Michigan Department of Agriculture & Rural Development

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Version 1

Weed Risk Assessment for *Cabomba caroliniana* A. Gray (Cabombaceae) – Carolina fanwort

Top left: *Cabomba caroliniana* submerged stems and leaves (source: Leslie J. Mehrhoff, University of Connecticut, Bugwood.org). Bottom left: Species infestation (source: Leslie J. Mehrhoff, University of Connecticut, Bugwood.org). Right: Dense mass of *C. caroliniana* (source: Troy Evans, Great Smoky Mountains National Park, Bugwood.org).

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Introduction The Michigan Department of Agriculture and Rural Development (MDARD) regulates aquatic species through a Prohibited and Restricted species list, under the authority of Michigan's Natural Resources and Environmental Protection Act (NREPA), Act 451 of 1994, Part 413 (MCL 324.41301-41305). Prohibited species are defined as species which "(i) are not native or are genetically engineered, (ii) are not naturalized in this state or, if naturalized, are not widely distributed, and further, fulfill at least one of two requirements: (A) The organism has the potential to harm human health or to severely harm natural, agricultural, or silvicultural resources and (B) Effective management or control techniques for the organism are not available." Restricted species are defined as species which "(i) are not native, and (ii) are naturalized in this state, and one or more of the following apply: (A) The organism has the potential to harm human health or to harm natural, agricultural, or silvicultural resources. (B) Effective management or control techniques for the organism are available." Per a recently signed amendment to NREPA (MCL 324.41302), MDARD will be conducting reviews of all species on the lists to ensure that the lists are as accurate as possible.

We use the United States Department of Agriculture's, Plant Protection and Quarantine (PPQ) Weed Risk Assessment (WRA) process (PPQ, 2015) to evaluate the risk potential of plants. 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., State 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.

Cabomba caroliniana A. Gray. – Carolina fanwort

Species Information

Family: Cabombaceae

Synonyms: No taxonomic synonyms were found or used in this literature review.

Common names: Carolina fanwort, fanwort, green cabomba, cabomba (Wilson, Darbyshire & Jones, 2007; Department of Agriculture, Fisheries and Forestry Biosecurity Queensland, 2013).

Botanical description: *Cabomba caroliniana* is a submerged freshwater macrophyte that grows in lakes, streams, and ponds. Its long stems can grow to 10 m in length, and its leaves may be submerged or floating (Matthews et. al, 2013; CABI, 2015; eFloras, 2015).

Initiation: In accordance with the Natural Resources and Environmental Protection Act Part 413, the Michigan Department of Agriculture and Rural Development was tasked with evaluating the aquatic species currently on Michigan's Prohibited and Restricted Species List (MCL 324.41302). The USDA Plant Epidemiology and Risk Analysis Laboratory's (PERAL) Weed Team worked with MDARD to evaluate this species.

Foreign distribution: This species is native to Brazil, Paraguay, Uruguay, and Argentina in South America (Xiaofeng, Bingyang, Shuqin & Weimei, 2005). It is naturalized in Asia (e.g., China, Japan, India), Australia, and Northern Europe (e.g., United Kingdom) (NGRP, 2015). This species is also cultivated but not yet naturalized in Canada, Mexico, Sri Lanka, Malaysia, Vietnam, Belgium, the Netherlands, Hungary, and Serbia, but has not yet naturalized (GBIF, 2015; McCracken, Bainard, Miller, & Husband, 2013; Vukov, Jurca, Rucando, Igic & Miljanovic, 2013).

U.S. distribution and status: *Cabomba caroliniana* is native to the southeastern United States (e.g., Alabama, Arkansas, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia) (NGRP, 2015). It has naturalized in California, Connecticut, Delaware, Illinois, Indiana, Kansas, Maine, Michigan, Missouri, New Hampshire, New Jersey, New York, Ohio, Oklahoma, Oregon, Pennsylvania, and Rhode Island, and Washington (GBIF, 2015). The species is regulated in Connecticut, Maine, Massachusetts, Michigan, New Hampshire, Vermont, Washington, and Wisconsin (CABI, 2015; NPB, 2015). This species is also cultivated as a popular aquarium plant (eFloras, 2015). *Cabomba caroliniana* is readily available online for purchase (DavesGarden, 2015; LiveAquaria, 2015), and has been found in local nurseries by Michigan nursery inspectors. The nurseries had obtained *C. caroliniana* through brokers and suppliers of the species in its native range, including Florida and Mississippi (Bryan, 2015).

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

1. *Cabomba caroliniana* analysis

Establishment/Spread Potential *Cabomba caroliniana* reproduces primarily vegetatively, and has an extremely high regenerative potential from both natural and human mediated fragmentation, leading to a wide potential of fragment spread through water-mediated dispersal (Bickel, 2015, Mackey & Swarbrick, 1997; Matthews et. al, 2013). It readily forms dense mats to quickly overrun bodies of water, and benefits strongly from fragmentation (McCracken, Bainard, Miller, & Husband, 2013; Schooler & Julien, 2011). Further, this species is able to adapt to a wide variety of climates, and can successfully overwinter in areas that are too cold for continuous growth (GBIF, 2015; Riemer & Ilnicki, 1968). We had a low amount of uncertainty for this risk element, given that the species is fairly well-studied.

Risk score = 16 Uncertainty index = 0.13

Impact Potential *Cabomba caroliniana* is primarily a weed of natural and anthropogenic systems (Bickel, 2015; McCracken, Bainard, Miller, & Husband, 2013). In natural systems, it shades out other submerged species due to its dense growth (Hogsden, Sager, & Hutchinson, 2007), alters the chemical and nutrient composition of the body of water it invades (Mackey & Swarbrick, 1997), smothers and outcompetes native species, and reduces the overall species diversity in aquatic systems (Schooler & Julien, 2011; Lyon & Eastman, 2006; Vukov, Jurca, Rucando, Igic & Miljanovic, 2013). In anthropogenic systems, this species poses a large threat to swimmers and boaters who may become entangled in the long stems (Schooler & Julien, 2011). *Cabomba caroliniana* interferes with dam machinery (Schooler & Julien, 2011), affects the use of waterways for industrial purposes, interferes with power generation (Wilson, Darbyshire & Jones, 2007), and decreases water quality, increasing water treatment costs (Schooler, Julien & Walsh, 2006).We had a low amount of uncertainty for this risk element.

Risk score = 3.4 Uncertainty index = 0.11

Geographic Potential Based on three climatic variables, we estimate that about 54.5 percent of the United States is suitable for the establishment of *Cabomba caroliniana* (Fig. 1). This predicted distribution is based on the species' known distribution elsewhere in the world and includes point-referenced localities and areas of occurrence. The map for *Cabomba caroliniana* represents the joint distribution of Plant Hardiness Zones 6-13, areas with 10-100+ inches of annual

[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).

precipitation, and the following Köppen-Geiger climate classes: tropical rainforest, tropical savanna, steppe, Mediterranean, humid subtropical, marine west coast, humid continental warm summers, and humid continental cool 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 pH, stream flow, and dissolved nutrient concentrations, may further limit the areas in which this species is likely to establish. *Cabomba caroliniana* is a freshwater, submerged species which prefers shallow, slow-moving bodies of water, and can photosynthesize in pH levels up to 8.4 (Schooler & Julien, 2011; Mackey & Swarbrick, 1997; Matthews et. al, 2013; Schooler, Julien & Walsh, 2006).

Entry Potential We did not assess the entry potential of *Cabomba caroliniana* because it is already present in the United States (McCracken, Bainard, Miller, & Husband, 2013).

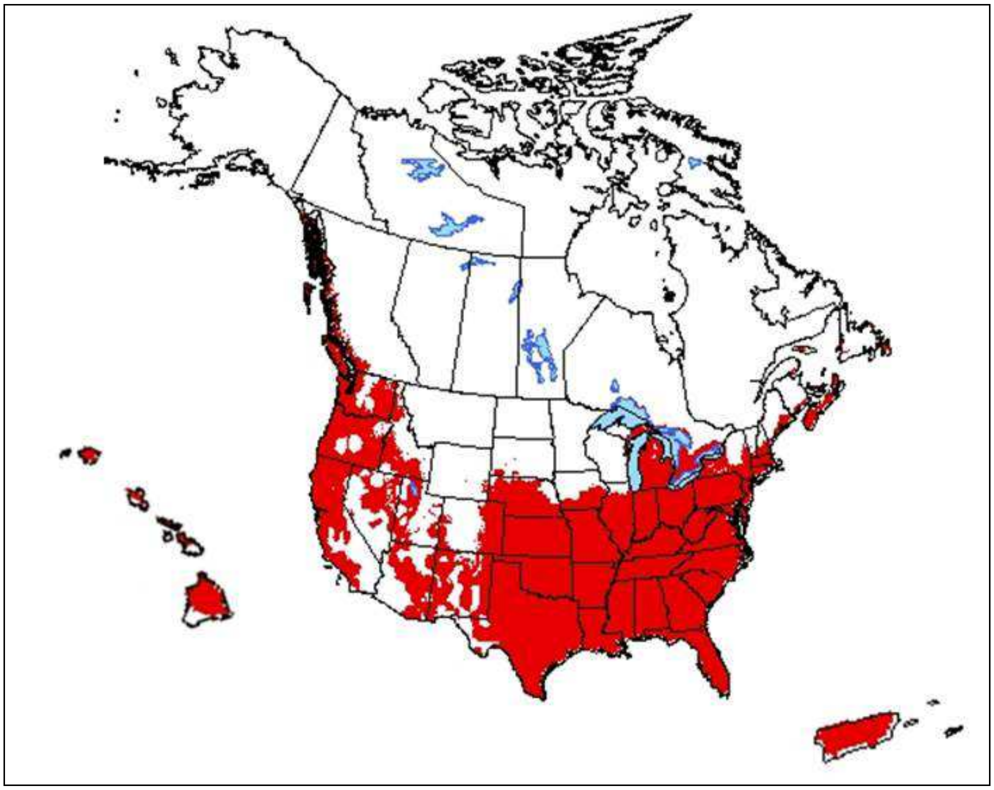

Figure 1. Predicted distribution of *Cabomba caroliniana* in the United States. Map insets for Alaska, Hawaii, and Puerto Rico are not to scale.

<u>2. Results</u>

Model Probabilities: P(Major Invader) = 84.3%
P(Minor Invader) = 15.1%
P(Non-Invader) = 0.6%

Risk Result = High Risk

Secondary Screening = Not Applicable

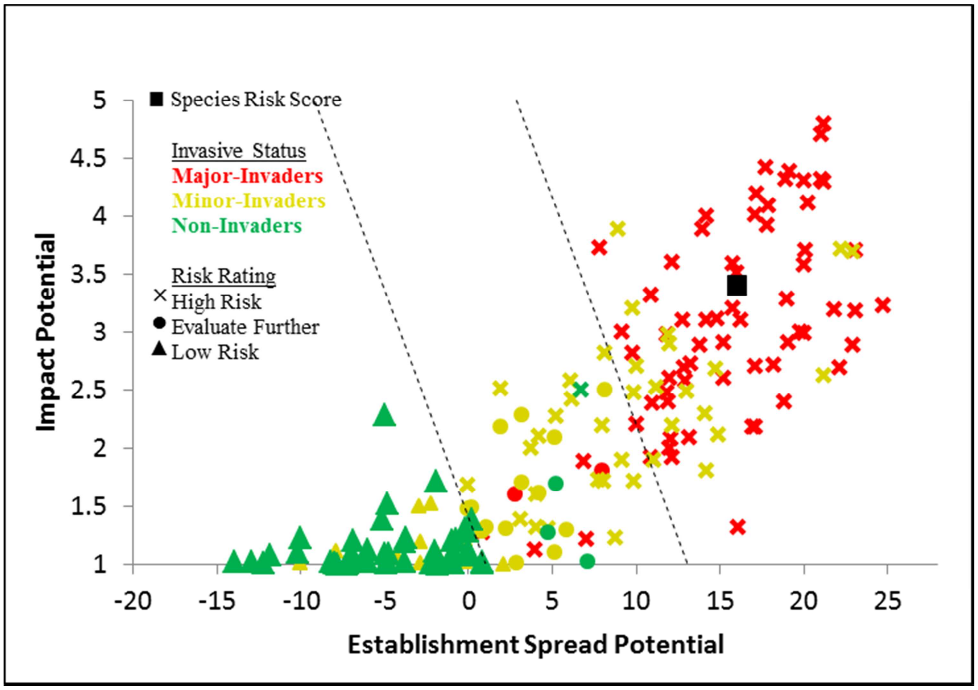

Figure 2. *Cabomba caroliniana* risk score (black box) relative to the risk scores of species used to develop and validate the PPQ WRA model (other symbols). See Appendix A for the complete assessment.

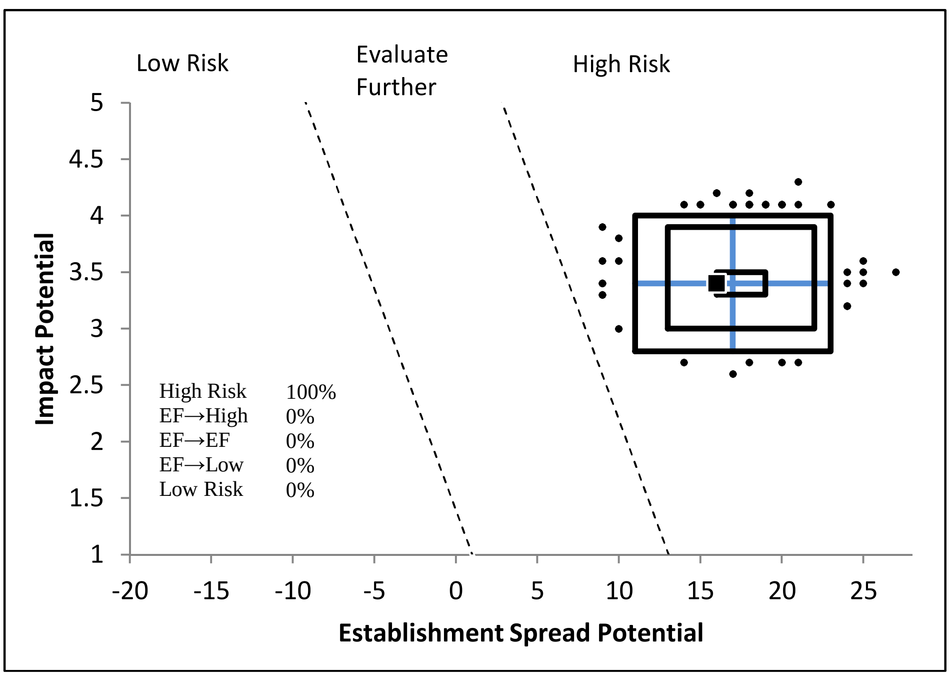

Figure 3. Model simulation results (N=5,000) for uncertainty around the risk score for *Cabomba caroliniana*. The blue "+" symbol represents the medians of the simulated outcomes. The smallest box contains 50 percent of the outcomes, the second 95 percent, and the largest 99 percent.

3. Discussion

The result of the weed risk assessment for *Cabomba caroliniana* was High Risk (Fig. 2). Our uncertainty analysis supports our conclusion, as all 5000 simulated risk scores resulted in an outcome of High Risk (Fig. 3). This species may experience repeated, multiple introductions to waterways via dumping of aquariums in natural waterways (Vukov, Jurca, Rucando, Igic & Miljanovic, 2013; Matthews et. al, 2013; Xiaofeng, Bingyang, Shuqin & Weimei, 2005). Aquarium owners who do not properly dispose of aquarium contents and simply discard them introduce the potential for *C. caroliniana* to spread beyond natural means of distribution. Control of this species in Australia in an 11 km stretch of the Darwin River consisted of a combination of shading, water drawdowns and mechanical removal of *C. caroliniana*, boom construction across waterways to prevent the spread of plant fragments downstream, and herbicide treatments (Australia Department of Land Resource Management, 2015). This combination of management strategies, in conjunction with monitoring and regular surveys to detect new growth of *C. caroliniana*, has succeeded at keeping the *C. caroliniana* biomass to less than 0.01% of the initial affected area (Australia Department of Land Resource Management, 2015). Weed risk assessments conducted on this species in Belgium, England, Spain, and Australia yielded similar high risk results for the species (Matthews et. al, 2013).

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Appendix A. Weed risk assessment for *Cabomba caroliniana* A. Gray (Cabombaceae). 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	*Cabomba caroliniana* A. Gray (fanwort) is a subtropical freshwater submerged aquatic plant that is spreading worldwide. The pattern of multiple introductions and subsequent spread of populations of *C. caroliniana* in the United States is supported by several observational and herbarium records (McCracken, Bainard, Miller, & Husband, 2013). *C. caroliniana*'s native distribution includes Brazil, Paraguay, Uruguay, and Argentina in South America, and extends into southeastern North America (Xiaofeng, Bingyang, Shuqin & Weimei, 2005). *Cabomba caroliniana* has naturalized in Australia, Belgium, Canada, England, Hungary, India, Malaysia, Mexico, the Netherlands, Serbia, Sri Lanka, and Vietnam (GBIF, 2015; McCracken, Bainard, Miller, & Husband, 2013; Vukov, Jurca, Rucando, Igic & Miljanovic, 2013). Typically considered a tropical or sub-tropical species, *C. caroliniana*'s spread through the northeastern United States and now into Canada is a more recent phenomenon that shows it is adaptable and capable of surviving in temperate or continental climates (Wilson, Darbyshire & Jones, 2007; Matthews et. al, 2013). *C. caroliniana* is the only species of the genus *Cabomba* that has been widely introduced outside its native range. In Canada, *C. caroliniana* overwinters under prolonged snow and ice cover and continues to thrive and spread, indicating that it can survive winter conditions (Matthews et. al, 2013). Spread of fanwort has been rapid since its first discovery at Kasshabog Lake in Canada in 1991 (Wilson, Darbyshire & Jones, 2007).This is similar in reports from Black Lake in Louisiana, where fanwort has spread to infest 2000 of 6000 ha (Wilson, Darbyshire & Jones, 2007). Alternate answers for the Monte Carlo simulation were both "e."
ES-2 (Is the species highly domesticated)	n - low	0	This species is cultivated in the aquarium trade (DavesGarden, 2015); we found no evidence that it has been bred to reduce weedy traits. Furthermore, wild and naturalized populations of *C. caroliniana* are similar to those sold via the aquatic plant trade (Matthews et. al, 2013), indicating no difference between the cultivated and wild populations.
ES-3 (Weedy congeners)	n - mod	0	The genus *Cabomba* contains seven species (Fassett, 1953). Randall (2012) categorizes five of these species as naturalized (e.g., *C. aquatica, C. furcata*), two as non-specific type weeds (*C. australis, C. haynesii*), and one as an agricultural weed (*C. pulcherrima*) somewhere in the world. However, none of these species have been well-studied, and we found very little evidence as to the weediness of these

Question ID	Answer - Uncertainty	Score	Notes (and references)
			species, and no direct evidence that any of these species are significant weeds. Information on the weediness of *C. caroliniana*'s congeners may be limited due to the fact that Darbyshire (2003) includes *C. pulcherrima* as well as *C. caroliniana* in his Inventory of Canadian Agricultural Weeds, but does not describe the agricultural effects of either species further than their establishment and spread. There is some taxonomic confusion surrounding *C. pulcherrima*; while some sources list *C. pulcherrima* as its own species (Darbyshire, 2003; Greening & Gerritsen, 1987, Prusak, O'Neal, & Kubanek, 2005), others list it as *C. caroliniana* var. *pulcherrima* (Hussner, Nehring, & Hilt, 2014; Vukov, Jurca, Rucando, Igic & Miljanovic, 2013). Because it is not clear whether *C. pulcherrima* is a variety of *C. caroliniana* or its own species, we answered no, but with moderate uncertainty.
ES-4 (Shade tolerant at some stage of its life cycle)	? - max	0	*Cabomba caroliniana* is a submerged aquatic species that can grow in waters up to 10 meters deep, but is more commonly found in waters up to 3 meters deep (Mackey & Swarbrick, 1997; Schneider & Jeter, 1982). The literature qualitatively defines this species as having high light and clear water requirements (Matthews et. al, 2013; Mackey & Swarbrick, 1997; Ørgaard, 1991). In one experimental study, high shade levels (99%) reduced *C. caroliniana* biomass to <10% of former abundance within 60 days and eliminated *C. caroliniana* within 120 days during summer at 1 to 3 m depth (Schooler, 2008). However, 99% shade is somewhat excessive and cannot be expected to occur naturally. With respect to this question, we consider 90% shade to be the threshold for a yes response. Schooler (2008) also evaluated the effect of 70% shade covering and found that this moderate amount of shading reduced *C. caroliniana* biomass at 2 m depth, and "arguably" at 3 m depth, but had no effect on biomass at 1 m depth or shallower (Schooler, 2008). For this question, we answered "unknown." This is a submerged species, indicating that it requires less light than emergent species. The literature states that the species has high light requirements, yet the variability of depth of growth depends on a variety of light attenuation factors, notably turbidity (Lyon & Eastman, 2006). Without knowing the exact light requirements of this species, we cannot answer more specifically.
ES-5 (Climbing or smothering growth form)	n - negl	0	Although this species has long submerged stems (Schooler & Julien, 2011), it is not a vine, nor does it form tightly appressed basal rosettes.
ES-6 (Forms dense thickets)	y - negl	2	In its introduced range, *C. caroliniana* forms dense monotypic stands (McCracken, Bainard, Miller, & Husband, 2013). The species' density is high in shallow water and decreases with increasing depth (Schooler & Julien, 2011). It forms large, dense, uniform beds and populations (Vukov, Jurca, Rucando, Igic & Miljanovic, 2013).
ES-7 (Aquatic)	y - negl	1	*Cabomba caroliniana* is categorized as a "freshwater submerged aquatic plant" (McCracken, Bainard, Miller, & Husband, 2013) and a "submerged aquatic macrophyte"

Question ID	Answer - Uncertainty	Score	Notes (and references)
			(Schooler, 2008).
ES-8 (Grass)	n - negl	0	This species is a member of the family Cabombaceae and is therefore not a grass (Bickel & Schooler, 2015).
ES-9 (Nitrogen-fixing woody plant)	n - negl	0	We found no evidence that this species fixes nitrogen. Further, this species is not in a plant family known to have N-fixing capabilities (Martin and Dowd, 1990).
ES-10 (Does it produce viable seeds or spores)	y - negl	1	Information about sexual reproduction is highly variable. It appears as though this species is able to reproduce sexually within its native range (Jacobs & Macisaac, 2009), but reproduces almost exclusively vegetatively outside of its native range. For this reason, we answered yes/negligible because it is apparent that this species is capable of reproducing through seeds, but only within its native range. Detailed evidence: *Cabomba caroliniana* rarely produces viable seeds in its introduced range and therefore depends primarily on humans to disperse vegetative propagules to new watersheds (Bickel & Schooler, 2015, Schooler, 2008). It does not appear to reproduce sexually in Kasshabog Lake in Canada (Jacobs & Macisaac, 2009). Some seeds and seedlings have been found near Darwin in the Northern Territory of Australia, but seeds have not been found at any other site in Australia (Schooler, Julien & Walsh, 2006). In New Jersey, no seedlings were found in the field, no seed germinated after elapsed times, and examination of longitudinal and cross-sections showed no evidence of an embryo in any of the seed sectioned, leading researchers to conclude that "reproduction by seed, if it occurs at all, is of very minor importance" (Riemer & Ilnicki, 1968). Of specific importance to northern states and nations is that seeds appear only in the plant's tropical native range and in tropical and subtropical regions of its non-native range (Matthews et. al, 2013), seed reproduction is thought to be rare to nonexistent in the northern parts of fanwort's range (Ørgaard, 1991).
ES-11 (Self-compatible or apomictic)	n - mod	-1	The literature is somewhat confounded as to the possibility of self-fertilization; while it appears that biologically, there are mechanisms in place to prevent self-fertilization, some sources indicate that self-fertilization has been observed. The results of caging experiments by Schneider & Jeter (1982) indicate that direct autogamy does not occur, since none of the 14 caged flowers produced seeds. Protogyny is, therefore, "absolute" (Schneider & Jeter, 1982). Biologically, flowers are designed to be protogynous, shedding pollen only after the stigma has ceased to be productive, effectively preventing self-fertilization (Wilson, Darbyshire & Jones, 2007). *Cabomba*, the genus, is protogynous with a 2 day flowering period; on the first day, stigmata are receptive in the flower. Flowers close in the evening, submerge, and reemerge as functionally staminate flowers on the second day (Taylor et. al, 2008). Ørgaard (1991) confirmed observations about the species' two-day flowering cycle and the mechanisms to prevent self-fertilization, but notes that the observations included fruit setting in plants that were

Question ID	Answer - Uncertainty	Score	Notes (and references)
			neither hand nor insect pollinated, and concludes that in field conditions, rain, wind, and passing animals would be enough to transfer pollen, and some degree of autogamy must be expected in nature. We answered no because the weight of the evidence indicates that *C. caroliniana* is not self-compatible, but used moderate uncertainty given Ørgaard's observations.
ES-12 (Requires special pollinators)	n - negl	0	*C. caroliniana* is an entomophilous species (Osborn, Taylor & Schneider, 1991) and is pollinated by small insects, primarily flies (Taylor et. al, 2008; Schneider & Jeter, 1982). In one study in Louisiana, honey bees were the main pollinators (Tarver & Sanders, 1977).
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	Because *C. caroliniana* reproduces primarily through vegetative reproduction and because we found very little information about seed reproduction, we evaluated this question using information about vegetative reproduction. Towards the end of the growing season, *C. caroliniana* stems become increasingly hard and brittle, and eventually fragment (Riemer & Ilnicki, 1968; Bickel & Schooler, 2015). Observations at Kasshabog Lake, Canada, indicate that turion-like structures either break free or remain attached to the rooted stem, and rooted and broken stems lie prostrate on the lake bottom throughout the winter. The stem fragments remain green under ice cover as illustrated by healthy green rooted plants and fragments collected immediately following ice break-up in the spring (Hogsden, Sager, & Hutchinson, 2007). Jacobs & Macisaac (2009) confirms that this species "can reproduce asexually via auto-fragmentation, provided there is at least one node and an intact leaf." Consequently, we answered "b". Because observations of "fast growth of *C. caroliniana* from fragments early in the growing season and the high number of asexual propagules" (Matthews et. al, 2013) indicate that natural fragmentation any time before the end of the growing season could result in new growth of individuals, we used "a" for both alternate answers for the Monte Carlo simulation. We used moderate uncertainty since human mediated forms of fragmentation (i.e. cutting from boat propellers) are very likely to happen in lakes in *C. caroliniana* beds, thus leading to multiple generations per year, even without natural fragmentation.
ES-14 (Prolific reproduction)	n - mod	-1	*C. caroliniana* has a low seed set throughout its native range (Ørgaard, 1991), even when compared to congeners (Mackey & Swarbrick, 1997). It also has a low seed set within its northern, introduced range (McCracken, Bainard, Miller, & Husband, 2013). A Serbian study found no evidence of seed production and concluded that "it could be assumed that in Serbia it propagates exclusively by stem fragments" (Vukov, Jurca, Rucando, Igic & Miljanovic, 2013), while Canadian risk analysts noted that "without seed reproduction" *C. caroliniana* "reproduces vegetatively" (CFIA, 2001). Although this question normally requires quantitative evidence, based on the amount of qualitative and anecdotal evidence; we answered no with moderate

Question ID	Answer - Uncertainty	Score	Notes (and references)
			uncertainty.
ES-15 (Propagules likely to be dispersed unintentionally by people)	y - negl	1	The most likely source of *C. caroliniana* spread is due to accidental transfer, “perhaps via boat traffic" (McCracken, Bainard, Miller, & Husband, 2013). It is easily spread across drainages on watercraft and boat trailers (Schooler & Julien, 2011; Hogsden, Sager, & Hutchinson, 2007; Vukov, Jurca, Rucando, Igic & Miljanovic, 2013). Jacobs & Macisaac (2009) utilized boater surveys to assess potential human-mediated transport, and "identified four lakes at high invasion risk" from human-mediated transport via boats, while noting that "more extensive sampling might pick up additional lakes placed at risk by outbound boaters."
ES-16 (Propagules likely to disperse in trade as contaminants or hitchhikers)	y - negl	2	In a Minnesota study of the movement of invasive aquatic species in trade, researchers bought a variety of aquatic plant species from nursery catalogues and online stores to determine the percentage of shipments that were incorrect due to misidentification or mislabeling. They found a "5% incidental receipt rate" of *C. caroliniana* for all shipments of plants purchased (Maki & Galatowitsch, 2004). A discussion of dispersal methods states that "it seems likely that commercial trade could facilitate global transport" (McCracken, Bainard, Miller, & Husband, 2013). Matthews et. al (2013) notes that the "main component of imported *C. aquatica* to the Netherlands actually consists of *C. caroliniana*".
ES-17 (Number of natural dispersal vectors)	2	0	Information relevant for ES-17a through ES-17e: The fruit is apocarpous, with 1-4 dark brown carpels which release the seeds by decomposition of the wall 14-30 days after anthesis. When there is only one carpel, this is pearl shaped and erect. When there are three or more carpels per flower, the ovaries become belly-shaped and diverge at maturity (Ørgaard, 1991). Fruits are 4-7mm long (Wilson, Darbyshire & Jones, 2007). The seed is globose to ovoid-oblong with slightly flattened ends, sometimes a bit more compressed if the fruit has contained several seeds. The testa layer is very thin (Ørgaard, 1991). The seed is 1.5-3.0mm x 1.0-1.5mm long. The fruits are submerged and released under water (Mackey & Swarbrick, 1997).
ES-17a (Wind dispersal)	n - negl		We found no evidence, and this method of dispersal is not included in the review of potential dispersal vectors in Matthews et. al (2013). Further, the fruit is released underwater and possesses no adaptations for wind dispersal, thus making it highly unlikely to be dispersed via wind.
ES-17b (Water dispersal)	y - negl		*Cabomba caroliniana* can be spread aquatically both by fruit/seeds and by stem fragments, the more common form of reproduction (Matthews et. al, 2013). After fertilization, flowers enclose the fruit and re-submerge. When the fruit matures, it breaks away from the plant, and either floats to a new location or falls directly to bottom of the body of water, depending on the strength of current. The fruit decomposes around the seed and leaves it at the “hydrosoil surface” (Mackey & Swarbrick, 1997). In their studies of *C. caroliniana* reproductive success in New Jersey, Riemer &

Question ID	Answer - Uncertainty	Score	Notes (and references)
			Ilnicki (1968) collected free-floating fruits from the field to use for seed germination experiments. In addition, given that this species is a submerged aquatic plant that can reproduce vegetatively (Bickel & Schooler, 2015), stem fragments are likely to float to the margins and establish new plants (Schooler, Julien & Walsh, 2006).
ES-17c (Bird dispersal)	y - high		The dispersal of seeds between waterways that are not connected or are completely isolated may be attributed to spread by waterfowl (Schooler & Julien, 2011; Wilson, Darbyshire & Jones, 2007). While transport by birds may be rare (Matthews et. al, 2013), it is likely that seeds adhering to the feathers of waterfowl or stuck in the mud on their feet are transported between habitats (Ørgaard, 1991). We answered yes, but with a high degree of uncertainty, given the lack of direct observation of this mode of dispersal.
ES-17d (Animal external dispersal)	? - max		We found no evidence that fruits or seeds are dispersed externally on animals, and this method of dispersal is not included in the review of potential dispersal vectors in Matthews et. al (2013). However, because external dispersal most likely occurs on birds due to seeds getting lodged on their feathers or on mud on their feed, it seems reasonable it could also occur on animals. Consequently, we answered unknown.
ES-17e (Animal internal dispersal)	? - max		We found no evidence. Fruit or seeds may be eaten by fish or mammals, but "nothing is known about this type of transport" (Ørgaard, 1991)
ES-18 (Evidence that a persistent (>1yr) propagule bank (seed bank) is formed)	y - high	1	In general, seeds are not frequently observed in the field, so evidence is limited. In the field, many small plants emerge which appear to be seedlings, but which actually are growing from previous years' stem fragments buried in the substrate (Riemer & Ilnicki, 1968). In one study, seeds did not germinate under laboratory conditions and no seedlings were observed in the field (Riemer & Ilnicki, 1968), however, field studies showed that fanwort seeds up to 2 years old germinated under natural conditions, suggesting that they are capable of prolonged dormancy and production of persistent seed banks (Wilson, Darbyshire & Jones, 2007). We answered yes, but with high uncertainty because there is a small sample size and very few studies have been conducted.
ES-19 (Tolerates/benefits from mutilation, cultivation or fire)	y - negl	1	*Cabomba caroliniana* has a high tolerance of fragmentation (Schooler & Julien, 2011) and is coupled with a high regeneration potential; a small piece of stem with a single node has a regeneration probability of 50%. Further, *C. caroliniana* fragments were found to be highly resistant to desiccation (Bickel, 2012). The species has a 100% survival probability for fragments that experienced a mass loss of up to 65%, and some fragments are able to tolerate a mass loss of 90% (Bickel, 2015).
ES-20 (Is resistant to some herbicides or has the potential to become resistant)	n - low	0	Herbicides have been cited as largely ineffective (Schooler, 2008; Schooler & Julien, 2011; Bultemeier, Netherland, Ferrell & Haller, 2009; Hiltibran, 1965), but it is not clear why. Although the species exhibits some tolerance, whether due to application or season, we found no evidence that it is

Question ID	Answer - Uncertainty	Score	Notes (and references)
			specifically resistant. Further, it is not listed by Heap (2015 as a weed that is resistant to herbicides.
ES-21 (Number of cold hardiness zones suitable for its survival)	7	0	
ES-22 (Number of climate types suitable for its survival)	8	2	
ES-23 (Number of precipitation bands suitable for its survival)	10	1	
IMPACT POTENTIAL			
General Impacts			
Imp-G1 (Allelopathic)	n - high	0	Studies conducted by Nakai, Inoue, Hosomi & Murakami (1999) on the allelopathy of freshwater macrophytes showed that *C. caroliniana* inhibited the growth of two blue-green algae specie, *Anabena flos-aquae* and *Phormidium tenue*. However, these experiments were conducted in a flask in a laboratory environment with macrophyte culture solutions and carefully constructed macrophyte concentrations of whole vegetation. These conditions are extremely unrepresentative of the natural environment. Given the manipulation of the traits studied in a controlled laboratory setting do not mimic natural conditions and the fact that we did not find any direct evidence of allelopathy in the natural environment, we are answered no, but with high uncertainty.
Imp-G2 (Parasitic)	n - negl	0	We found no evidence that this species is parasitic. Furthermore, *Cabomba caroliniana* does not belong to a family known to contain parasitic plants (Heide-Jorgensen, 2008; NGRP, 2015; Nickrent, 2009).
Impacts to Natural Systems			
Imp-N1 (Change ecosystem processes and parameters that affect other species)	y - low	0.4	In areas where *Cabomba caroliniana* density is abundant, it alters nutrient regimes (Vukov, Jurca, Rucando, Igic & Miljanovic, 2013). Massive diebacks and decomposition of dense stands of *C. caroliniana* in the winter release large amounts of manganese into the system, and depletes oxygen (Mackey & Swarbrick, 1997). Further, *C. caroliniana* is an efficient utilizer of nitrogen and phosphorous, and can absorb these nutrients directly from the water through its shoots, leaves, and stems (Wilson, Darbyshire & Jones, 2007). While nutrient removal from an aquatic system reduces eutrophication of the system, it can also limit the growth of other native macrophytes in the system (Mackey & Swarbrick, 1997). Further, dense *C. caroliniana* beds significantly reduce light penetration (Matthews et. al, 2013; Hogsden, Sager, & Hutchinson, 2007).
Imp-N2 (Changes habitat structure)	y - mod	0.2	*Cabomba caroliniana* changes structurally diverse macrophyte beds and can alter habitat availability for macroinvertebrates, affecting both primary and secondary productivity rates (Matthews et. al, 2013). *Cabomba caroliniana* may reduce germination of desirable native emergent plants (Schooler & Julien, 2011).
Imp-N3 (Changes species diversity)	y - negl	0.2	*C. caroliniana* can smother native submerged plants such as pondweed, stoneworts, and water nymph (Schooler & Julien, 2011) and can have a significant effect on macrophyte

Question ID	Answer - Uncertainty	Score	Notes (and references)
			composition, leading to reduction of diversity (McCracken, Bainard, Miller, & Husband, 2013). Further, alteration of the natural flora is thought to have reduced populations of platypus and water rats in Australia (Schooler & Julien, 2011). Fanwort populations in Canada have been shown to grow as virtual monocultures, and these dense stands reduce the diversity of native plant species (Lyon & Eastman, 2006) and displace native animal species (Vukov, Jurca, Rucando, Igic & Miljanovic, 2013). Where native macrophytes are present, low light penetration through dense *C. caroliniana* growth further reduces abundance and these species are unevenly distributed (Hogsden, Sager, & Hutchinson, 2007). Significantly more epiphytic algae are present on *C. caroliniana* stands, and macroinvertebrate abundance is substantially higher, indicating that *C. caroliniana* changes macrophyte composition of waterways and creates new habitat for previously rare macroinvertebrates (Hogsden, Sager, & Hutchinson, 2007).In a comparison study of macrophyte beds in Kasshabog Lake in Canada, Hogsden, Sager, & Hutchinson (2007) found that beds dominated by *C. caroliniana* and beds of native macrophytes didn't differ in biomass and total number of species, but the vast majority of biomass in *C. caroliniana* beds resulted from that species, and rates of occurrence of native species were significantly lower than in native beds. While the same species were present in both beds, the proportions of each were significantly different.
Imp-N4 (Is it likely to affect federal Threatened and Endangered species)	y - negl	0.1	*Cabomba caroliniana* negatively affects populations of the endangered Mary River cod in Australia through its alteration of the natural system (Schooler & Julien, 2011). Further, *C. caroliniana* has been shown to displace established native species in Canada (Wilson, Darbyshire & Jones, 2007), which would include native endangered species. This species is therefore very likely to similarly affect threatened and endangered species in the United States, and given its impact on natural systems discussed in Imp-N1 through Imp-N3, answered yes with negligible uncertainty.
Imp-N5 (Is it likely to affect any globally outstanding ecoregions)	y - low	0.1	*Cabomba caroliniana* is already present as a noxious weed in counties in California and Washington (BONAP, 2014) which are listed as globally outstanding ecoregions (Ricketts et. al, 1999). Further, this species alters nutrient regimes (Vukov, Jurca, Rucando, Igic & Miljanovic, 2013), displaces native macrophytes and benthic species (Mackey & Swarbrick, 1997; Hogsden, Sager, & Hutchinson, 2007; Bickel, 2015), and reduces the overall biodiversity of an ecosystem (McCracken, Bainard, Miller, & Husband, 2013; Lyon & Eastman, 2006). Given the ecological impacts of this species (further addressed in Imp-N1 through Imp-N3), it can be expected to have similar impacts in the globally outstanding ecoregions in which it already occurs. Thus, we answered yes with low uncertainty.

Question ID	Answer - Uncertainty	Score	Notes (and references)
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) taxon a weed and evidence of control efforts]	c - negl	0.6	*Cabomba caroliniana* is a significant environmental weed with serious impacts (Bickel, 2015). It is a declared weed throughout Australia and it is illegal to propagate, move, or sell this noxious plant. It is also listed as one of the 20 Weeds of National Significance in Australia (Schooler & Julien, 2011). *Cabomba caroliniana* is a persistent, competitive and invasive plant that has significant impacts on aquatic ecosystems in its introduced range (Wilson, Darbyshire & Jones, 2007). In the Great Lakes region, the species is prohibited in Wisconsin, Illinois, and Michigan (USGS 2014). Several methods are used against *C. caroliniana*, including mechanical harvesting (Schooler & Julien, 2011), herbicide treatments (Bultemeier, Netherland, Ferrell & Haller, 2009), shading (Schooler, 2008), and, biological control with grass carp (Matthews et. al, 2013). Alternate answers for the Monte Carlo simulation were both "b."
Impact to Anthropogenic Systems (cities, suburbs, roadways)			
Imp-A1 (Impacts human property, processes, civilization, or safety)	y - negl	0.1	*Cabomba caroliniana* interferes with dam machinery, such as valves, pumps, and aerators (Schooler & Julien, 2011), affects the use of waterways for industrial purposes, interferes with power generation (Wilson, Darbyshire & Jones, 2007), and decreases water quality for human consumption by tainting and discoloring potable water supplies, therefore increasing water treatment costs (Schooler, Julien & Walsh, 2006).
Imp-A2 (Changes or limits recreational use of an area)	y - negl	0.1	*Cabomba caroliniana* can have a significant effect on human recreational activities (McCracken, Bainard, Miller, & Husband, 2013). Its long stems impede the movement of boats and can become tangled in propellers, paddles, and fishing lines. In addition, it poses a danger to swimmers who may become entangled in the long stems (Schooler & Julien, 2011). Most infestations occur in natural lakes and rivers, and have the most severe impact on amenity values, and by extension, the outdoor recreation and tourism industries (Wilson, Darbyshire & Jones, 2007).
Imp-A3 (Outcompetes, replaces, or otherwise affects desirable plants and vegetation)	? - max	0	A botanical bulletin from 1900 shared one gardener's experience: "It spread and is inclined to take complete possession of the lower ground, mixing in and crowding the water lilies which were previously well established" (Beal, 1900). Another gardener noted that *C. caroliniana* could be used as an aerator, but that it is "persistent and competitive" and must be pruned back daily (BackyardAquaponics, 2015). These two sources suggest that *C. caroliniana* may affect ornamental gardens, but without more well-documented effects we answered unknown.
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	*C. caroliniana* was positioned 8th in a list ranking invasive plants in order of undesirability in a survey of Dutch water-boards (Matthews et. al, 2013). It had completely clogged one commercially used canal in the Netherlands; however, management intervention (at 350,000 Euros per year) was able to reduce this infestation by 75% (Matthews et. al, 2013). Herbicide use is severely regulated in or around

Question ID	Answer - Uncertainty	Score	Notes (and references)
			public water supplies (Schooler, 2008), so physical removal of the species around public areas of Ewen Maddock Reservoir in Australia was conducted using trained SCUBA divers (Schooler & Julien, 2011). 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)	n - mod	0	Wilson, Darbyshire & Jones (2007) state that *C. caroliniana* could interfere with aquaculture, and may also have detrimental effects on native wild-rice. However, given the lack of direct evidence, we answered no, with moderate uncertainty.
Imp-P2 (Lowers commodity value)	n - mod	0	We found no evidence.
Imp-P3 (Is it likely to impact trade)	y - low	0.2	A study of the movement of aquatic invasive plants via trade found that *C. caroliniana* was accidentally shipped instead of the desired species in 5% of the shipments that were brought into Minnesota, indicating that the unintentional movement of *C. caroliniana* through trade occurs (Maki & Galatowitsch, 2004). Shipments turned away from areas where *C. caroliniana* is regulated will affect trade. Currently, Australia, Taiwan, and Nauru require phytosanitary certificates declaring shipments free of *C. caroliniana* (APHIS, 2015), while the species is banned from import/sale in the US states of Connecticut, Massachusetts, Michigan, and Vermont (CABI, 2015). Further, *Cabomba caroliniana* is a declared weed throughout all of Australia and it is illegal to propagate, move, or sell this noxious plant (Schooler & Julien, 2011). Thus we answered yes, but with low uncertainty.
Imp-P4 (Reduces the quality or availability of irrigation, or strongly competes with plants for water)	n - high	0	*Cabomba caroliniana* grows best in slow-moving waterways, such as irrigation canals, and prolific growth can clog these canals (Mackey & Swarbrick, 1997; Matthews et. al, 2013; Schooler, Julien & Walsh, 2006). However, we found no direct evidence of this occurring in canals used for irrigation; rather, the literature presents it as a strong possibility, as *C. caroliniana* forms dense stands and grows well in slow-moving water. Consequently we answered no with high uncertainty since it certainly appears to be likely to occur.
Imp-P5 (Toxic to animals, including livestock/range animals and poultry)	n - low	0	We found no strong or direct evidence that *C. caroliniana* is toxic. While it induces a chemical defense when attacked by either the crayfish *Procambrus clarkii* or the snail *Pomacea canaliculata* (Morrison & Hay, 2011), there is no indication that this defense is toxic to the animals, nor is it indicated in the literature that *C. caroliniana* is toxic or defensive beyond these two targeted predators.
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	a - low	0	We found no evidence that *C. caroliniana* is regarded as a weed in production systems. Alternate answers for the Monte Carlo simulation were both "b."

Question ID	Answer - Uncertainty	Score	Notes (and references)
efforts]			
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 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 - negl	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z5 (Zone 5)	n - high	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z6 (Zone 6)	y - low	N/A	Several points in the United States.
Geo-Z7 (Zone 7)	y - low	N/A	United States. One point each in Germany, Japan, and Sweden.
Geo-Z8 (Zone 8)	y - negl	N/A	A few points each in Australia, Belgium, the Netherlands, and the United States.
Geo-Z9 (Zone 9)	y - negl	N/A	Australia and the United States. Three points in the United Kingdom and 2 points in Japan.
Geo-Z10 (Zone 10)	y - negl	N/A	Australia. Three points in the United States. A few points in Argentina and Paraguay.
Geo-Z11 (Zone 11)	y - low	N/A	One point each in Bolivia, New Zealand, and Taiwan. Two points in Brazil.
Geo-Z12 (Zone 12)	y - low	N/A	Some points in Australia and Mexico. One point in Taiwan.
Geo-Z13 (Zone 13)	y - high	N/A	One point in coastal Colombia and another in Brazil. One point in Australia that is very close to the edge of zone 12.
Köppen -Geiger climate classes			
Geo-C1 (Tropical rainforest)	y - high	N/A	Two points in Australia. Two points near this climate class in Brazil.
Geo-C2 (Tropical savanna)	y - negl	N/A	Some points in Australia and a few in across Bolivia, Brazil, and Paraguay.
Geo-C3 (Steppe)	y - high	N/A	One point in Australia.
Geo-C4 (Desert)	n - high	N/A	We found no evidence that it occurs in this climate class.
Geo-C5 (Mediterranean)	y - negl	N/A	Some points in the United States (GBIF, 2015; Kartesz, 2015).
Geo-C6 (Humid subtropical)	y - negl	N/A	Argentina, Paraguay, and the United States.
Geo-C7 (Marine west coast)	y - negl	N/A	Belgium, Germany, the Netherlands, the United Kingdom.
Geo-C8 (Humid cont. warm sum.)	y - negl	N/A	The United States.
Geo-C9 (Humid cont. cool sum.)	y - low	N/A	The United States. Two points in Sweden.
Geo-C10 (Subarctic)	n - high	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)	n - high	N/A	We found no evidence that it occurs in this precipitation band.
Geo-R2 (10-20 inches; 25-51 cm)	y - high	N/A	One point in Australia.
Geo-R3 (20-30 inches; 51-76 cm)	y - low	N/A	A few points in Bolivia and Paraguay, and three points in Sweden (GBIF, 2015). Three counties in CA (United States;

Question ID	Answer - Uncertainty	Score	Notes (and references)
			Kartesz, 2015).
Geo-R4 (30-40 inches; 76-102 cm)	y - negl	N/A	Belgium, Germany, The Netherlands, and the United Kingdom.
Geo-R5 (40-50 inches; 102-127 cm)	y - negl	N/A	Australia. Some points in Argentina, Paraguay, and the United States.
Geo-R6 (50-60 inches; 127-152 cm)	y - negl	N/A	Australia. Some points in Argentina, Brazil, and the United States.
Geo-R7 (60-70 inches; 152-178 cm)	y - negl	N/A	United States. Two points in the United Kingdom.
Geo-R8 (70-80 inches; 178-203 cm)	y - negl	N/A	Some points in Australia and a few in the United States.
Geo-R9 (80-90 inches; 203-229 cm)	y - low	N/A	Two points each in Australia, Japan, and the United States.
Geo-R10 (90-100 inches; 229-254 cm)	y - mod	N/A	Two points in Japan.
Geo-R11 (100+ inches; 254+ cm)	y - mod	N/A	Two points in Taiwan.
ENTRY POTENTIAL			
Ent-1 (Plant already here)	y - negl	1	This species has native populations in the southern United States and introduced populations in the northern United States (McCracken, Bainard, Miller, & Husband, 2013).
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	-	N/A	

Question ID	Answer - Uncertainty	Score	Notes (and references)
natural dispersal)			