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Weed Risk Assessment for *Saccharum spontaneum* L. (Poaceae) – Wild sugarcane

Saccharum spontaneum blooming on hillside in Panama (top, source: Graham Bonnett 2016). Dense stand and inflorescence (bottom, source: Kristin Saltonstall 2016),

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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.

Saccharum spontaneum L. – Wild sugarcane

Species Information

Family: Poaceae

Synonyms: The circumscription of the genus *Saccharum* and its closely related genera is very controversial and complex due to polyploidy, frequent hybridization, and gene flow among this group of species (Welker et al., 2015). Depending on the author, the genus *Saccharum* may contain anywhere from 2 to 40 species (Carneiro et al., 2016; Mabberley, 2008; Weakley, 2015). We did not find any synonyms relevant to the WRA for *S. spontaneum* to include here; however, for a full list of known synonyms see The Plant List (2016).

Common names: Wild sugarcane (NRCS, 2016), serio grass (Holm et al., 1997), thatch grass, wild grass, wild cane (CABI, 2016), kans grass (Raju, 1998), Caña de azúcar silvestre (Acevedo-Rodríguez and Strong, 2012).

Botanical description: *Saccharum spontaneum* is an erect perennial grass with fibrous roots and sometimes creeping rhizomes (Holm et al., 1997). It is highly polymorphic with plant morphotypes ranging from small bunchgrass, stalkless plants to plants with six-meter tall stalks (Carneiro et al., 2016; Holm et al., 1997; Reed, 1977). The species evolved in the sub-Himalayan Valleys of India and has formed a wide range of polyploids ($2n = 40$ to 128; Panje, 1970). From there, the higher-count polyploids spread into Africa and southeast Asia, while the lower-count polyploids spread southward into India. The polyploids that developed in central India tend to form rhizomes, and it is these that have become troublesome weeds (Panje, 1970).

Initiation: Due to concerns of potential gene flow from genetically engineered sugarcane (*S. officinarum*) to *S. spontaneum* (e.g., Bonnett et al., 2008; Bonnett et al., 2010; Olivares-Villegas et al., 2010), APHIS-PPQ decided to evaluate the baseline risk potential of *S. spontaneum*. Although APHIS regulates this species as a Federal Noxious Weed (7 CFR § 360, 2016), we do not have a current WRA available for it.

Foreign distribution and status: This species has a very broad native distribution ranging from Africa (e.g., Algeria, Egypt, Ghana, Kenya, Egypt) and Italy through temperate Asia (e.g., Afghanistan, China, Israel, Japan, Oman, Saudi Arabia) and tropical Asia (e.g., Bangladesh, Bhutan, India, Pakistan, Papua New Guinea, Vietnam) (NGRP, 2016; Ohwi, 1984). It is naturalized elsewhere, including in France (Neff, 2005), Panama (Bonnett et al., 2014), Costa Rica (Singh, 2009), Cuba (Acevedo-Rodríguez and Strong, 2012; NGRP, 2016), and Australia (Randall, 2007). This species is considered invasive in France (Brunel and Tison, 2005) and very invasive in Panama (Bonnett et al., 2014; Labrada, 2003), as well as in India, where it is native (Raju, 1998; Reddy et al., No Date). *Saccharum spontaneum* is regulated in Australia, Ecuador, Guatemala, Honduras, Mexico, Nauru, Paraguay, and Peru (APHIS, 2016; Puerto, No Date).

U.S. distribution and status: *Saccharum spontaneum* was introduced into the United States for use in sugarcane breeding programs (Brandes et al., 1939; NRCS, 2016; USDA, 1953). It is naturalized in three Florida counties (Bodle, 2009; Kartesz, 2016; Wunderlin and Hansen, 2016), Guam (Whistler, 1995), Hawaii (Wagner et al., 1999), and Puerto Rico (Acevedo-Rodríguez and Strong, 2012; Más and Lugo-Torres, 2013). In Florida, populations have been detected growing in sugarcane fields (Westbrooks and Miller, 1993) and other habitats (Bodle, 2009). We found no evidence that this species is cultivated as an ornamental in the United States (e.g., Dave's Garden, 2016; Page and Olds, 2001), only some potential interest in cultivation by a gardener (GardenWeb.com, 2016). This species has been regulated by APHIS as a Federal Noxious Weed since 1981 (7 CFR § 360, 2016; Westbrooks and Miller, 1993).

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

1. *Saccharum spontaneum* analysis

Establishment/Spread Potential

Saccharum spontaneum has already demonstrated its potential to escape and spread (Neff, 2005; Singh, 2009), particularly in Panama, where in a period of a few decades it spread along a region of the Panama Canal (Craven et al., 2009) to become a significant weed. *Saccharum spontaneum* is a polymorphic, drought-hardy C4 grass that is adapted to a wide range of environment conditions (Brandes et al., 1939; Holm et al., 1997). It forms dense stands (Brandes et al., 1939) and reproduces by seeds, rhizomes, and stem fragments (Bonnett et al., 2014; CABI, 2016; Panje, 1970), and it is dispersed by wind (Holm et al., 1997; Wright, 2009), commercial trade (Singh, 2009; Smither-Kopperl, 2007), and most likely water. *Saccharum spontaneum* is very tolerant of fire and repeated biomass loss, and it appears to benefit from such disturbance since it forms pure stands on highly disturbed lands (Holm et al., 1997; Hooper et al., 2002; Saltonstall and Bonnett, 2012). We had low uncertainty for this risk element.

Risk score = 19 Uncertainty index = 0.08

Impact Potential

Saccharum spontaneum has significant impacts in natural and production systems. It has been reported as a weed in 33 countries (Holm et al., 1997). In southeast Asia, it is primarily a weed of agricultural systems, where it causes losses in a variety of crops (CABI, 2016; Panje, 1970; Raju, 1998). In Panama it reduces the growth and increases the mortality of newly planted timber species (Craven et al., 2009). *Saccharum spontaneum* has infested 3-4 million hectares of land in India, forcing farmers to abandon entire fields (Holm et al., 1997; Panje, 1970; Raju, 1998). It is difficult to control because the rhizomes grow as deep as 50 cm (Panje, 1970). In natural

[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).

systems that have been disturbed, *S. spontaneum* reduces species diversity (Bonnett et al., 2014; Whistler, 1995), forms dense grass swards that limit the recruitment of light-demanding species (Hooper et al., 2002), and promotes fire in ecosystems that do not typically burn (Hooper et al., 2002; Saltonstall and Bonnett, 2012). In tropical areas, it effectively stops forest succession (Hooper et al., 2005). To mitigate this impact, natural resource managers are planting nurse trees to shade out the grass and attract frugivores to recruit other species underneath them (Bonnett et al., 2014; Hammond, 1999). We had low uncertainty for this risk element.
Risk score = 4.2 Uncertainty index = 0.11

Geographic Potential Based on three climatic variables, we estimate that about 61 percent of the United States is suitable for the establishment of *S. spontaneum* (Fig. 1). This predicted distribution is based on the species' known distribution elsewhere in the world and includes point-referenced localities, areas of occurrence, and reported physiological limits. The map for *S. spontaneum* 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, Mediterranean, desert, humid subtropical, marine west coast, and humid continental warm summers.

The area of the United States shown to be climatically suitable (Fig. 1) 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. *Saccharum spontaneum* grows in a diverse range of habitats including lake shores, irrigation ditches, fallow fields, marshes, waste places, sand dunes, railroads, highways, stream banks, orchards, flood basins, forest edges, and poorly drained sites (Hammond, 1999; Holm et al., 1997; Marler and Moral, 2011; Raju, 1998; Wunderlin and Hansen, 2016). It also grows across a wide range of elevations and soil textures (Holm et al., 1997).

Entry Potential We did not assess the entry potential of *S. spontaneum* because it is already naturalized in the United States (Kartesz, 2016; Más and Lugo-Torres, 2013; Wagner et al., 1999; Whistler, 1995; Wunderlin and Hansen, 2016), where it is used in sugarcane breeding programs (NRCS, 2016; USDA, 1953).

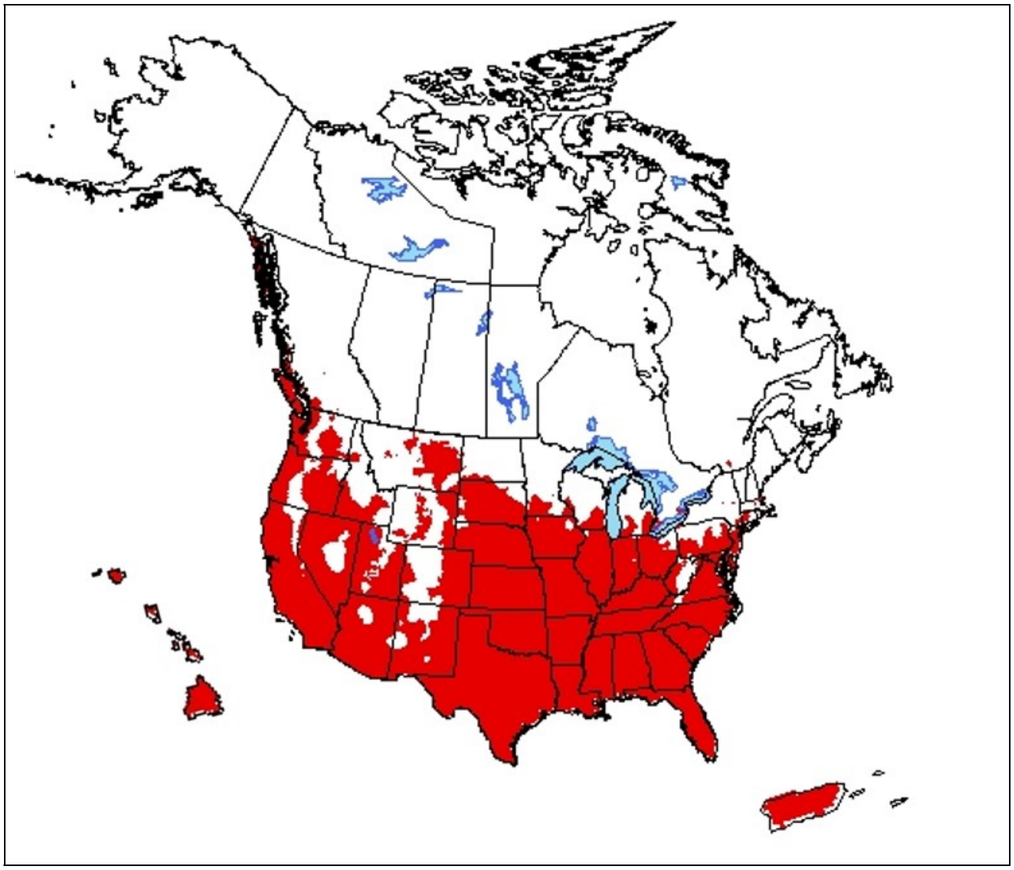

Figure 1. Potential geographic distribution of *S. spontaneum* in the United States and Canada. Map insets for Hawaii and Puerto Rico are not to scale.

2. Results

Model Probabilities: P(Major Invader) = 94.6%
P(Minor Invader) = 5.2%
P(Non-Invader) = 0.2%

Risk Result = High Risk

Secondary Screening = Not Applicable

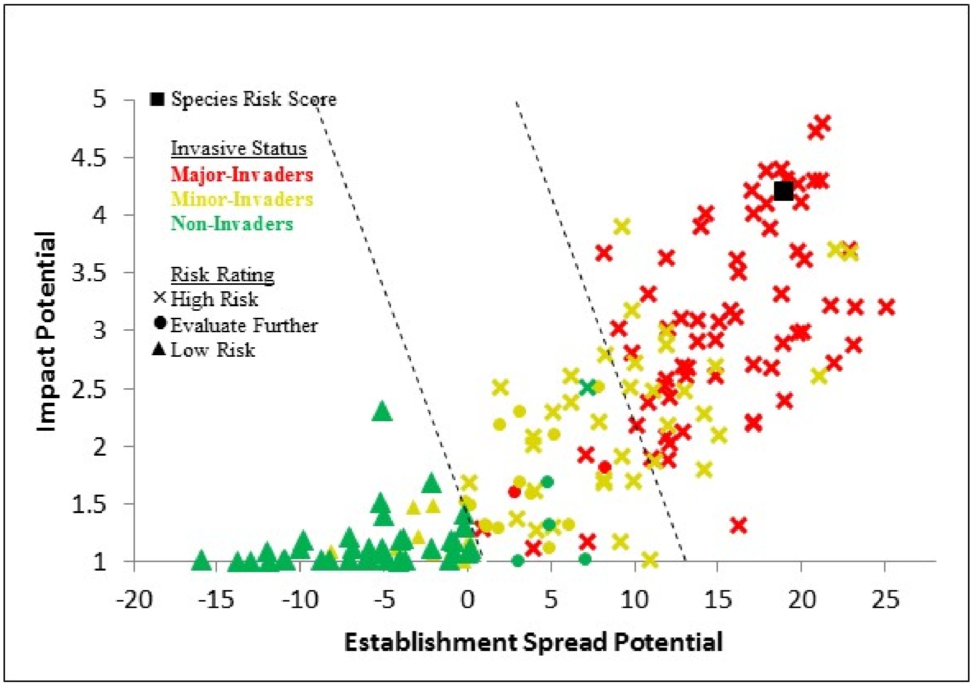

Figure 2. *Saccharum spontaneum* risk score (black box) relative to the risk scores of species used to develop and validate the PPQ WRA model (other symbols). See Appendix A for the complete assessment.

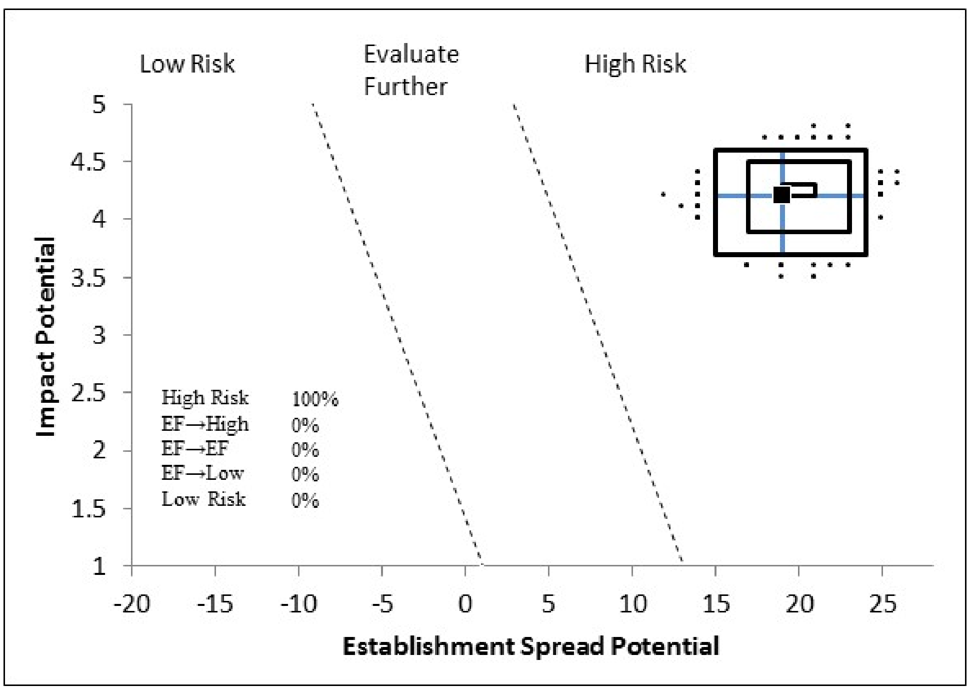

Figure 3. Model simulation results (N=5,000) for uncertainty around the risk score for *S. spontaneum*. The blue "+" symbol represents the medians of the simulated outcomes. The smallest box contains 50 percent of the outcomes, the second 95 percent, and the largest 99 percent.

3. Discussion

The result of the weed risk assessment for *Saccharum spontaneum* is High Risk (Fig. 2). Because of this species' relatively extreme risk scores (Fig. 2) and the overall low level of uncertainty associated with the analysis, our result is well supported by our uncertainty analysis (Fig. 3). An independent evaluation using the Hawaii WRA also concluded that this species poses a high risk potential (WRA score =17; UH, 2016). *Saccharum spontaneum* is an invasive species with a variety of well-documented, significant environmental and agricultural impacts. High genetic and morphological diversity has probably contributed to the success of this species. As discussed under the background section of this assessment, *S. spontaneum* is a polymorphic species with populations that vary from short bunchgrasses to those that produce 4 to 6 meter tall stems. It grows in a diverse range of environments from wet to dry habitats, low to high elevations, and tropical to temperate climates (Brandes et al., 1939; Holm et al., 1997). This phenotypic diversity is matched by the wide range of cytotypes that it exhibits (2n = 40 to 128; Carneiro et al., 2016; Panje, 1970).

Although *S. spontaneum* is widely distributed around the world, it appears to be particularly problematic in only India and Panama. This may be because not all forms are equally invasive and/or weedy (Leon et al., 2015). In India, the weedy and problematic types of *S. spontaneum* have many rhizomes, tend to occur in drier soils, and have chromosome counts ranging from 60 to 70 (Holm et al., 1997). It is not clear which morpho- or cytotypes have been introduced to Panama, the United States, and other regions of the world, and whether these other introductions have the same invasive potential as the central India forms. Intraspecific differences in plant biology can have a significant impact on the invasive behavior of a taxon. For example, in the United States, exotic genotypes of *Phragmites australis* are much more invasive than native genotypes, and in fact, in some places, native forms are disappearing (Meyerson et al., 2009; Price et al., 2014). Although a large portion of the United States is climatically suitable for the establishment of *S. spontaneum* (Fig. 1), it is unclear whether the climate is perfectly suited for this species to express its full invasive potential. For example, several clones of energycane, an F1 hybrid between *S. officinarum* and *S. spontaneum*, did grow as well in the Florida subtropics as they did in the humid tropics of Costa Rica (Leon et al., 2015).

Saccharum spontaneum is valuable for sugarcane breeding programs because it is used to increase disease resistance, tillering, yield, rattooning ability, cold tolerance, and other traits in sugarcane (Carneiro et al., 2016). Introduction, use, and maintenance of clones for sugarcane breeding at research facilities poses a risk for the escape and spread of this species in the United States (Westbrooks and Miller, 1993). Because *S. spontaneum* is regulated as a Federal Noxious Weed (7 CFR § 360, 2016), researchers mush apply for an APHIS permit to use and maintain clones, and must follow specific guidelines for how the clones are handled and disposed of. To better understand the risks posed by clones used in sugarcane breeding, we recommend that researchers more carefully investigate the relationship between cytotypes and invasive behavior and then determine whether the invasive cytotypes are being used in sugarcane breeding. Researchers should also evaluate and consider the invasive potential of clones being used in the production of Energycane, which is being proposed for use as lignocellulosic bioenergy feedstock (e.g., Leon et al., 2015).

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Appendix A. Weed risk assessment for *Saccharum spontaneum* L. (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	*Saccharum spontaneum* has a very broad native distribution ranging from Africa (e.g., Algeria, Egypt, Ghana, Kenya, Egypt) and Italy through temperate Asia (e.g., Afghanistan, China, Israel, Japan, Oman, Saudi Arabia) and tropical Asia (e.g., Bangladesh, Bhutan, India, Pakistan, Papua New Guinea, Vietnam) (NGRP, 2016; Ohwi, 1984). It is naturalized elsewhere, including France (Neff, 2005), Panama (Bonnett et al., 2014), Costa Rica (Singh, 2009), Cuba (Acevedo-Rodríguez and Strong, 2012; NGRP, 2016), Australia (Randall, 2007), and the United States in Puerto Rico (Más and Lugo-Torres, 2013), Florida (Westbrooks and Miller, 1993), Guam (Whistler, 1995), and Hawaii (Wagner et al., 1999). In Mediterranean France, it is categorized as an emerging invader, which is a naturalized species that is spreading geographically (Brunel and Tison, 2005). After it was introduced to Panama, *S. spontaneum* spread rapidly throughout the country and is now also in Costa Rica (Bonnett et al., 2014; Labrada, 2003). This species tillers profusely and spreads fast (Raju, 1998). It is categorized as an invasive species in its native range in India, where invasive is defined as a species that readily spreads and causes harm (Reddy et al., No Date). Alternate answers for the uncertainty simulation were both "e."
ES-2 (Is the species highly domesticated)	n - low	0	*Saccharum spontaneum* "is used by villagers [of SE Asia] as a fodder for cattle, buffaloes and, in some places, elephants. It is also used to prevent erosion of sandy soils. The foliage is used for thatching and the plant is used as an ornamental and to produce paper pulp" (Manidool, 1992). However, we found no evidence that this species is highly domesticated, or that it has been bred to reduce or eliminate traits associated with weediness. *Saccharum spontaneum* is highly polymorphic and ranges from Africa through southern Asia into Malesia (Panje, 1970), so even if some forms have been highly domesticated, this assessment is being done at the species level, which has not been domesticated.
ES-3 (Weedy congeners)	y - low	1	The circumscription of the genus *Saccharum* and its closely related genera is very controversial and complex due to polyploidy and reticulate evolution (Welker et al., 2015). The genus includes about 35-40 species (Mabberley, 2008). The species in *Ripidium* are sometimes included in *Saccharum* (Welker et al., 2015). Other closely related genera in the grass tribe Andropogoneae include *Zea*, *Sorghum*, and *Miscanthus* (Welker et al., 2015). *Miscanthus* is believed to have contributed to the genus

Question ID	Answer - Uncertainty	Score	Notes (and references)
			through natural hybridization (Carneiro et al., 2016; Welker et al., 2015). Therefore, because of the uncertainty surrounding the circumscription of the genus and its close relationship with other genera, we considered these other genera to fall within the scope of this question. *Saccharum benghalense* is considered a principal weed of Bangladesh (Holm et al., 1991).). Two species of *Miscanthus* are considered weedy and invasive, and raise concern as they have been proposed as bioenergy plants (Glaser and Glick, 2012). *Imperata cylindrica*, which is also closely related to *Saccharum* and is biologically similar to *S. spontaneum* (Hammond, 1999), is a major weed, has numerous impacts (Weber, 2003), and is a U.S. Federal Noxious Weed (7 CFR § 360, 2016). We also note that *Saccharum ravennae* (synonym: *Erianthus ravennae*) is naturalized in the United States (NGRP, 2016).
ES-4 (Shade tolerant at some stage of its life cycle)	n - negl	1	In a one-year field experiment in an *S. spontaneum* dominated field in Panama, artificial shading with 95 percent shade cloth significantly reduced plant biomass and growth rate, effectively eliminating the grass (Hooper et al., 2002). A similar study showed a very similar response, and even shading with 75 percent shade cloth results in a significant difference in plant biomass. *Saccharum spontaneum* is a C4 grass that thrives in conditions of high light and is shade intolerant (Hammond, 1999).
ES-5 (Plant a vine or scrambling plant, or forms tightly appressed basal rosettes)	n - negl	0	The species is an upright terrestrial grass (Holm et al., 1997; Panje, 1970) and not a vine. We used negligible uncertainty, but note that a researcher once collected a specimen that was growing up a tree like a vine (Panje, 1970).
ES-6 (Forms dense thickets, patches, or populations)	y - negl	2	Forms dense stands in Guam (Whistler, 1995) and Panama in abandoned and deforested lands (Bonnett et al., 2014; Hooper et al., 2005). Quickly spreads to form "mini-forests" (Raju, 1998). Median live stem density in unburned plots is 24 stems per square meter (Saltonstall and Bonnett, 2012). "Sugarcane [*Saccharum officinarum*] expands aggressively underground by sending out rhizomes, tillers (secondary shoots), and tertiary shoots, which together form stools or clumps. The tillering pattern is so intricate and dense in *S. spontaneum* that it can almost be considered a sod-forming grass (rather than a tufted grass, which describes the rest of the genus)" (Hammond, 1999). In its native range, it forms dense stands called canebreaks along rivers (Brandes et al., 1939).
ES-7 (Aquatic)	n - low	0	Taxon is an upright perennial grass growing to 4 or sometimes 6 meters high that grows in a wide range of habitats (Holm et al., 1997). "The commonest habitats of the plant are sandy alluvial belts, flood basins of rivers, banks of ponds and freshwater streams, waterlogged lowlands, border-ridges of fields, edges of forests and wasteland. The author once collected an *S. spontaneum* plant which was ... growing in fresh water like an aquatic plant, and yet another, considerably attenuated, but surviving well on the dry side of a half-submerged rock"

Question ID	Answer - Uncertainty	Score	Notes (and references)
			(Panje, 1970). Because this species is not an obligate aquatic plant, we answered no. Note that Raju (1998) reported it is generally susceptible to waterlogging of soils.
ES-8 (Grass)	y - negl	1	This species is a grass (NGRP, 2016).
ES-9 (Nitrogen-fixing woody plant)	n - low	0	We found no direct evidence that this species fixes nitrogen; however, the author of a species factsheet reports that it has been associated with nitrogen-fixing bacteria in the Philippines (Manidool, 1992). Regardless, because this species is not a woody plant, we answered no, with low uncertainty. We used low uncertainty because we did not have access to more detailed information about its association with nitrogen-fixing bacteria.
ES-10 (Does it produce viable seeds or spores)	y - negl	1	Reproduces by seeds, rhizomes, and stem fragments (Bonnett et al., 2014; CABI, 2016; Panje, 1970). Nearly 90 percent of the seeds germinate (Raju, 1998). Produces viable seeds in Florida (Westbrooks and Miller, 1993). It was reported as one of the first species to colonize a newly developed volcanic island in Indonesia in 1929 (Holm et al., 1997), presumably through seed dispersal.
ES-11 (Self-compatible or apomictic)	y - negl	1	"Plants can be self- and cross-pollinated without difficulty" (Holm et al., 1997). Selfed progeny can be produced (Tai et al., 1999). "Possibly there are various degrees of apomixis" (Panje, 1970). The congener, *Saccharum officinarum* is self-compatible (Bonnett et al., 2008; Walker, 1971). Additionally, experiments have demonstrated that S. spontaneum seedlings from selfing experiments do not show loss of vigor or inbreeding depression. Additionally, experiments have demonstrated that *S. spontaneum* seedlings from selfing experiments do not show loss of vigor or inbreeding depression (Stevenson, 1965).
ES-12 (Requires specialist pollinators)	n - negl	0	Pollen is wind-borne (Holm et al., 1997). The vast majority of grasses are wind-pollinated (Faegri and Van der Pijl, 1979).
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	*Saccharum spontaneum* reproduces vegetatively from rhizomes, stolons, tillers, and stem fragments, as well as by seeds (Brandes et al., 1939; Holm et al., 1997; Panje, 1970). Overall, the species is described as a perennial (Holm et al., 1997), but one researcher commented that it can behave as an annual (Panje, 1970). With regard to sexual reproduction, a sugarcane researcher noted that no one has followed the time it takes for a seed to germinate, grow, and produce its own seed in the wild, but expects that in an ideal environment, this will likely happen within a year and certainly within two (Bonnett, 2016). However, another researcher believes that seed to flowering will likely take about two years (Saltonstall, 2016). With regard to vegetative reproduction, a fire completely cleared a population of *S. spontaneum* in Panama, and by October, the population had regenerated and was blooming (Saltonstall and Bonnett, 2012). The rapid regeneration associated with the population that burned in Panama indicates a minimum generation of about a year or less. Alternate answers for our uncertainty simulation were both

Question ID	Answer - Uncertainty	Score	Notes (and references)
			“c.” Other evidence: in a common garden experiment, most clones of *S. spontaneum* flowered in their second year after establishment (Panje and Srinivasan, 1959), but this does not necessarily reflect what would happen under natural conditions, nor is it clear if these clones were established by cuttings or seed.
ES-14 (Prolific seed producer)	y - high	1	Some biotypes from the Philippines produce 12,000 seeds per plant, whereas some in India produced 3,042 (Holm et al., 1997). In Panama, it produced a median of 24 live stems per square meter in an unburned plot, and 48 live stems per square meter in a burned plot; four and twelve of these stems bloomed per square meter, respectively (Saltonstall and Bonnett, 2012), and by November there were 16 flowering stems per square meter in burned plots (Bonnett, 2016). Each inflorescence produces hundreds of seeds (Bonnett et al., 2014). In one field study, germination ability (not seed viability) of seeds ranged from 30 to 70 percent, depending on the site of planting and the week of measurement (Bonnett et al., 2014), but averages at about 50 percent (Bonnett, 2016). Assuming 16 flowering stems per square meter and 50 percent seed viability, each flowering stem would need to produce 625 seeds to meet a threshold of 5000 seeds per square meter. This threshold is likely met in Panama (Bonnett, 2016). Sugarcane inflorescences are estimated to produce on average about 24,600 florets (cited in Australian Government, 2011).
ES-15 (Propagules likely to be dispersed unintentionally by people)	y - low	1	One source states it was introduced into Panama accidentally on construction equipment that had been just used to build a U.S. airstrip in Thailand (Hammond, 1999). We answered yes based on this evidence alone. However, because the seeds are small and could readily be present in mud that attaches to cars, and because stem fragments that are inappropriately disposed of could readily sprout (Bonnett et al., 2014), we used low rather than moderate uncertainty.
ES-16 (Propagules likely to disperse in trade as contaminants or hitchhikers)	y - negl	2	This species has been intercepted in the United States in pineapple tops from Costa Rica (Singh, 2009) and marble from Turkey (Smither-Kopperl, 2007). Seeds have been intercepted on fresh fruit imported into New Zealand (Popay et al., 2003).
ES-17 (Number of natural dispersal vectors)	2	0	Propagule traits for questions ES-17a through ES-17e: "Fruit is a dry, indehiscent, 1-seeded caryopsis 3.25 mm long, 1 mm wide; basal hairs several times longer than florets and form cottony web encompassing several seeds" (Holm et al., 1997). See drawings in Gunn and Ritchie (1988) and Reed (1977).
ES-17a (Wind dispersal)	y - negl		Seeds are readily wind dispersed (Holm et al., 1997; Wright, 2009). Callus hairs around the seed form a parachute mechanism to aid in wind dispersal (CABI, 2016). Between 1990 and 2011, about 229 seeds per year were trapped at Barro Colorado Island, a forest research facility that is over 2 kilometers away from the nearest source of *S. spontaneum* (Bonnett et al., 2014).

Question ID	Answer - Uncertainty	Score	Notes (and references)
ES-17b (Water dispersal)	y - low		Sugarcane seeds have silky hairs, which are useful for water dispersal (Hammond, 1999). Although seeds of this species are clearly adapted for wind dispersal, water dispersal seems very reasonable, particularly since the species often occurs in flood plains and wetlands, and along river banks and streams (Hammond, 1999; Holm et al., 1997).
ES-17c (Bird dispersal)	n - high		We found no evidence; however, because it is possible that birds may use parts of the silky infructescences to build their nests, we used high uncertainty.
ES-17d (Animal external dispersal)	n - mod		We found no evidence of *S. spontaneum* propagules being dispersed in this manner.
ES-17e (Animal internal dispersal)	n - mod		We found no evidence of *S. spontaneum* propagules being dispersed in this manner.
ES-18 (Evidence that a persistent (>1yr) propagule bank (seed bank) is formed)	n - mod	-1	It does not form a persistent soil seed bank (CABI, 2016). Seeds are relatively short-lived (Brandes et al., 1939). However, they can be stored under artificial conditions for a long time (Tai et al., 1999). Without more detailed or specific information, we answered no with moderate uncertainty.
ES-19 (Tolerates/benefits from mutilation, cultivation or fire)	y - negl	1	Repeated burning of cropland forms nearly pure stands of this species in Indonesia (Holm et al., 1997). Data from a field study in Panama indicates that "fire promotes the growth of *Saccharum* [*spontaneum*] and may enhance its spread by stimulating new shoot growth, increasing flowering shoot density and thereby seed production, and creating available habitat for recruitment of new populations by removing litter. It also may delay flowering thus extending the reproductive period of the species in Panama" (Saltonstall and Bonnett, 2012). In another study, mowing once or three times did not affect the growth rate of this species, indicating that it is tolerant to mutilation (Hooper et al., 2002). *Saccharum spontaneum* is one of the most prevalent species on a volcanic island in Indonesia, and its rhizomes withstand repeated eruptions and burial in volcanic ash (Holm et al., 1997). Forest land that is not burned or farmed has much less of this species (Holm et al., 1997), indicating that relative to other species, it is adapted to and thrives on repeated disturbance. Floating roots develop in some biotypes when flooded due to development of arenchyma tissue, and these plants can withstand flooding for over 8 months (Holm et al., 1997). Plants can readily propagate vegetatively since each node has a root band with root primordia (Artschwager 1942 in Holm et al., 1997); however, sprouting of stem fragments is dependent on their burial depth, size of fragments, and the number of nodes associated with the fragment (Bonnett et al., 2014). Some biotypes have long decumbent stems that never flower (Holm et al., 1997). Roots may reach depths of 2 meters, and rhizomes are typically at depths of 20–30 cm, although some grow down to a meter (Raju, 1998). "Desiccation [of cut stems] reduced sprouting ability to some extent but 39% of buds still sprouted after six weeks of drying" (Bonnett et al., 2014).

Question ID	Answer - Uncertainty	Score	Notes (and references)
ES-20 (Is resistant to some herbicides or has the potential to become resistant)	n - low	0	We found no evidence that it is resistant to herbicides. Furthermore, it is not listed by Heap (2016).
ES-21 (Number of cold hardiness zones suitable for its survival)	9	0	
ES-22 (Number of climate types suitable for its survival)	8	2	
ES-23 (Number of precipitation bands suitable for its survival)	11	1	
IMPACT POTENTIAL			
General Impacts			
Imp-G1 (Allelopathic)	y - high	0.1	*Saccharum spontaneum* may be allelopathic to crops as leachates from rhizomes and roots inhibited shoot and root growth of three wheat varieties in petri dishes (Amritphale and Mall, 1978). Ordinarily, we do not consider results from one or a few laboratory studies as adequate evidence to answer yes for this question because such studies are based on chemical extracts of compounds at what are probably unnatural concentrations. However, in this study, the authors used leachates derived by soaking *S. spontaneum* plant material in water for 12 hours (Amritphale and Mall, 1978). From a field study on the reproduction of the species, Bonnett et al. (2014) speculated that "[t]he high mortality seen in the seed-added plots could be due to negative interactions on a seed-seed or seed-seedling basis, such as competitive or allelopathic effects which were compounded by the high densities of seeds and seedlings. Such effects have been shown in sugarcane ... and several other species ... but not yet demonstrated for *S. spontaneum*" Based on this evidence, we answered yes, but with high uncertainty.
Imp-G2 (Parasitic)	n - negl	0	We found no evidence. Furthermore, this species does not belong to a family known to contain parasitic plant species (Heide-Jorgensen, 2008; Nickrent, 2009).
Impacts to Natural Systems			
Imp-N1 (Changes ecosystem processes and parameters that affect other species)	y - negl	0.4	Invasion of *S. spontaneum* into tropical regions of Panama has very likely changed local fire regimes (Saltonstall and Bonnett, 2012). In abandoned farmlands in Panama dominated by *S. spontaneum*, fires occur frequently. Under these high fire regimes, many recruiting tree species are unable to survive (Hooper et al., 2002). It is has been well established that some alien grasses change ecosystem processes by changing fire regimes (D'Antonio and Vitousek, 1992). Under short agricultural cycles in central India, *S. spontaneum* dominates secondary successional communities (Ramakrishnan and Vitousek, 1989). In abandoned agricultural areas dominated by *S. spontaneum* in Panama, this species interferes with forest regeneration by reducing seedling growth (Hooper et al., 2005). Because of these impacts to fire regime and forest regeneration, we answered yes with negligible uncertainty.
Imp-N2 (Changes habitat structure)	y - negl		In a dense sward, only about 5 percent of photosynthetically active radiation (PAR; i.e., light) is

Question ID	Answer - Uncertainty	Score	Notes (and references)
			making it to half a meter height, which limits the recruitment of light-demanding species (Hooper et al., 2002). Furthermore, dense root mats just below the surface of the soil may reduce seedling growth and survival during the dry season because of intense competition for soil moisture (Hooper et al., 2002). "*Saccharum spontaneum*, negatively affects germination, survival, and growth of native tree seedlings in abandoned Panamanian farmland" by creating high above- and belowground constraints to their establishment (Hooper et al., 2002). A different study by Hooper et al. (2005) showed that isolated, fruit-bearing trees in the grass swards are critical for promoting forest succession because their shade limits competition and interference from *S. spontaneum*, and they attract frugivores that will disperse seeds of other species. Based on this evidence, it is clear that dense swards or canebreaks of this species eliminate the plants at the ground level, which includes seedlings of forest tree species.
Imp-N3 (Changes species diversity)	y - negl	0.2	In Panama, dense stands impede the growth of other plants and provide little useful habitat for animals (Bonnett et al., 2014). Dense stands choke out vegetation (Whistler, 1995). Grasslands in certain regions of India are dominated by this species, which has led to changes in species diversity (Bhatt et al., 2012). "In the course of his exploration of the sub-Himalayan area, the author observed that wherever the felling of forests was indiscriminate and proceeded faster than the proper agricultural utilization of the felled area, a particular ecotype of *S. spontaneum* colonised the unused land to the exclusion of other vegetation" (Panje, 1970). In dry areas in India on agricultural land that has been abandoned, *S. spontaneum* replaces *Imperata cylindrica* (cogongrass) through natural succession (Raju, 1998). "The dense root mat creates intense root competition for any competing vegetation and is almost impenetrable for young seedlings" (Hammond, 1999).
Imp-N4 (Is it likely to affect federal Threatened and Endangered species?)	y - low	0.1	We found no direct evidence that it impacts T&E species. However, because this species invades natural areas and forms dense stands that reduce diversity (see evidence considered under Imp-N1), it is likely to affect T&E species.
Imp-N5 (Is it likely to affect any globally outstanding ecoregions?)	y - low	0.1	Because this species forms large and dense stands that change fire regimes and arrest forest succession (see evidence considered under Imp-N1), and because there are several globally outstanding ecoregions in the United States (Ricketts et al., 1999) where this species could establish (see geographic potential section), it is likely to affect them. Invasive tropical grasses are some of the most significant invaders and are considered to be agents of global change (D'Antonio and Vitousek, 1992).
Imp-N6 [What is the taxon’s weed status in natural systems? (a) Taxon not a weed; (b) taxon a weed but no evidence of control;	c - low	0.6	In a literature review, this species was classified as an invader of natural areas (Daehler, 1998). It is considered problematic in its native range in the Philippines (Dice et al., 2014). Plant monitoring surveys on Barro Colorado Island (BCI), a tropical forest research station in the

Question ID	Answer - Uncertainty	Score	Notes (and references)
(c) taxon a weed and evidence of control efforts]			Panama Canal, have found isolated small patches of *S. spontaneum* in tree fall gaps in the forest interior (Bonnett et al., 2014). *Saccharum spontaneum* is naturalized in Soberania National Park in Panama (Saltonstall and Bonnett, 2012). Weed of natural areas in Australia (Randall, 2007). Conservation areas in Panama that are dominated by *S. spontaneum,* and where forest succession has been arrested, are being managed by planting isolated trees in the exotic grasslands to promote forest succession (Hammond, 1999). Alternate answers for the uncertainty simulation were both "b."
Impact to Anthropogenic Systems (e.g., cities, suburbs, roadways)			
Imp-A1 (Negatively impacts personal property, human safety, or public infrastructure)	n - mod	0	We found no evidence of *S. spontaneum* causing this impact.
Imp-A2 (Changes or limits recreational use of an area)	? - max		Reported to form "dense and impenetrable" stands in Panama (Hooper et al., 2005); however, because it is not clear if this is affecting the recreational use of an area, we answered unknown.
Imp-A3 (Affects desirable and ornamental plants, and vegetation)	n - mod	0	We found no evidence of *S. spontaneum* causing this impact.
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]	b - high	0.1	Serious weed of horticultural gardens (CABI, 2016). Weed of wastelands (Raju, 1998). Alternate answers were "a" and "c."
Impact to Production Systems (agriculture, nurseries, forest plantations, orchards, etc.)			
Imp-P1 (Reduces crop/product yield)	y - negl	0.4	In India, this species causes severe crop losses in tea, sugarcane, cotton, and sorghum (CABI, 2016). In Thailand it reduces yield in forage crops (CABI, 2016). In the Philippines, it is a serious weed of pineapple, pastures, and sugarcane (CABI, 2016). In Indonesia, it affects the productivity of rubber and tea (CABI, 2016). It also acts as an alternate host for many sugarcane pests and diseases (CABI, 2016), as well as corn (Raju, 1998). Reduces yield of winter cereals including wheat in central India (Panje, 1970). In Panama, it reduces the growth and increases mortality of timber species (Craven et al., 2009).
Imp-P2 (Lowers commodity value)	y - negl	0.2	"The plant has infested nearly 4 million ha in central India, often forcing farmers to abandon entire fields" (cited in Holm et al., 1997). Large infestations with deep rhizomes are very difficult to control and have forced farmers to abandon their farms (Panje, 1970). "In India the weed occupies more than three million hectares of neglected lands which otherwise can be used for cropping" (Raju, 1998). A study in Panama showed that controlling this species in timber plantations is necessary to promote tree species establishment and costs from about $150 to $400 per hectare, depending on the intensity of control (Craven et al., 2009). We answered yes based on the fact that this species reduces the economic value of the land itself and

Question ID	Answer - Uncertainty	Score	Notes (and references)
			will require control in order to maintain agricultural productivity.
Imp-P3 (Is it likely to impact trade?)	y - low	0.2	*Saccharum spontaneum* is regulated in Australia, Ecuador, Guatemala, Honduras, Mexico, Nauru, Paraguay, and Peru (APHIS, 2016; Puerto, No Date). *Saccharum repens* is regulated by South Korea (APHIS, 2016). Because this species is able to follow trade pathways as a contaminant (see evidence under ES-16), it is likely to impact trade.
Imp-P4 (Reduces the quality or availability of irrigation, or strongly competes with plants for water)	n - high	0	This species grows in marshes, wetlands, banks of streams and ponds, drainage basins, and other lowland habitats (Hammond, 1999; Holm et al., 1997; Marler and Moral, 2011). It has also been collected in drainage ditches (GBIF, 2016); however, it has never been reported to affect irrigation or drainage. Because of the dense root mats that *S. spontaneum* forms (Hooper et al., 2002), it may be able to outcompete crops for moisture, but this specific impact has not been reported.
Imp-P5 (Toxic to animals, including livestock/range animals and poultry)	n - negl	0	We found no evidence that this species or others in the genus are toxic to animals (e.g. Bruneton, 1999; Burrows and Tyrl, 2013). In fact, it can be used as a forage for some livestock (Holm et al., 1997). Furthermore, its congener *S. officinarum* is one of the most important species used in refined sugar production, and it has not been reported to be toxic (e.g., Moore and Botha, 2013).
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	*Saccharum spontaneum* is an economically important weed (Holm et al., 1991; Reed, 1977) that is "a serious or principal weed of forages in Thailand; pasture and pineapple in the Philippines; pasture, sugarcane, and tea in India; and rubber and tea in Indonesia. It is a common weed of sugarcane in Bangladesh and the Philippines; tobacco in the Philippines; and wheat in India..." (Holm et al., 1997). It is also a weed of rice throughout Southeast Asia countries (Galinato et al., 1999; Moody, 1989), pineapple in Costa Rica (Rohrbach and Johnson, 2003), soybeans in India (Mishra, 2010), and other crops in tropical and subtropical climates (CABI, 2016). It is also a host for crop pests (Bhatt et al., 2012). "Deep plowing followed by several lighter tillage operations helps reclaim fields, but reinfestation occurs unless control measures are continued (Panje, 1970). Mulching infested areas with sugarcane trash to 10 to 15 cm after sugarcane emergence is beneficial in India" (Holm et al., 1997). Deep plowing is an effective control strategy for *S. spontaneum* in fields because it disrupts the roots and rhizomes; in India, a special plow was created for controlling this species (cited in CABI, 2016). Authors of one study examined control options in tree plantations in Panama and determined that use of herbicides and annual mechanical clearings of the grass improve growth and survival of the tree species for the first three years after planting (Craven et al., 2009). Raju (1998) provides several control strategies. Alternate answers for the uncertainty simulation were both "b."

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GEOGRAPHIC POTENTIAL			Unless otherwise indicated, the following evidence represents geographically referenced points obtained from the Global Biodiversity Information Facility (GBIF, 2016).
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 zone.
Geo-Z3 (Zone 3)	n - negl	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z4 (Zone 4)	n - high	N/A	One point each in China and Pakistan, but this is in a mountainous region where hardiness zones will change rapidly with elevation. Consequently, we answered no.
Geo-Z5 (Zone 5)	y - high	N/A	Two points on the edge of this zone in Pakistan. Northern varieties of *S. spontaneum* can withstand temperatures down to -20 °F in the winter (Brandes et al., 1939).
Geo-Z6 (Zone 6)	y - low	N/A	Two points in Afghanistan and one in Pakistan. Because this species is reported to withstand temperatures down to -20 °F (Brandes et al., 1939), we used low rather than moderate uncertainty.
Geo-Z7 (Zone 7)	y - low	N/A	A few points in Afghanistan and two in Pakistan. Because this species is reported to withstand temperatures down to -20 °F (Brandes et al., 1939), we used low rather than moderate uncertainty.
Geo-Z8 (Zone 8)	y - negl	N/A	A few points in Afghanistan. One point in Japan. Three points in France. Northern varieties of *S. spontaneum* can withstand temperatures down to -20 °F in the winter (Brandes et al., 1939).
Geo-Z9 (Zone 9)	y - negl	N/A	China and Taiwan.
Geo-Z10 (Zone 10)	y - negl	N/A	China, India, Israel. A few points in Papua New Guinea, Japan, and Thailand.
Geo-Z11 (Zone 11)	y - negl	N/A	Australia, Israel, and Taiwan. One point in the United States (Florida). Widespread distribution in India (Panje, 1970).
Geo-Z12 (Zone 12)	y - negl	N/A	Australia, Israel, and Taiwan. Widespread distribution in India (Panje, 1970).
Geo-Z13 (Zone 13)	y - negl	N/A	Panama, Papua New Guinea, and Taiwan. Widespread distribution in India (Panje, 1970).
Köppen -Geiger climate classes			
Geo-C1 (Tropical rainforest)	y - negl	N/A	Some points in Indonesia, Panama, and Papua New Guinea. Widespread distribution in India (Panje, 1970).
Geo-C2 (Tropical savanna)	y - negl	N/A	Some points in Panama and Thailand. One point in the United States (Florida). Widespread distribution in India (Panje, 1970).
Geo-C3 (Steppe)	y - negl	N/A	Some points in Afghanistan and Israel. Widespread distribution in India (Panje, 1970).
Geo-C4 (Desert)	y - low	N/A	Some points in Afghanistan and a few in Pakistan. Regional occurrence in Turkmenistan (GBIF, 2016).
Geo-C5 (Mediterranean)	y - negl	N/A	Many points in Israel. Three points in Afghanistan and India. Three points in France.
Geo-C6 (Humid subtropical)	y - negl	N/A	China, India, Taiwan, and the United States (Florida).
Geo-C7 (Marine west coast)	y - mod	N/A	Some points in China. Two points in India and one in Nepal.
Geo-C8 (Humid cont. warm sum.)	y - high	N/A	One point near the edge of this climate class in Afghanistan. Regional occurrence in Afghanistan (GBIF,

Question ID	Answer - Uncertainty	Score	Notes (and references)
			2016). Grows to about 40 degrees latitude in Tajikistan and Uzbekistan, which includes this climate class in the region (Brandes et al., 1939).
Geo-C9 (Humid cont. cool sum.)	n - high	N/A	One point on the edge of this climate class in Pakistan.
Geo-C10 (Subarctic)	n - negl	N/A	We found no evidence that it occurs in this climate class.
Geo-C11 (Tundra)	n - negl	N/A	We found no evidence that it occurs in this climate class.
Geo-C12 (Icecap)	n - negl	N/A	We found no evidence that it occurs in this climate class.
10-inch precipitation bands			
Geo-R1 (0-10 inches; 0-25 cm)	y - high	N/A	Some points in Israel. We answered yes because this C4 grass (Holm et al., 1997) may be able to grow in this precipitation band in restricted environments such as along rivers, drainage ditches, etc.
Geo-R2 (10-20 inches; 25-51 cm)	y - negl	N/A	Many points in Israel. A few points in Papua New Guinea.
Geo-R3 (20-30 inches; 51-76 cm)	y - negl	N/A	Many points in Israel. A few points in Papua New Guinea. In central India, grows under a precipitation range of 20-200 inches per year (Mukherjee, 1950).
Geo-R4 (30-40 inches; 76-102 cm)	y - negl	N/A	Taiwan. A few points in Papua New Guinea. In central India, grows under a precipitation range of 20-200 inches per year (Mukherjee, 1950).
Geo-R5 (40-50 inches; 102-127 cm)	y - negl	N/A	Taiwan. A few points in Papua New Guinea. One point in the United States (Florida). In central India, grows under a precipitation range of 20-200 inches per year (Mukherjee, 1950).
Geo-R6 (50-60 inches; 127-152 cm)	y - negl	N/A	China and Taiwan. A few points in Papua New Guinea. In central India, grows under a precipitation range of 20-200 inches per year (Mukherjee, 1950).
Geo-R7 (60-70 inches; 152-178 cm)	y - negl	N/A	China and Taiwan. A few points in Papua New Guinea. In central India, grows under a precipitation range of 20-200 inches per year (Mukherjee, 1950).
Geo-R8 (70-80 inches; 178-203 cm)	y - negl	N/A	China and Taiwan. A few points in Papua New Guinea. One point in the United States (Florida). In central India, grows under a precipitation range of 20-200 inches per year (Mukherjee, 1950).
Geo-R9 (80-90 inches; 203-229 cm)	y - negl	N/A	China and Taiwan. A few points in Papua New Guinea. One point in the United States (Florida). In central India, grows under a precipitation range of 20-200 inches per year (Mukherjee, 1950).
Geo-R10 (90-100 inches; 229-254 cm)	y - negl	N/A	China and Taiwan. A few points in Papua New Guinea. In central India, grows under a precipitation range of 20-200 inches per year (Mukherjee, 1950).
Geo-R11 (100+ inches; 254+ cm)	y - negl	N/A	China, Panama, and Taiwan. A few points in Papua New Guinea. In central India, grows under a precipitation range of 20-200 inches per year (Mukherjee, 1950).
ENTRY POTENTIAL			
Ent-1 (Plant already here)	y - negl	1	*Saccharum spontaneum* is already present in the United States, where it is used in sugarcane breeding programs (NRCS, 2016; USDA, 1953). It is naturalized in three Florida counties (Kartesz, 2016; Wunderlin and Hansen, 2016), Guam (Whistler, 1995), Puerto Rico (Acevedo-Rodríguez and Strong, 2012; Más and Lugo-Torres, 2013), and Hawaii (Osgood and Wiemer, 1992; Wagner et al., 1999).

Question ID	**Answer - Uncertainty**	**Score**	**Notes (and references)**
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	