

Chemical:

Herbicides may provide initial control of a new invasion or a severe infestation, but used alone, they are rarely a complete or long-term solution to invasive species management [17]. Herbicides are most effective on large infestations when incorporated into long-term management plans that include replacement of weeds with desirable species, careful land use management, and prevention of new infestations. Control with herbicides is temporary, as it does not change the conditions that allowed the invasion to occur (e.g. [179]). See The Nature Conservancy's Weed Control Methods Handbook
for considerations on the use of herbicides in Natural Areas and detailed information on specific chemicals.

Imazapyr and glyphosate help control cogon grass [43,70,146,148,165,167]. Imazapyr is nonselective and has some soil residual activity. Glyphosate is also nonselective but is less residual, offering more flexibility in timing and species selection for posttreatment revegetation [44]. Rhizomes must be killed for effective, long-lasting control [70,88,96]. Depending upon rhizome reserves, multiple herbicide applications and follow-up spot treatments are usually needed for complete rhizome kill and long-term control [25,96]. Fall applications are usually recommended because cogon grass transports carbohydrates and herbicides down into its rhizomes and roots at that time of year [70,88,96]. Shilling and others [133] found autumn applications of glyphosate or imazapyr provided better control than spring or summer applications. Winter applications can be effective if plants are still green. Analysis of rhizome total nonstructural carbohydrates (TNC) can show when carbohydrate allocation is directed toward rhizomes and therefore, when herbicide applications are likely to be most effective. In Florida, TNC content showed a small peak in December and January, and showed greatest gains in February and May. Rhizome TNC content was lowest in November [133]. Twelve and sixteen months after Florida field trials, Gaffney [44] found December application was twice as effective as either September or January application. Imazapyr gave better control than glyphosate.

Follow-up herbicide applications in spring, prior to flowering, can suppress cogon grass seed production [96]. Young plants can often be controlled using fewer applications and/or lower doses of herbicide than plants with well-developed rhizomes [34]. Demers and Long [30] provide standard application rate recommendations for cogon grass. High concentrations of herbicides do not necessarily translate into higher rate of cogon grass kill compared to recommended rates of application. In a loblolly pine plantation study in Florida, Ramsey and others [118] report high rates of glyphosate or imazapyr actually inhibit translocation of the herbicide to rhizomes. They recommend half-dose applications, sprayed twice a year, to ensure good rhizome kill. Terry and others [146] found glyphosate application to newly burned cogon grasslands was not effective. Glyphosate is usually a foliar-applied and foliar-absorbed herbicide, and top-killed cogon grass lacked sufficient aboveground surface area to carry the herbicide to rhizomes [146].

Carefully timed herbicide treatments may control cogon grass for as long as 1 or 2 years, but without establishment of desirable native species, cogon grass can eventually reinfest treated areas [118,133] (see Cultural control below).

Altering soil nutrient status

can increase the competitive ability of native species on sites with cogon grass. In a Mississippi study, addition of large amounts of phosphorus slowed rate of cogon grass invasion into longleaf pine savannas. Native plant species were seemingly not affected by the fertilizer. The mechanism of cogon grass inhibition was unknown, but the authors speculated that the addition of phosphorus could have caused changes to the soil microbial community, chemical changes in the soil, or a phosphorus toxicity reaction in cogon grass [13]. Cogon grass forms mycorrhizal associations in Indonesia (Tjitrosemito and others 1994, as cited in [146]); these associations help cogon grass obtain phosphorus, which is often limiting in tropical ecosystems. This competitive advantage is lost, however, where phosphorus is not limiting. Applying phosphorus on sites where it is already plentiful may help control cogon grass [146].

Cultural control of cogon grass is effective, and is widely practiced in Asia and Africa [20,42,66]. Posttreatment revegetation gives best long-term control of cogon grass [22,43]. Because many legume species outcompete cogon grass for light and rapidly shade it out, legume plantings are particularly useful for cogon grass control [118]. Managers and farmers in tropical countries successfully plant legume and other herbaceous species after using herbicides for cogon grass control [66,133,153]. In a Mississippi study, cogon grass invasion was negatively correlated with relative abundance of native legumes on unfertilized plots [13]. Trees planted in cogon grass swards can shade cogon grass out when small areas around the trees are controlled: this method is used to control cogon grass in tropical orchards and plantations or to reclaim tropical forest that has converted to cogon grassland [14,42,66,67,83,84]. Fire may be excluded as part of the control method in orchards and plantations, using mechanical and herbicide controls on reinvading cogon grass [42,53].

On a phosphate mine site in central Florida, nonnative hairy indigo (*Indigo hirsuta*), nonnative perennial ryegrass (*Lolium perenne*), native bahia grass (*Paspalum notatum*), native switch grass (*Panicum virgatum*), or native partridge pea (*Chamaecrista fasciculata*) were planted after imazapyr or glyphosate treatments to control cogon grass. Imazapyr treatment followed by hairy indigo seedings gave best cogon grass control (100% control at posttreatment year 1), followed by imazapyr and switch grass or partridge pea plantings (86% control). Perennial ryegrass and bahia grass showed poor establishment [133]. Shilling and others [133] found a significantly lower ($p<0.001$) density of cogon grass establishment in fields planted to bahia grass. Presence of bahia grass lowered cogon grass seedling density by 25% and lowered cogon grass ramet density by 37%. A combination of herbicides and revegetating with Bermuda grass and hairy indigo also gave good control of cogon grass 2 years after posttreatment seedings [133].

Cultural plantings in cogon grass swards that have been burned but not otherwise treated does not provide control. Barnard [9] calls it "a failure and a waste of seed."

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