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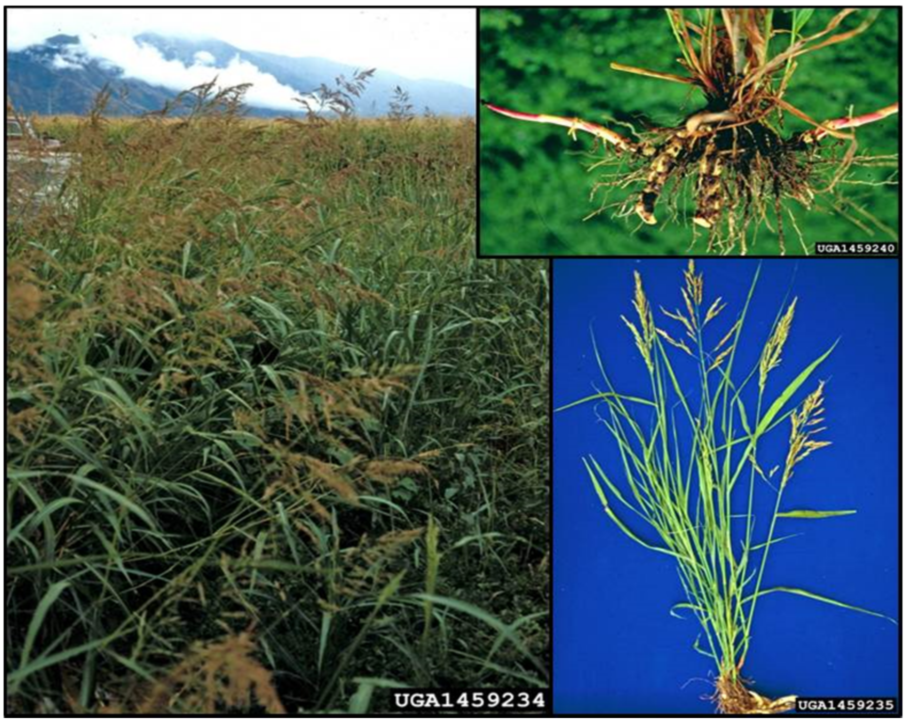
Weed Risk Assessment for *Sorghum halepense* (L.) Pers. (Poaceae) – Johnsongrass



Left: Johnsongrass infestation. Top right: Roots/rhizomes. Bottom right: Profile (source: Steve Dewey, Utah State University, Bugwood.org).

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Introduction Plant Protection and Quarantine (PPQ) regulates noxious weeds under the authority of the Plant Protection Act (7 U.S.C. § 7701-7786, 2000) and the Federal Seed Act (7 U.S.C. § 1581-1610, 1939). A noxious weed is defined as "any plant or plant product that can directly or indirectly injure or cause damage to crops (including nursery stock or plant products), livestock, poultry, or other interests of agriculture, irrigation, navigation, the natural resources of the United States, the public health, or the environment" (7 U.S.C. § 7701-7786, 2000). We use the PPQ weed risk assessment (WRA) process (PPQ, 2015) to evaluate the risk potential of plants, including those newly detected in the United States, those proposed for import, and those emerging as weeds elsewhere in the world.

The PPQ WRA process includes three analytical components that together describe the risk profile of a plant species (risk potential, uncertainty, and geographic potential; PPQ, 2015). At the core of the process is the predictive risk model that evaluates the baseline invasive/weed potential of a plant species using information related to its ability to establish, spread, and cause harm in natural, anthropogenic, and production systems (Koop et al., 2012). Because the predictive model is geographically and climatically neutral, it can be used to evaluate the risk of any plant species for the entire United States or for any area within it. We then use a stochastic simulation to evaluate how much the uncertainty associated with the risk analysis affects the outcomes from the predictive model. The simulation essentially evaluates what other risk scores might result if any answers in the predictive model might change. Finally, we use Geographic Information System (GIS) overlays to evaluate those areas of the United States that may be suitable for the establishment of the species. For a detailed description of the PPQ WRA process, please refer to the *PPQ Weed Risk Assessment Guidelines* (PPQ, 2015), which is available upon request.

We emphasize that our WRA process is designed to estimate the baseline—or unmitigated—risk associated with a plant species. We use evidence from anywhere in the world and in any type of system (production, anthropogenic, or natural) for the assessment, which makes our process a very broad evaluation. This is appropriate for the types of actions considered by our agency (e.g., Federal regulation). Furthermore, risk assessment and risk management are distinctly different phases of pest risk analysis (e.g., IPPC, 2015). Although we may use evidence about existing or proposed control programs in the assessment, the ease or difficulty of control has no bearing on the risk potential for a species. That information could be considered during the risk management (decision making) process, which is not addressed in this document.

***Sorghum halepense* (L.) Pers. – Johnsongrass**

Species Information Family: Poaceae

Synonyms: Numerous synonyms have been listed for this species, including the following that are listed at the USDA's Germplasm Resource Information Network (NGRP, 2015): *S. controversum* (Steud.) Snowden; *S. miliaceum* (Roxb.) Snowden; *Andropogon controversus* Steud.; *A. halepensis* (L.) Brot; *A. miliaceus* Roxb.; *A. miliformis* Schult.; *Holcus exiguus* Forssk; *H. halepensis* L. (basionym); *H. sorghum* var. *exiguus* (Forssk.) Hitchc. Additional synonyms are listed in the following sources: ITIS, 2015; McWhorter, 1971; The Plant List, 2015.

Common names: Johnsongrass (NGRP, 2015), Aleppo grass (NGRP, 2015), Aleppo milletgrass (ITIS, 2015), Cuba grass, Egyptian grass, evergreen millet, guinea grass, Means grass (McWhorter, 1971; Parsons and Cuthbertson, 2001).

Botanical description: Johnsongrass is an erect, perennial C4 grass that grows 0.5 to 3 meters tall and spreads by seeds and long creeping rhizomes (Baker and Terry, 1991; Holm et al., 1977; Parsons and Cuthbertson, 2001). Leaves are alternate with a prominent midrib, and range in length from 20 to 60 cm long (Parsons and Cuthbertson, 2001). A "ribbed leaf sheath, conspicuous midrib, the large, purplish panicle, and the extensively creeping rhizomes are distinguishing characteristics of this species" (Holm et al., 1977). Johnsongrass is an old tetraploid hybrid with a chromosome count of 2N = 40 (Sangduen and Hanna, 1984), although one researcher reports tropical ecotypes that are diploid (2N = 20; McWhorter, 1989). While one of its parents is *Sorghum bicolor*, it is unclear what the other parent is. There is speculation that it could be *S. virgatum*, *S. propinquum*, or perhaps a different race within *S. bicolor* (Hoang and Liang, 1988; McWhorter, 1989; Sangduen and Hanna, 1984). In the United States, johnsongrass is highly variable (McWhorter, 1989).

Initiation: On February 22, 2013, the biotechnology company CERES Inc. sent APHIS a letter (Hamilton, 2013) seeking confirmation that their TRSBG101B *Sorghum bicolor* ssp. *bicolor* (sweet sorghum) plant, which they genetically engineered without any plant pest sequences using a biolistic (i.e., gene gun) method, was not a regulated article under APHIS's biotechnology regulations (7 CFR § 340, 2015). The transformed sorghum produces greater biomass and more fermentable sugars than the untransformed parent (Hamilton, 2013). Although the transgenic sorghum is not regulated by APHIS, APHIS is concerned about the weed risk potential of TRSBG101B (APHIS-BRS, 2014) and its ability to hybridize with and transfer genes for greater biomass to two other sorghums that are common agricultural weeds: *S. halepense* (johnsongrass) and *S. bicolor* nothosubsp. *drummondii* (shattercane). In this document, we characterize the weed risk potential of johnsongrass.

Foreign distribution: Johnsongrass is native to the region from northeastern Africa through the Middle East to India, including the countries of Afghanistan, Armenia, Azerbaijan, Egypt, Iran, Iraq, Israel, Jordan, Lebanon, Libya, Kazakhstan, Kyrgyzstan, Pakistan, Syria, Turkey, Turkmenistan, and Uzbekistan (NGRP, 2015). It is widely naturalized in other countries in warm temperate regions (NGRP, 2015).

U.S. distribution and status: Johnsongrass was introduced into the United States around 1830, possibly earlier in South Carolina (USDA-FS, 1953), and was intentionally introduced during the late 1800s (McWhorter, 1971). It was planted both for forage and as a cover crop during the 19th century (McWhorter, 1971). Its use declined during the early part of the 20th century, but then increased again during World War II (McWhorter, 1989). This species is widely naturalized in the United States and is known to occur in all U.S. states except Alaska, Maine, and Minnesota (Kartesz, 2015). It has been reported for about 90 percent of all counties in the southern half of the United States (Kartesz, 2015). It is a regulated non-quarantine pest in the United States (7 CFR § 361, 2014). It is also listed as a state noxious weed and state noxious weed seed by 33 states (NRCS, 2015; USDA-AMS, 2014).

WRA area[1]: Entire United States, including territories.

1. *Sorghum halepense* analysis

Establishment/Spread Potential

As evidenced by the very high risk score for johnsongrass for this risk element, it possesses many traits that contribute to its ability to establish and spread. This species produces thousands of viable seeds (Scopel et al., 1988), is self-compatible (Clements and DiTommaso, 2012), does not rely on insects for pollination, is dispersed unintentionally by people (Christoffoleti et al., 2007; Ghersa et al., 1993) and by all five natural dispersal vectors (Holm et al., 1977; McWhorter, 1989; Parsons and Cuthbertson, 2001), forms a long-term soil seed bank (Parsons and Cuthbertson, 2001), is very tolerant to mutilation (Maillet, 1991), and is resistant to some herbicides (Heap, 2015). Arguably, its two worst features are its ability to produce thousands of seeds within a few months of germination, and the large rhizome system it develops (Holm et al., 1977). Widespread distribution in other countries [e.g., Australia (Parsons and Cuthbertson, 2001), Italy (Follak and Essl, 2013)], along with reports of rapid spread [e.g., Australia (Parsons and Cuthbertson, 2001), Austria (Follak and Essl, 2013), Slovenia (Follak and Essl, 2013), and the United States (McWhorter, 1971; Rout and Chrzanowski, 2009)], indicates that this is a highly invasive species. We had a very low amount of uncertainty for this risk element.

Risk score = 26 Uncertainty index = 0.03

Impact Potential

Johnsongrass impacts primarily agricultural systems, but is also problematic in natural areas and anthropogenic systems. In agricultural systems, it reduces yield (McWhorter, 1989; Mitskas et al., 2003), increases the costs of production (Keeley and Thullen, 1981; McWhorter and Anderson, 1981), and is toxic to livestock under some circumstances (Burrows and Tyrl, 2013). It is one of the world's worst agricultural weeds (Holm et al., 1977; Maillet, 1991; Randall, 2012). Despite the improvements in johnsongrass control over the last 20 years, researchers continue to search for effective control strategies (Andújar et al., 2013a; Johnson and Norsworthy, 2014), including control of herbicide-resistant populations (Johnson et al., 2014). The first U.S. appropriations bill for weed control research was passed in 1900 specifically for controlling johnsongrass (McWhorter, 1989). In natural areas, johnsongrass changes species diversity and alters soil properties due to associations with nitrogen-fixing bacteria (Rout and Chrzanowski, 2009; Rout et al., 2013b); however, we saw little evidence that it is perceived as an environmental weed. In anthropogenic systems, it presents a potential safety hazard on roadways (Parsons and Cuthbertson, 2001), and invades home gardens (Dave's Garden, 2015). We had a high amount of uncertainty for this risk element, primarily associated with its impacts in natural systems.

Risk score = 4 Uncertainty index = 0.23

[1] "WRA area" is the area in relation to which the weed risk assessment is conducted (definition modified from that for "PRA area") (IPPC, 2012).

Geographic Potential Based on three climatic variables, we estimate that about 78 percent of the United States is suitable for the establishment of johnsongrass (Fig. 1). This predicted distribution is based on the species' known distribution and includes point-referenced localities and areas of occurrence. The map for johnsongrass represents the joint distribution of Plant Hardiness Zones 5-13, areas with 0-100+ inches of annual precipitation, and the following Köppen-Geiger climate classes: tropical rainforest, tropical savanna, steppe, desert, Mediterranean, humid subtropical, marine west coast, humid continental warm summers, humid continental cool summers, and subarctic. We found a few point occurrences in Plant Hardiness Zone 4, but did not answer yes for this zone (Geo-Z4) because these points may represent incorrect identifications, plants growing in protected climates, or plants that never established permanent populations. However, we note that johnsongrass has been adapting and moving into progressively colder regions over the last few decades (Warwick et al., 1986).

The area of the United States shown to be climatically suitable is likely overestimated since our analysis considered only three climatic variables. Other environmental variables, such as soil and habitat type, may further limit the areas in which this species is likely to establish. Johnsongrass occurs in temperate, subtropical, and tropical regions where it frequently occurs in ditches, field borders, cultivated lands, waste places, roadsides, other rights-of-ways, creeks, canal banks, and prairies (Holm et al., 1977; McWhorter, 1971; Parsons and Cuthbertson, 2001; Rout et al., 2013a).

Entry Potential We did not assess the entry potential of johnsongrass because it is widely distributed in the United States (Kartesz, 2015; NRCS, 2015) and has been present since the early 1800s (McWhorter, 1971).

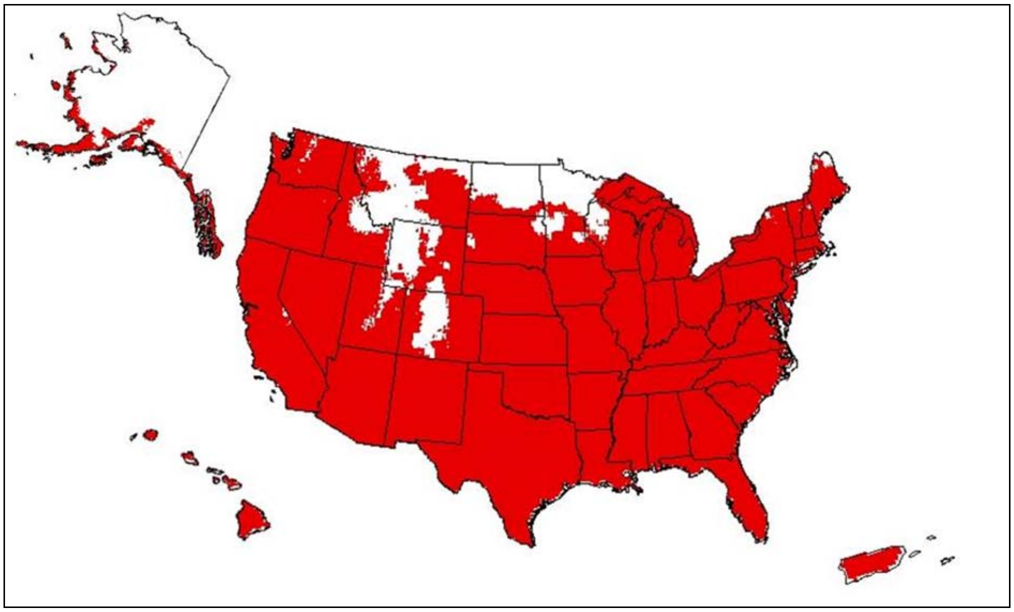

Figure 1. Predicted distribution of *Sorghum halepense* in the United States. Map insets for Alaska, Hawaii, and Puerto Rico are not to scale.

2. Results

Model Probabilities: P(Major Invader) = 98.8%
P(Minor Invader) = 1.2%
P(Non-Invader) = 0.0%

Risk Result = High Risk

Secondary Screening = Not Applicable

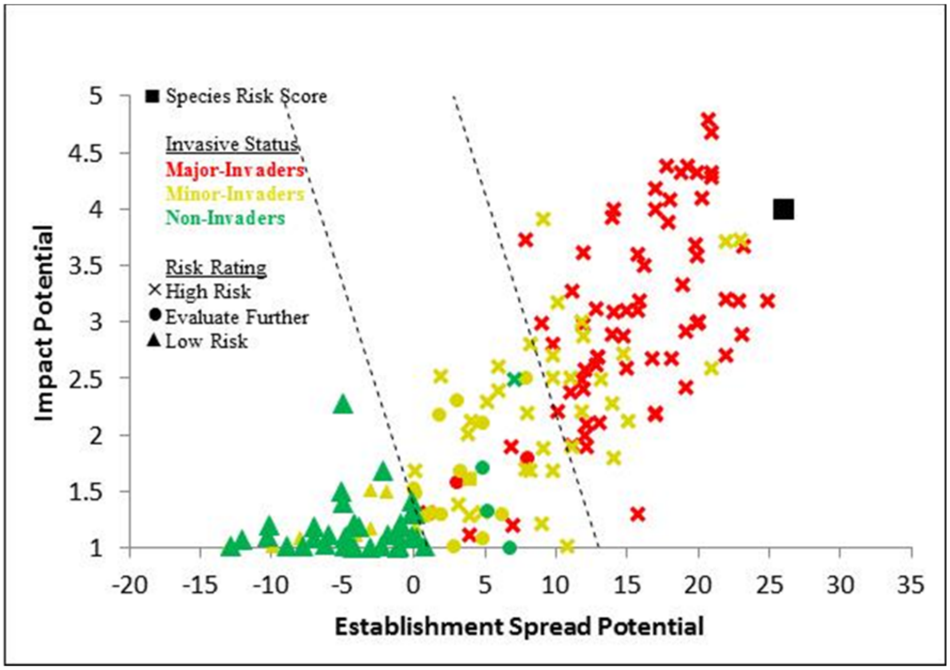

Figure 2. *Sorghum halepense* risk score (black box) relative to the risk scores of species used to develop and validate the PPQ WRA model (other symbols). See Appendix A for the complete assessment.

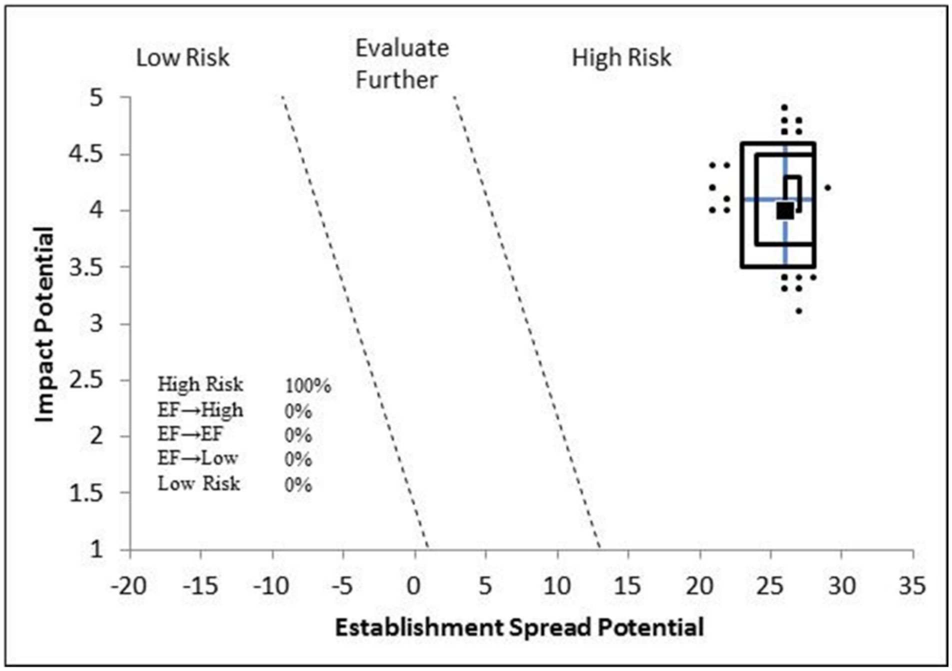

Figure 3. Model simulation results (N=5,000) for uncertainty around the risk score for *Sorghum halepense*. The blue "+" symbol represents the medians of the simulated outcomes. The smallest box contains 50 percent of the outcomes, the second 95 percent, and the largest 99 percent.

3. Discussion

The result of the weed risk assessment for *Sorghum halepense* is High Risk (Fig. 2) and is well supported by our uncertainty analysis (Fig. 3). Of the approximately 300 species that we have evaluated using this risk assessment model, this species obtained the highest risk score for establishment/spread potential (Fig. 2). This is consistent with reports that it is one of the worst weeds in the world (Holm et al., 1977; Maillet, 1991; Randall, 2012). Despite the fact that johnsongrass is widely distributed and naturalized in the world and the United States (GBIF, 2015; NGRP, 2015), it is still an emerging weed problem in some areas (Follak and Essl, 2013). Furthermore, climate change seems likely to result in further expansion (Follak and Essl, 2013). In the United States, johnsongrass has been moving into progressively colder regions over the last few decades (Warwick et al., 1986), suggesting either that these areas are becoming more favorable for this species due to climate change or that johnsongrass populations are adapting to colder temperatures, or both. In addition, phenotypic variation in the depth of rhizome production is associated with survival at the northern limit of its range in Ontario (Parsons and Cuthbertson, 2001).

This WRA was initiated due to concerns that there may be gene flow from a sweet sorghum (*S. bicolor* subsp. *bicolor*), which has been genetically engineered for increased biomass, to johnsongrass. It was not the intent of this risk assessment to evaluate the likelihood of gene flow from genetically engineered sweet sorghum into johnsongrass, but to establish the baseline risk potential of johnsongrass. However, we note that johnsongrass can hybridize with either diploid *S. bicolor* (2n = 20) to form 2n = 3*x* = 30 hybrids, or it can hybridize with tetraploid *S.*

bicolor (2n = 40) to form 2n = 4*x* = 40 hybrids (Sangduen and Hanna, 1984). These hybrids are sometimes called *Sorghum* × *almum* Parodi (Burrows and Tyrl, 2013). A field experiment showed that hybridization can occur over distances of 100 meters (Arriola and Ellstrand, 1996). Additional review is needed to evaluate the fitness level of hybrids relative to their parents.

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Appendix A. Weed risk assessment for *Sorghum halepense* (L.) Pers. (Poaceae). Below is all of the evidence and associated references used to evaluate the risk potential of this taxon. We also include the answer, uncertainty rating, and score for each question. The Excel file, where this assessment was conducted, is available upon request.

Question ID	**Answer - Uncertainty**	**Score**	**Notes (and references)**
ESTABLISHMENT/SPREAD POTENTIAL			
ES-1 [What is the taxon's establishment and spread status outside its native range? (a) Introduced elsewhere =>75 years ago but not escaped; (b) Introduced <75 years ago but not escaped; (c) Never moved beyond its native range; (d) Escaped/Casual; (e) Naturalized; (f) Invasive; (?) Unknown]	f - negl	5	Johnsongrass is native to the region encompassing northeastern Africa through the Middle East to India (NGRP, 2015). It is widely naturalized in other countries in warm temperate and tropical regions (Acevedo-Rodríguez and Strong, 2012; NGRP, 2015; Parsons and Cuthbertson, 2001). Widespread distribution in other countries [e.g., Australia (Parsons and Cuthbertson, 2001), Italy (Follak and Essl, 2013)], along with reports of rapid spread [e.g., Australia (Parsons and Cuthbertson, 2001), Austria (Follak and Essl, 2013), Slovenia (Follak and Essl, 2013), and the United States (McWhorter, 1971; Rout and Chrzanowski, 2009)], indicates that this is a highly invasive species. It is also naturalized in Ontario, Canada (Brouillet et al., 2015). Alternate answers for the Monte Carlo simulation were both "e."
ES-2 (Is the species highly domesticated)	n - low	0	Although this species is cultivated for forage and hay (McWhorter, 1989), we found no evidence of selective breeding, let alone breeding for traits associated with reduced weed potential.
ES-3 (Weedy congeners)	y - negl	1	*Sorghum arundinaceum* is a principal weed in Venezuela (Holm et al., 1979). *Sorghum verticilliflorum* is either a serious or principal weed in four countries (Holm et al., 1979). *Sorghum vulgare* is a principal weed in two countries (Holm et al., 1979). *Sorghum bicolor* subsp. *drummondii*, commonly known as shattercane, is a significant weed of other grains because it reduces yield (Defelice, 2006).
ES-4 (Shade tolerant at some stage of its life cycle)	n - low	0	Growth is retarded when light falls below 20 percent of full daylight (Parsons and Cuthbertson, 2001). In shaded conditions, seeds don't germinate, and seedlings don't grow well (Holm et al., 1977).
ES-5 (Climbing or smothering growth form)	n - negl	0	The species is neither a vine nor an herb with a basal rosette of leaves; it is a grass that produces upright stems (McWhorter, 1989).
ES-6 (Forms dense thickets)	y - negl	2	"Its vigorous rhizomatous growth facilitates rapid establishment of the dense stands desired by cattle producers" (Burrows and Tyrl, 2013). Forms dense populations in crop fields in Austria (Follak and Essl, 2013). Ramets that develop from buds on rhizomes contributed to the formation of dense monocultures (Rout and Chrzanowski, 2009). Can reach densities of 74 shoots per square meter in cotton (Keeley and Thullen, 1981).
ES-7 (Aquatic)	n - negl	0	This is an upland terrestrial species and not an aquatic plant (Holm et al., 1977).
ES-8 (Grass)	y - negl	1	This plant is a grass (NGRP, 2015).

Question ID	**Answer - Uncertainty**	**Score**	**Notes (and references)**
ES-9 (Nitrogen-fixing woody plant)	n - negl	1	Because this species is not a woody plant, we answered no. However, there is some evidence supporting nitrogen fixation. One study showed that johnsongrass is associated with endophytic bacteria that exhibit nitrogen fixation. Furthermore, the study showed that soil nitrogen levels (and that of other nutrients) were higher in invaded plots than in non-invaded plots (Rout and Chrzanowski, 2009). A second study verified these results and showed that the endophytic bacteria were transmitted horizontally along rhizomes and vertically into seeds (Rout et al., 2013b). When bacteria were suppressed with tetracycline, plant growth slowed, supporting the importance of these bacteria to plant growth (Rout et al., 2013b).
ES-10 (Does it produce viable seeds or spores)	y - negl	1	Reproduces by seed (Parsons and Cuthbertson, 2001). Produces viable seed (McWhorter, 1972).
ES-11 (Self-compatible or apomictic)	y - low	1	Is capable of self-fertilization (cited in Rout et al., 2013a). It is primarily self-fertilizing (Clements and DiTommaso, 2012). The vast majority of *Sorghum*s are capable of self-pollination (Gressel and Levy, 2014). We answered yes, but used low uncertainty because these references are not from the primary literature.
ES-12 (Requires special pollinators)	n - low	0	We found no direct evidence that this species requires specialist pollinators. Grass species in general are wind-pollinated (Faegri and Van der Pijl, 1979), and thus this question received a no response.
ES-13 [What is the taxon's minimum generation time? (a) less than a year with multiple generations per year; (b) 1 year, usually annuals; (c) 2 or 3 years; (d) more than 3 years; or (?) unknown]	b - mod	1	Johnsongrass is a perennial species (McWhorter, 1989), that begins flowering 7 weeks after seedling emergence (Parsons and Cuthbertson, 2001). Crown development is much faster on plants arising from rhizomes vs. seeds (Holm et al., 1977). "A single johnsongrass plant may produce 40 to 90 m of rhizomes in a single season" (McWhorter, 1989). Individual rhizomes may reach more than 2 meters in length (cited in McWhorter, 1972). Seedlings begin producing rhizomes a few weeks after emergence (McWhorter, 1972; Parsons and Cuthbertson, 2001), but once they are initiated, rhizomes don't begin developing until after flowering. Each plant produces hundreds to thousands of nodes on rhizomes but these don't normally develop due to strong apical dominance (reviewed in McWhorter, 1989). Either through sexual or vegetative reproduction, this species produces at least one generation per year. We found no evidence that plant culms can produce additional culms vegetatively in the same year without mechanical disturbance. However, because we suspect it may be producing multiple generations per year, we answered "b" with moderate uncertainty and used "a" for both alternate answers.
ES-14 (Prolific reproduction)	y - negl	1	In one study that measured seed production in one season, the authors estimated that dense clumps were producing 8080 ± 4300 full seeds per square meter (Scopel et al., 1988). That same study cites another (Ghersa et al., 1985) that reported seed production rates

Question ID	Answer - Uncertainty	Score	Notes (and references)
			of 30,000 full seeds per square meter in dense patches. Field level production rates of seed range from 540 to 1440 kg per hectare (McWhorter, 1989). Assuming that 333 seeds weigh a gram (McWhorter, 1989), this converts to 17,982 to 47,952 seeds per square meter. If the glume is removed, 95 percent of seeds germinate (Holm et al., 1977). A prolific seed producer (Holm et al., 1977; McWhorter, 1989). A single plant may produce more than 170 stems (McWhorter, 1989). Based on this evidence, we answered yes with negligible uncertainty.
ES-15 (Propagules likely to be dispersed unintentionally by people)	y - negl	1	One study that established seed traps from a clump of johnsongrass along the path of a combine showed that 20 percent of the seeds were dispersed within 50 meters from the clump (Ghersa et al., 1993). Another study showed that combines disperse seeds at least 22 meters from infestations (Barroso et al., 2012). A study of the spatial distribution of populations in tomato and maize fields showed that *S. halepense* populations were elongated along the direction of tillage (Andújar et al., 2012; Andújar et al., 2013b). Seed may spread in mud sticking to machinery and other vehicles, and rhizomes may spread during cultivation and road grading (Parsons and Cuthbertson, 2001; Veldman and Putz, 2010). "Johnsongrass seed escaped from railroad box cars causing general distribution along rights-of-way" (McWhorter, 1971).
ES-16 (Propagules likely to disperse in trade as contaminants or hitchhikers)	y - negl	2	"*Sorghum halepense* was introduced in the southern region of Brazil by the rail transport of flax, lucerne (*Medicago sativa*), sunflower (*Helianthus annuus*) and sorghum (*Sorghum bicolor*) from Argentina" (Christoffoleti et al., 2007). When soybean fields are harvested with combines, johnsongrass seeds and trash contaminate the harvested commodity (McWhorter and Anderson, 1981). Seed may also be spread as a contaminant in agricultural products (Parsons and Cuthbertson, 2001). Likely to have been a seed contaminant of grains and seeds in the 1800s due to the limited ability of technology available then to separate out weed seeds (McWhorter, 1971). In one study of the spatial distribution of this species in Austria over time, the authors concluded that it was likely initially introduced as a seed contaminant of agricultural seeds (Follak and Essl, 2013).
ES-17 (Number of natural dispersal vectors)	5	4	Fruit and seed description for questions ES-17a through ES-17e: The grain of johnsongrass is about 3 mm long and oval in shape (McWhorter, 1989).
ES-17a (Wind dispersal)	y - low		Detached spikelets are blown in the wind (Parsons and Cuthbertson, 2001). Ghersa et al. (1993) used seed traps to demonstrate that most seeds fall within or next to a johnsongrass clump, but some are dispersed by wind up to a few meters away. Wind dispersed (Holm et al., 1977; McWhorter, 1989). Johnsongrass does not appear to be specifically adapted for wind dispersal; however,

Question ID	Answer - Uncertainty	Score	Notes (and references)
			based on the dispersal study and the number of anecdotal accounts, we answered yes.
ES-17b (Water dispersal)	y - low		Detached spikelets float on water (Holm et al., 1977; Parsons and Cuthbertson, 2001). Dispersed by water (Busso et al., 2013; McWhorter, 1989). A study of the spatial distribution of the species in tomato fields showed higher infestation levels in low-lying areas subject to flooding (Andújar et al., 2013b), suggesting water dispersal may be important. Seeds are carried by overflow, drainage, and irrigation water (Talbot, 1928). We used low uncertainty instead of negligible because johnsongrass does not appear to be specifically adapted for water dispersal and because these were not primary references.
ES-17c (Bird dispersal)	y - low		Seeds pass unharmed through bird guts (Parsons and Cuthbertson, 2001). Dispersed by birds through ingestion (Holm et al., 1977). Dispersed by birds (McWhorter, 1989).
ES-17d (Animal external dispersal)	y - mod		Spikelets readily attach to animal fur (Parsons and Cuthbertson, 2001). Disperses on coats of animals (Holm et al., 1977).
ES-17e (Animal internal dispersal)	y - low		Seeds pass unharmed through animal guts (Parsons and Cuthbertson, 2001). One study that planted seeds under soil, on the soil surface, and under a mesh that excludes birds and animals showed that seed abundance declines exponentially in a corn field; presence of rodent droppings strongly suggested that rodents were consuming seeds (Scopel et al., 1988). McWhorter (1971) suspects it was dispersed by horses during the Civil War. Dispersed through consumption by animals and seeds remain viable (Holm et al., 1977). Seeds survive animal passage, but if they remain in sheep for more than 14 hours, they are no longer viable (reviewed in McWhorter, 1989). The evidence suggests that some animals are likely dispersing seeds, but perhaps others are not.
ES-18 (Evidence that a persistent (>1yr) propagule bank (seed bank) is formed)	y - negl	1	When first released, johnsongrass seed is dormant and contains 20 to 40 percent hard seeds, which can remain dormant for long periods of time (Parsons and Cuthbertson, 2001). "A seed burial experiment in the United States showed 48% of Johnson grass seed to be viable at the end of 5.5 years" (Parsons and Cuthbertson, 2001). Some seeds survive for more than one year in the soil (Bagavathiannan and Norsworthy, 2013; Ghersa et al., 1993). Seeds have remained viable in the soil for 30 months (Holm et al., 1977). Seed dormancy is imposed mostly through a physical restriction of the seed coat (Holm et al., 1977).
ES-19 (Tolerates/benefits from mutilation, cultivation or fire)	y - negl	1	Johnsongrass produces a complex rhizome system (Holm et al., 1977) that it begins developing a few weeks after seedling emergence (cited in McWhorter, 1972). Rhizomes contain numerous nodes from which the plant can resprout, following cultivation (Maillet, 1991).

Question ID	Answer - Uncertainty	Score	Notes (and references)
			Johnsongrass readily resprouts from short (about 7 cm long) and long (about 15 cm long) rhizome fragments, at soil depths of 10 to 15 cm (McWhorter, 1972). One study showed that rhizome biomass can vary from about 1 kg to 2.5 kg per square meter (McWhorter, 1972). "In Yugoslavia a block of field soil measuring 1 sq m by 30 cm in thickness contained 1.2 kg of rhizomes which were 28 m in length and contained 2,000 buds" (Holm et al., 1977). "The high concentration of carbohydrates in johnsongrass (nearly 50% of the total dry weight) apparently aids in providing johnsongrass with a rapid regrowth potential, making johnsongrass difficult to control with both chemical and mechanical methods" (McWhorter, 1989).
ES-20 (Is resistant to some herbicides or has the potential to become resistant)	y - negl	1	Johnsongrass has developed resistance to a variety of herbicides (Heap, 2015; Scarabel et al., 2014). Poor translocation of herbicides to dormant buds in rhizomes limits the effectiveness of other herbicides (McWhorter, 1972). Populations of johnsongrass that don't have resistance may be able to acquire it through hybridization or gene flow with other species that are resistant such as *Sorghum bicolor* (Heap, 2015). Johnsongrass hybridizes with *Sorghum bicolor* to produce *Sorghum* × *almum* Parodi (Burrows and Tyrl, 2013). It can hybridize with either diploid *S. bicolor* (2n = 20) to form 2n = 3*x* = 30 hybrids, or it can hybridize with tetraploid *S. bicolor* (2n = 40) to form 2n = 4*x* = 40 hybrids (Sangduen and Hanna, 1984).
ES-21 (Number of cold hardiness zones suitable for its survival)	9	0	
ES-22 (Number of climate types suitable for its survival)	10	2	
ES-23 (Number of precipitation bands suitable for its survival)	11	1	
IMPACT POTENTIAL			
General Impacts			
Imp-G1 (Allelopathic)	y - high	0.1	In a detailed review of the biology of johnsongrass, McWhorter (1989) reviewed the evidence for allelopathy, citing numerous studies that have reported potential allelopathy. "The allelopathic chemicals most often associated with johnsongrass include the cyanogenic glucoside dhurrin, its decomposition product p-hydroxybenzaldehyde, and taxiphyllin (177). These chemicals, in addition to other extracts from johnsongrass, have a wide variety of effects on many higher plants and bacteria. These effects include reduced germination, root growth, shoot growth, and yields" (McWhorter, 1989). However, McWhorter (1989) reports there is no conclusive evidence that it is allelopathic under field conditions and that studies have not tried to separate the effects of potential allelopathy from competition. In a later study, Rout et al. (2013a) used field and greenhouse studies to show that leachates

Question ID	Answer - Uncertainty	Score	Notes (and references)
			from johnsongrass inhibited vegetative and sexual growth of the dominant Texas prairie grass in the United States (Rout et al., 2013a). Because competition was not a factor in Rout et al.'s field study, we answered yes, but with high uncertainty.
Imp-G2 (Parasitic)	n - negl	0	We found no evidence that this well-studied species is parasitic. Furthermore, it is not a member of a plant family known to contain parasitic plants (Heide-Jorgensen, 2008; Nickrent, 2009; Walker, 2014).
Impacts to Natural Systems			
Imp-N1 (Change ecosystem processes and parameters that affect other species)	y - low	0.4	"Through its association with bacteria, *S. halepense* appears to alter plant species diversity and resource availability, which subsequently modifies the habitat within the remnant tallgrass prairie" (Rout and Chrzanowski, 2009). A study that compared soil nutrients between plots that were dominated by native species, invaded by johnsongrass, and transitional between the two found that "[i]nvaded soils contained two to four times greater concentrations of alkaline metals, micronutrients, and essential plant nutrients than native prairie soils" (Rout and Chrzanowski, 2009). Bacterial endophytes associated with johnsongrass also solubilized phosphorus and increased concentration of iron oxides in the soil (Rout et al., 2013b).
Imp-N2 (Change habitat structure)	? - max		We found no direct evidence of changes to habitat structure, but suspect it is likely given the dense populations it can form.
Imp-N3 (Change species diversity)	y - low	0.2	A study that examined plant species composition in a native prairie, an area dominated by johnsongrass, and the transitional zone between the two at the wave front showed that johnsongrass changed community composition as it invaded an area. In the transition zone, where neither johnsongrass nor the native grass dominated, other species were common that do not occur in either the native or invaded communities, but even these species were excluded once johnsongrass became dominant (Rout et al., 2013a).
Imp-N4 (Is it likely to affect federal Threatened and Endangered species)	? - max		We found no direct evidence. Ordinarily, we answer yes for invaders that change species diversity in plant communities; however, because johnsongrass is primarily a weed of production and anthropogenic systems, and because we only found a few studies documenting impact in natural systems (see evidence under Imp-N1 and Imp-N2) we answered unknown.
Imp-N5 (Is it likely to affect any globally outstanding ecoregions)	? - max		We found no direct evidence. Ordinarily, we answer yes for invaders that change ecosystem processes; however, because johnsongrass is primarily a weed of production and anthropogenic systems, and because we only found a few studies documenting impact in natural systems (see evidence under Imp-N1 and Imp-N2) we answered unknown.
Imp-N6 [What is the taxon’s weed status in natural systems? (a) Taxon	b - high	0	Johnsongrass has been reported as an environmental weed (Randall, 2012). It is listed as a weed of southern

Question ID	Answer - Uncertainty	Score	Notes (and references)
not a weed; (b) taxon a weed but no evidence of control; (c) taxon a weed and evidence of control efforts]			forests and/or their margins (Miller, 2003), including riparian areas in Big Bend National Park (Young and Schrader, 2014). It is also able to invade natural areas (Rout et al., 2013a). We answered “b”, but used high uncertainty because the majority of the evidence indicates that johnsongrass is primarily a weed of cultivated and disturbed land. Alternate answers for the Monte Carlo simulation were “a” and “c.”
Impact to Anthropogenic Systems (cities, suburbs, roadways)			
Imp-A1 (Impacts human property, processes, civilization, or safety)	y - high	0.1	It "presents a safety hazard on roads by restricting visibility on curves and at corners" (Parsons and Cuthbertson, 2001). Prevented sale of the property of John H. Means in the mid-1800s (McWhorter, 1971). We answered yes but used high uncertainty because any tall plant can obstruct visibility and because the impact to Means’ property occurred so long time ago that this kind of impact may no longer be an issue.
Imp-A2 (Changes or limits recreational use of an area)	n - mod	0	We found no evidence.
Imp-A3 (Outcompetes, replaces, or otherwise affects desirable plants and vegetation)	y - mod	0.1	A few commenters on the online gardening forum report that it invades their lawns and gardens and must be removed to protect their plants (Dave's Garden, 2015).
Imp-A4 [What is the taxon’s weed status in anthropogenic systems? (a) Taxon not a weed; (b) Taxon a weed but no evidence of control; (c) Taxon a weed and evidence of control efforts]	c - negl	0.4	Common weed of roadsides, ditches, and railroad easements (McWhorter, 1989; Parsons and Cuthbertson, 2001). Mowing of roadside colonies along with competition with lower growing grass species is effective for control (Parsons and Cuthbertson, 2001). A Texas law in 1901 required railway companies to prevent johnsongrass from going to seed along railways (McWhorter, 1971, 1989). Herbicidal oils and flame burners have been used on ditchbanks and canals in the West (McWhorter, 1989). Controlled by gardeners (Dave's Garden, 2015). Alternate answers for the Monte Carlo simulation were both "b."
Impact to Production Systems (agriculture, nurseries, forest plantations, orchards, etc.)			
Imp-P1 (Reduces crop/product yield)	y - negl	0.4	It "causes severe crop losses as a result of direct competition, allelopathic action and by acting as an alternate host to crop pests and diseases" (Parsons and Cuthbertson, 2001). Weed interference caused by johnsongrass at a density of about 100 stems per square meter reduced corn grain yield by 10, 31, and 54 percent when grown with corn for 4, 6, and 8 weeks after sowing (Mitskas et al., 2003). As little as 4 plants per 10 square meters reduces soybean yield by 7 percent, and under full season interference, it can reduce yield by as much as 59 to 88 percent (Williams and Hayes, 1984). Infestations result in 25-50 percent reductions in the yield of ratoon crops of sugarcane (Holm et al., 1977). In a detailed review of this species' biology, McWhorter (1989) cited numerous studies documenting yield reduction in maize, cotton, sugarcane, grain sorghum, and soybeans. Johnsongrass is an alternate host for maize dwarf mosaic and maize chlorotic dwarf viruses, and

Question ID	Answer - Uncertainty	Score	Notes (and references)
			when johnsongrass is controlled with selective herbicides, arthropod vectors switch hosts and transmit these viruses to maize, which results in yield loss (King and Hagood, 2003). Due to cyanogenic compounds in plant tissues, it has resulted in the loss of up to 50 percent of cattle herds (Parsons and Cuthbertson, 2001). Hybridization of johnsongrass (2n=40) with sorghum (2n=20) produces either sterile but vegetatively spreading triploids (2n=30) or fertile tetraploids (2n=40) that are weeds in grain sorghum, and reduce yield (Parsons and Cuthbertson, 2001).
Imp-P2 (Lowers commodity value)	y - negl	0.2	In soybeans, johnsongrass infestations indirectly lower the grade quality of harvested soybeans due to increased harvest moisture content and damaged soybeans (McWhorter and Anderson, 1981). "In some cases, the total economic losses caused by johnsongrass, because of reductions in grading components, exceeded the direct losses caused by competition" (McWhorter, 1989). Infestations interfere with orchard management (Parsons and Cuthbertson, 2001). "In the United States the weed has often forced the abandonment of row crop culture on good soils because it became dominant" (Holm et al., 1977). The best management strategy for severe infestations of johnsongrass is to leave fields fallow for a year followed by herbicide treatment, but this strategy is rarely used due to the costs of weed control and lost revenue from leaving the fields fallow (McWhorter and Anderson, 1981). Because cotton does not grow very rapidly after planting in the spring, johnsongrass is particularly competitive and results in higher costs for early season management (Keeley and Thullen, 1981). Weedy grasses lower market value of grain when they occur as contaminants (Baker and Terry, 1991).
Imp-P3 (Is it likely to impact trade)	y - negl	0.2	This species is a regulated weed in Argentina, Australia, Chile, China, New Zealand, and in a few island nations (APHIS, 2015; Parsons and Cuthbertson, 2001). It is a regulated non-quarantine pest in the United States (7 CFR § 361, 2014). Because seeds can follow the pathway as contaminants of agricultural commodities, including seeds and grain (Christoffoleti et al., 2007; GTA, No Date; McWhorter and Anderson, 1981; Parsons and Cuthbertson, 2001), it is likely to impact trade.
Imp-P4 (Reduces the quality or availability of irrigation, or strongly competes with plants for water)	? - max	0.1	Under low water conditions, johnsongrass is more competitive than corn and is able to maintain higher water content and stomatal conductance (Acciaresi et al., 2012; Leguizamón et al., 2011). This evidence suggests that in infested corn fields, johnsongrass may reduce the availability of water to corn. However, without direct evidence we answered unknown.
Imp-P5 (Toxic to animals, including livestock/range animals and poultry)	y - negl	0.1	Johnsongrass is cultivated as a forage grass and is very useful when properly managed and controlled (McWhorter, 1989). However, under certain seasonal conditions, it accumulates prussic acid (hydrocyanic

Question ID	Answer - Uncertainty	Score	Notes (and references)
			acid) in its leaves and stems (Holm et al., 1977). Periods of very dry weather or those after a first frost are especially dangerous (Holm et al., 1977). Due to cyanogenic compounds in plant tissues, it has resulted in the loss of up to 50 percent of cattle herds (Parsons and Cuthbertson, 2001). The risk of animal poisoning has resulted in best management practices for using johnsongrass for forage and hay (McWhorter, 1989). It is "well accepted that *Sorghum* is toxic in certain environmental conditions. In many instances, the risk of toxicity seems to be greater in times of drought, but this has not been a consistent finding. The genus produces four disease syndromes - ataxia, cystitis, and teratogenesis; photosensitization; nitrate accumulation; and cyanogenesis" (Burrows and Tyrl, 2013). In the United States, there have been sporadic losses of livestock (Burrows and Tyrl, 2013). Although this species and genus is toxic only under specific environmental conditions, it is clear it can be toxic. Thus we answered yes with negligible uncertainty.
Imp-P6 [What is the taxon's weed status in production systems? (a) Taxon not a weed; (b) Taxon a weed but no evidence of control; (c) Taxon a weed and evidence of control efforts]	c - negl	0.6	Significant weed of agriculture (USDA-FS, 1953) and rangelands (Busso et al., 2013) with detailed recommendations for control dating back about 100 years (Talbot, 1928). One of the most important weeds of maize and sorghum in the world (Maillet, 1991). A significant and serious weed in cotton, maize, citrus, vineyards, alfalfa, sugar beets, wheat, peanuts, sorghum, soybeans, vegetables, beans, and rice (Holm et al., 1977). It is the most widely reported weed species in the world (Randall, 2012). Sheeting with plastic material is effective at reducing and eliminating populations in agricultural areas because increased soil temperature kills rhizomes (Parsons and Cuthbertson, 2001). A variety of herbicides can be used to control johnsongrass in crops, but integrated control programs give the best results (Parsons and Cuthbertson, 2001). Despite the improvements in johnsongrass control over the last 20 years, researchers continue to search for the most effective control strategies (Andújar et al., 2013a; Johnson and Norsworthy, 2014), including control of herbicide-resistant populations (Johnson et al., 2014). The first federal appropriations bill for weed control research was passed in 1900 specifically for controlling johnsongrass (McWhorter, 1989). Alternate answers for the Monte Carlo simulation were both "b."
GEOGRAPHIC POTENTIAL			Unless otherwise indicated, the following evidence represents geographically referenced points obtained from the Global Biodiversity Information Facility (GBIF, 2015).
Plant hardiness zones			
Geo-Z1 (Zone 1)	n - negl	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z2 (Zone 2)	n - negl	N/A	We found no evidence that it occurs in this hardiness

Question ID	Answer - Uncertainty	Score	Notes (and references)
			zone.
Geo-Z3 (Zone 3)	n - mod	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z4 (Zone 4)	n - high	N/A	One point in Finland, a few in the Austrian Alps, and one in Canada. We did not answer yes because these points may represent mistaken identifications, plants growing in protected climates, or artifacts due to map error. However, we note that this species has been adapting and moving into to progressively colder and colder regions over the last few decades (Warwick et al., 1986).
Geo-Z5 (Zone 5)	y - mod	N/A	A few points in Sweden, Norway, and Finland. Some points in the United States.
Geo-Z6 (Zone 6)	y - negl	N/A	Germany. A few points in Norway, Romania, Sweden, and the United States.
Geo-Z7 (Zone 7)	y - negl	N/A	Germany, Sweden, and the United States.
Geo-Z8 (Zone 8)	y - negl	N/A	France, Germany, and the United States.
Geo-Z9 (Zone 9)	y - negl	N/A	Lots of points in Australia and Spain. Temperatures of 2°C to -4°C kill rhizomes after a few hours (McWhorter, 1989).
Geo-Z10 (Zone 10)	y - negl	N/A	Lots of points in Australia and Spain.
Geo-Z11 (Zone 11)	y - negl	N/A	Australia. A few points in India, Mozambique, Portugal, and South Africa.
Geo-Z12 (Zone 12)	y - negl	N/A	A few points in Australia, Brazil, India, Nicaragua, and Mexico.
Geo-Z13 (Zone 13)	y - negl	N/A	Two points in India. Some points in Costa Rica and Nicaragua.
Köppen -Geiger climate classes			
Geo-C1 (Tropical rainforest)	y - low	N/A	A few points in Australia, Costa Rica, Guatemala, and Mexico.
Geo-C2 (Tropical savanna)	y - negl	N/A	Australia, Mexico, and Honduras. Three points in Mozambique.
Geo-C3 (Steppe)	y - negl	N/A	Australia, South Africa, and Spain.
Geo-C4 (Desert)	y - mod	N/A	Ten points in Australia. Many points in Mexico and the United States. One point in South Africa and Namibia. All of these occurrences are probably in low-lying areas.
Geo-C5 (Mediterranean)	y - negl	N/A	Australia, Greece, Portugal, and Spain.
Geo-C6 (Humid subtropical)	y - negl	N/A	Australia, Croatia, Italy, and South Africa.
Geo-C7 (Marine west coast)	y - negl	N/A	Australia, France, and the United Kingdom.
Geo-C8 (Humid cont. warm sum.)	y - negl	N/A	Many points in the United States.
Geo-C9 (Humid cont. cool sum.)	y - low	N/A	Austria, Germany, Sweden, and the United States.
Geo-C10 (Subarctic)	y - high	N/A	Two points in Germany. A few points in Finland, Norway, and Sweden.
Geo-C11 (Tundra)	n - high	N/A	A few points in Austria and in the German Alps. This climate seems too cold for this species' biology. We answered no because these may be incorrect identifications, plants growing in protected sites, or temporary occurrences due to seeds brought in from warmer climates.
Geo-C12 (Icecap)	n - negl	N/A	We found no evidence that this species occurs in this climate class.

Question ID	Answer - Uncertainty	Score	Notes (and references)
10-inch precipitation bands			
Geo-R1 (0-10 inches; 0-25 cm)	y - mod	N/A	Some points in Australia, Afghanistan, Namibia, Mexico, Pakistan, South Africa, Spain, and the United States. These plants are likely in low lying or perhaps artificial environments such as ditches and canals.
Geo-R2 (10-20 inches; 25-51 cm)	y - negl	N/A	Australia and Spain.
Geo-R3 (20-30 inches; 51-76 cm)	y - negl	N/A	Australia, Spain, and Sweden.
Geo-R4 (30-40 inches; 76-102 cm)	y - negl	N/A	Australia, Spain, Sweden, and the United Kingdom. Present in Argentina where yearly rainfall is 1000 mm (Ghersa et al., 1993).
Geo-R5 (40-50 inches; 102-127 cm)	y - negl	N/A	Australia, Norway, Spain, and the United Kingdom.
Geo-R6 (50-60 inches; 127-152 cm)	y - negl	N/A	Australia, India, Spain, and the United States. One point in the United Kingdom.
Geo-R7 (60-70 inches; 152-178 cm)	y - low	N/A	Mexico, Spain, and the United States.
Geo-R8 (70-80 inches; 178-203 cm)	y - low	N/A	Belize, Honduras, and Taiwan.
Geo-R9 (80-90 inches; 203-229 cm)	y - low	N/A	Brazil and El Salvador.
Geo-R10 (90-100 inches; 229-254 cm)	y - low	N/A	A few points in Costa Rica and Mexico.
Geo-R11 (100+ inches; 254+ cm)	y - low	N/A	Costa Rica, Mexico, and Taiwan.
ENTRY POTENTIAL			
Ent-1 (Plant already here)	y - negl	1	This species is widely naturalized in the United States and has been present since the early 1800s (McWhorter, 1971).
Ent-2 (Plant proposed for entry, or entry is imminent)	-	N/A	
Ent-3 (Human value & cultivation/trade status)	-	N/A	
Ent-4 (Entry as a contaminant)			
Ent-4a (Plant present in Canada, Mexico, Central America, the Caribbean or China)	-	N/A	
Ent-4b (Contaminant of plant propagative material (except seeds))	-	N/A	
Ent-4c (Contaminant of seeds for planting)	-	N/A	
Ent-4d (Contaminant of ballast water)	-	N/A	
Ent-4e (Contaminant of aquarium plants or other aquarium products)	-	N/A	
Ent-4f (Contaminant of landscape products)	-	N/A	
Ent-4g (Contaminant of containers, packing materials, trade goods, equipment or conveyances)	-	N/A	
Ent-4h (Contaminants of fruit, vegetables, or other products for consumption or processing)	-	N/A	
Ent-4i (Contaminant of some other pathway)	-	N/A	
Ent-5 (Likely to enter through natural dispersal)	-	N/A	