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Version 1

Weed Risk Assessment for *Hydrilla verticillata* (Hydrocharitaceae) – Hydrilla

Top left: *Hydrilla verticillata* growth habit; top right: *H. verticillata* close-up (Leslie J. Mehrhoff, University of Connecticut, Bugwood.org); bottom left: *H. verticillata* turions (Robert Videki, Doronicum Kft., Bugwood.org); bottom right: vertical view of H. verticillata plants (Chris Evans, University of Illinois, Bugwood.org).

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Executive Summary

The result of the weed risk assessment for *Hydrilla verticillata* is High Risk of spreading to new areas and causing a significant impact. *Hydrilla verticillata* is a submerged aquatic herb that is invasive in natural and anthropogenic systems. It is invasive in the United States and present in most states and in Puerto Rico. It is a Federal Noxious Weed and regulated in 23 states, several of which have control programs. Whenever it has been introduced to a new area, it has spread extensively, and it can contaminate shipments of aquatic plants. It forms dense mats on the water surface and can tolerate shade. If cut into fragments, many of the fragments will grow into new plants. Some populations have developed resistance to the herbicide fluridone. It is listed as one of the worst aquatic weeds in the world, and millions of dollars are spent each year to control it in natural systems, canals and reservoirs, and irrigation channels. It blocks sunlight to submerged vegetation and outcompetes native plant species. Several species of fish tend to grow smaller in waters infested by this weed. We estimate that 52 to 94 percent of the United States is suitable for *H. verticillata* to establish. This species is most likely to be spread to new areas as a hitchhiker on boats and fishing gear; however, it did enter California as a contaminant of an aquatic plant shipment.

Plant Information and Background

PLANT SPECIES: *Hydrilla verticillata* (L.f.) Royle (Hydrocharitaceae) (NPGS, 2020).

SYNONYMS: None.

COMMON NAMES: Hydrilla, Florida-elodea, water-thyme (NPGS, 2020).

BOTANICAL DESCRIPTION: *Hydrilla verticillata* is a shallowly-rooted aquatic herb that lives in freshwater habitats from a few inches to 20 feet deep, and tolerates a range of environmental conditions. The leaves grow in whorls at approximately 2-inch intervals along the slender stems and have saw-toothed margins (Ramey, 2001). It produces seed in its native range (Lal and Gopal, 1993), but in the United States, it reproduces only through detached buds called turions and by fragmentation. Turions may be axillary or subterranean, although the subterranean type are often referred to as "tubers" (Ramey, 2001). Both monoecious and dioecious[1] varieties are present in the United States (Ramey, 2001).

INITIATION: *Hydrilla verticillata* is a Federal Noxious Weed and a U.S. invasive plant. We developed this assessment to review and summarize the traits that have made this species a significant invader.

WRA AREA[2]: United States and Territories.

FOREIGN DISTRIBUTION: *Hydrilla verticillata* is native to Asia, Australia, tropical Africa, central to southeastern Europe, and the islands of Madagascar, Reunion, Mauritius, Great Britain, and Ireland (BSBI, 2020; NPGS, 2020). It is naturalized throughout South America and in Mexico, New Zealand, New Caledonia, Fiji, and the Canary Islands (NPGS, 2020). It has been cultivated as an aquarium plant (Ramey, 2001).

U.S. DISTRIBUTION AND STATUS: *Hydrilla verticillata* is naturalized through the United States as far north as Connecticut, on both the Atlantic and Pacific coasts (Ramey, 2001), and in Puerto Rico (Jacono et al., 2020). It is more common in the eastern part of the country (Mullin et al., 2000). The monoecious biotype is most common north of South Carolina, and the dioecious biotype is most common in the southern states (Ramey, 2001) and California (Yeo and McHenry, 1977). While we found no evidence of it being cultivated or offered for sale in the United States (Amazon, 2020; Buce Plant, 2020; Plant Information Online, 2020), it was most likely introduced to Florida in the 1950s as an aquarium plant (Ramey, 2001). It is a Federal Noxious Weed (7 CFR § 360, 2010) and

[1] "Monoecious" means that either both male and female flowers are produced on the same plant or the plant produces bisexual flowers. "Dioecious" means that an individual plant produces either male or female flowers.

[2] The "WRA area" is the area in relation to which the weed risk assessment is conducted (definition modified from that for "PRA area") (IPPC, 2017).

regulated in 23 states (NPB, 2020). State control programs have been active in Florida, North Carolina, Alabama, Georgia, Maryland, Mississippi, Tennessee, and Virginia (Balciunas et al., 2002; Benton, 2018; Cox and Madsen, 2010; Dodson et al., 2015; Fouts et al., 2017; MISC, 2016; Ramey, 2001; Weberg, 2013; WSFA, 2019). California and Washington initiated eradication programs (Lake County, 2020; Mullin et al., 2000), and the species has been eradicated from Washington (Shearer, 2014).

Analysis

ESTABLISHMENT/SPREAD POTENTIAL: *Hydrilla verticillata* is an aquatic weed that has spread extensively upon introduction to new areas (Dodson et al., 2015; Langeland, 1996; Monterroso et al., 2011). Human activity can spread it as a hitchhiker on boats and fishing gear (Ramey, 2001; Sousa, 2011) and as a contaminant of aquatic plants in trade (CABI, 2020), which is how it was introduced to California from Maryland (Maki and Galatowitsch, 2004). It can reproduce vegetatively from both subterranean and axillary turions (Ramey, 2001). These can be produced in large numbers (Sutton et al., 1992), allow for dispersal on water (Madsen and Smith, 1999), and persist for several years (Netherland, 1997; Van and Steward, 1990). The plant tolerates mutilation; a fragment with a single whorl of leaves has a 50 percent chance of developing into a new plant (Langeland, 1996). The plant can grow under deep shade and may form dense mats on the surface of the water (Ramey, 2001). It disperses naturally in water and externally on birds and other animals (Langeland, 1996; Madsen and Smith, 1999; Sousa, 2011) and may also be dispersed internally by birds (Langeland, 1996). We had very low uncertainty for this risk element due to the abundance of information.

Risk score = 24.0 Uncertainty index = 0.05

IMPACT POTENTIAL: *Hydrilla verticillata* is listed as one of the worst aquatic weeds globally (Hofstra and Clayton, 2014), and U.S. managers spend millions of dollars annually to control it in natural systems, canals and reservoirs, and irrigation channels (Manuel et al., 2013; Mullin et al., 2000; Stocker and Hagstom, 1986). It shades and outcompetes native plants, as its dense mats block sunlight to submerged vegetation (Hofstra and Clayton, 2014; Langeland, 1996). Several species of fish grow smaller in waters infested with *H. verticillata* (Colle and Shireman, 1980), and infested waters also have smaller populations of gastropods (Colon-Gaud et al., 2004). It is present in every drainage basin and 43 percent of public lakes in Florida (Langeland, 1996), so it is likely to affect globally significant ecoregions (Ricketts et al., 1999). Boating, swimming, and fishing can become difficult or impossible in infested waters (Ramey, 2001; Yeo et al., 1984). The plant clogs canals, pumping stations, and irrigation channels and affects hydroelectric power generation (Ramey, 2001; Sousa, 2011). During the 1970s, it affected 500 miles of irrigation channels in California (Mullin et al., 2000). We had very low uncertainty for this risk element due to the extensive documentation of the impact of this species.

Risk score = 4.3 Uncertainty index = 0.04

RISK MODEL RESULTS: The risk scores for establishment/spread and impact potential were used to estimate the probabilities of invasiveness and overall risk result.

Model Probabilities: P(Major Invader) = 98.4%
P(Minor Invader) = 1.6%
P(Non-Invader) = 0.0%
Risk Result = High Risk
Risk Result after Secondary Screening = Not Applicable

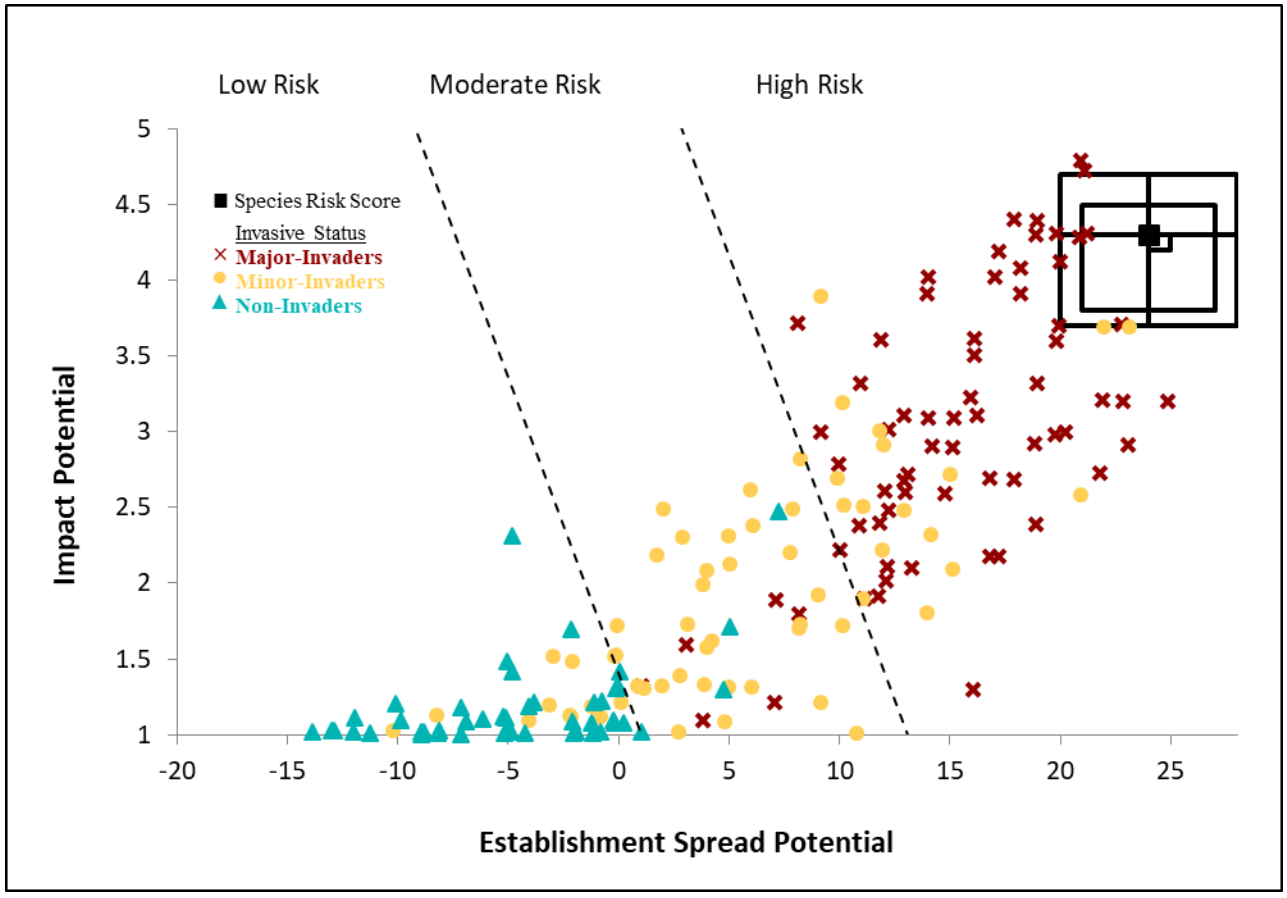

Figure 1. Risk and uncertainty results for *Hydrilla verticillata*. The risk score for this species (solid black symbol) is plotted relative to the risk scores of the species used to develop and validate the PPQ WRA model (Koop et al., 2012). The results from the uncertainty analysis are plotted around the risk score for *H. verticillata*. The smallest black box contains 50 percent of the simulated risk scores, the second is 95 percent, and the largest is 99 percent. The black vertical and horizontal lines in the middle of the boxes represent the medians of the simulated risk scores (N=5000). For additional information on the uncertainty analysis used, see Caton et al. (2018)

GEOGRAPHIC POTENTIAL: Using the PPQ climate-matching model for weeds (Magarey et al., 2017), we estimate that about 52 to 94 percent of the United States is suitable for the establishment of *H. verticillata* (Fig. 2). The larger area represents the joint distribution of Plant Hardiness Zones 2-13, areas with 0-100+ inches of annual precipitation, and the following Köppen-Geiger climate classes: tropical rainforest, tropical savanna, steppe, desert, Mediterranean, humid subtropical, humid continental warm summers, humid continental cool summers, and subarctic: (app. A). The area of the United States shown to be climatically suitable was determined using only these three climatic variables. Other factors, such as soil, hydrology, disturbance regime, and species interactions may alter the areas in which this species is likely to establish. *Hydrilla verticillata* is an aquatic plant and will only grow in water.

ENTRY POTENTIAL: We did not assess the entry potential of *Hydrilla verticillata* because it is already present in the United States (Mullin et al., 2000; Ramey, 2001) (Fig. 2).

Discussion

The result of the weed risk assessment for *Hydrilla verticillata* is High Risk of spreading to new areas and causing a significant impact. The impact and establishment potential of the species are well-documented, so we have very low uncertainty about this result. It is a serious weed in many watersheds in the United States and can easily be spread on boats and fishing equipment (Hofstra and Clayton, 2014; Ramey, 2001). It can grow until it fills a body of water and is a severe threat to native aquatic plants (Hofstra and Clayton, 2014; Ramey, 2001). Control programs spend millions of dollars annually to address these threats (Mullin et al., 2000).

Hydrilla verticillata has monecious and dioecious biotypes, and both are present in the United States (Ramey, 2001). The dioecious type in the United States is closely related to populations in India (Madeira et al., 1997). he monoecious type in the United States was thought to be related to populations in South Korea (Madeira et al., 1997), but more recent work indicates that it is likely a hybrid between Indian and Indonesian types (Benoit, 2011). The dioecious type is found in the southern United States and in California, while the monoecious type is found north of South Carolina (Ramey, 2001; Yeo and McHenry, 1977). Both biotypes were formerly present in Lake Gaston, on the border between North Carolina and Virginia (Langeland, 1996), but the monecious type has apparently displaced the dioecious type there (Richardson, 2020). The dioecious populations in the United States have female flowers only, and the monoecious populations are triploid and cannot produce seed (Benoit, 2011). As a result, the plants only reproduce vegetatively (Yeo and McHenry, 1977).

In the United States, the dioecious type produces turions in response to short days, while the monoecious type produces them year-round in warm climates; however, in temperate climates, it produces them only during warm weather, dying back during winter (Netherland, 1997). Turions produced by either type can be subterranean or axillary. The subterranean turions, often called tubers, are attached to the roots, while the axillary turions are produced in the leaf axils (Ramey, 2001). The U.S. populations also produce more subterranean turions than those in other parts of the world. In Europe and Japan, the dioecious type produces only axillary turions, while the monoecious type in Japan produces only subterranean turions (Netherland, 1997). Because the U.S. populations are triploid, they may be more vigorous and more successful as invaders (Benoit, 2011).

Most management research in the United States has been conducted on the dioecious type. The use of grass carp as a biocontrol and of herbicides are common to both biotypes; however, hydrilla leaf-mining flies cannot be used in areas where the monoecious type dies back in the winter because the flies do not survive without habitat for overwintering (True-Meadows et al., 2016). The monoecious type also produces many more subterranean turions. Consistent annual applications of herbicide can largely eliminate them over a period of years, but missing even one year of application allows a resurgence of up to 85 percent of the original infestation (Nawrocki, 2011).

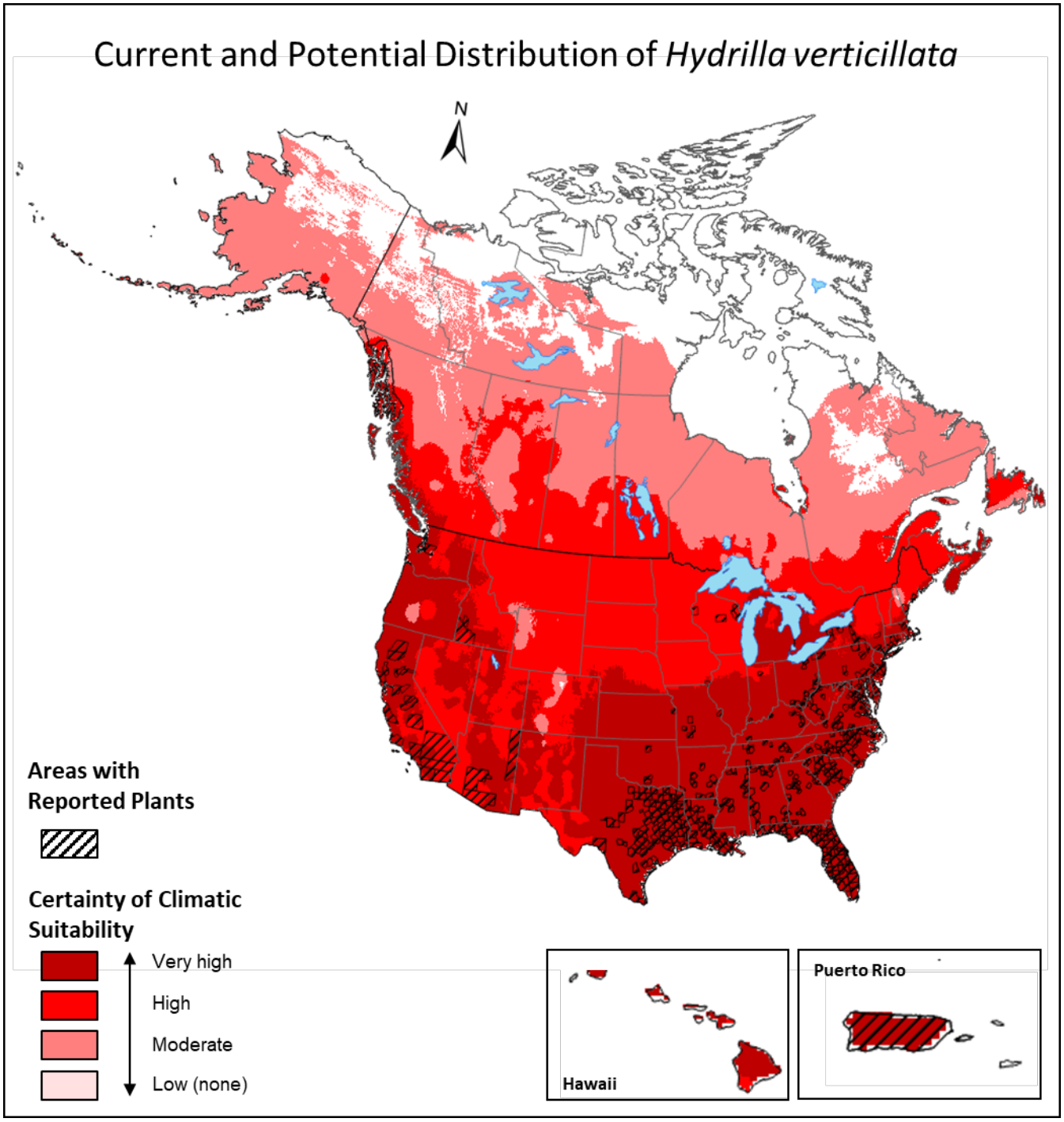

Figure 2. Current and potential distribution of *Hydrilla verticillata* in the United States. Climatic suitability was determined using the APHIS-PPQ climate matching tool for invasive plants (Magarey et al., 2017). The known distribution of *H. verticillata* was based on county distribution records from EddMaps (EDDMapS, 2020) and GBIF

(GBIF Secretariat, 2020). Counties with reported plants were not independently verified and are assumed to represent naturalized occurrences of the species. Map components are shown at different scales.

Suggested Citation

PPQ. 2020. Weed risk assessment for *Hydrilla verticillata* (L.f.) Royle (Hydrocharitaceae) - Hydrilla. United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine (PPQ), Raleigh, NC. 25 pp.

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Appendix A. Weed risk assessment for *Hydrilla verticillata* (L.f.) Royle (Hydrocharitaceae)

The following table includes 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.

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	*Hydrilla verticillata* is believed to be native to Asia, Australia, tropical Africa, Madagascar, Mauritius, Reunion, central to southeastern Europe, and Ireland (NPGS, 2020). It is naturalized in the Canary Islands, New Zealand, Mexico, the United States, Fiji, and New Caledonia and also throughout South America (NPGS, 2020). It was discovered in the United States (Florida) in 1960 and by the 1970s, it was present in every drainage basin in the state (Langeland, 1996). In North Carolina, it has been spreading since the 1980s (Dodson et al., 2015). Similarly, it was observed in a lake in Guatemala in 2000 and by 2002, it was a major weed (Monterroso et al., 2011). Because it has clearly shown the ability to spread in new areas, we answered "f" with negligible uncertainty. Our alternate answers for the uncertainty simulation were both "e."
ES-2 (Is the species highly domesticated)	n - negl	0	It has been sold as an aquarium plant (Ramey, 2001), but it is highly unlikely that it has undergone any domestication.
ES-3 (Significant weedy congeners)	y - high	1	*Hydrilla* is a monotypic genus (Ramey, 2001). According to Zhu et al. (2015) *Vallisneria natans*, *V. spinulosa*, and *Najas marina* are close relatives. *Najas marina* is a fast-growing weed in lakes and reservoirs (Agami et al., 1980; Hoffmann et al., 2013), but we found no evidence that *V. natans* or *V. spinulosa* is weedy. The genus *Elodea* is also closely related to *Hydrilla* (McComas, 2003), and *E. canadensis* (Spicer and Catling, 1988) and *E. nuttallii* (Hoffmann et al., 2013) are weeds. Our uncertainty is high since we do not have actual congeners for comparison.
ES-4 (Shade tolerant at some stage of its life cycle)	y - negl	1	*Hydrilla verticillata* can grow in only one percent of full sunlight (Ramey, 2001). Van et al. (1976) found that it reached a higher rate of photosynthesis at a lower light level than several other aquatic plants.

Question ID	Answer - Uncertainty	Score	Notes (and references)
ES-5 (Plant a vine or scrambling plant, or forms tightly appressed basal rosettes)	n - negl	0	It is an aquatic herb (Ramey, 2001).
ES-6 (Forms dense thickets, patches, or populations)	y - negl	2	It can form dense mats on the water surface (Colle and Shireman, 1980; Ramey, 2001).
ES-7 (Aquatic)	y - negl	1	It is a submersed and rooted aquatic plant (Ramey, 2001).
ES-8 (Grass)	n - negl	0	*Hydrilla verticillata* is not a grass (Poaceae); it is in the family Hydrocharitaceae (NPGS, 2020).
ES-9 (Nitrogen-fixing woody plant)	n - negl	0	We found no evidence that this species fixes nitrogen. Furthermore, it is not a member of a plant family that is known to contain nitrogen fixing species (Santi et al., 2013).
ES-10 (Does it produce viable seeds or spores)	y - low	1	Lal and Gopal (1993) collected viable seed from a monoecious population in India, but other researchers have not observed viable seedlings (Madsen and Smith, 1999; Steward, 1993). The dioecious biotype does not produce seed in the United States because only female plants are present (Madsen and Smith, 1999). Steward (1993) attempted crosses of plants from various populations, both monoecious and dioecious. Most crosses produced viable seed, including those with dioecious female plants from Florida.
ES-11 (Self-compatible or apomictic)	y - low	1	The monoecious biotype is self-compatible (Steward, 1993), although the triploid U.S. populations do not produce viable seed (Benoit, 2011). Each dioecious plant produces flowers of only one sex. Therefore, it cannot be self-compatible.
ES-12 (Requires specialist pollinators)	n - negl	0	The male flowers detach from the plant and release pollen to drift to female flowers in the air or water; no animal pollinators are involved (Cook, 1988; Tanaka et al., 2004).

Question ID	Answer - Uncertainty	Score	Notes (and references)
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	*Hydrilla verticillata* is a perennial in the southern United States, but the plants are dioecious with only female flowers (Ramey, 2001; Yeo and McHenry, 1977) and reproduce from stem fragments, and subterranean and axillary turions. In the northern United States, where the plants are monoecious, the subterranean turions overwinter and sprout in the spring (Ramey, 2001). Researchers in Brazil found a biomass doubling time of 20 days for plants growing from stem fragments and 2.5 to 11 days for plants growing from subterranean turions (Bianchini Jr. et al., 2010). It therefore seems likely that the plant could produce a new generation in a single year. Since a vegetative fragment with a single whorl of leaves is often enough to produce a new plant (Langeland, 1996), repeated fragmentation may produce several new individuals within a year. Therefore our answers for the uncertainty simulation were both "a."
ES-14 (Prolific seed producer)	n - high	-1	A monecious plant grown from a single subterranean turion can produce over 6000 tubers/m^2 (Sutton et al., 1992), though field observations have shown a maximum of 1200/m^2 (Netherland, 1997). Seed production and viability are lower than in many other weeds (Langeland, 1996). We answered "no" with high uncertainty because the threshold of 5000 propagules/m^2 has only been reported from laboratory conditions.
ES-15 (Propagules likely to be dispersed unintentionally by people)	y - negl	1	It spreads mainly as fragments on boats and fishing tackle (Ramey, 2001; Sousa, 2011).
ES-16 (Propagules likely to disperse in trade as contaminants or hitchhikers)	y - negl	2	Shipments of aquatic plants have been found contaminated with *H. verticillata* (CABI, 2020). It has arrived on aquatic plant shipments into Minnesota and was introduced to California in a contaminated shipment of water lilies from Maryland (Maki and Galatowitsch, 2004).

Question ID	Answer - Uncertainty	Score	Notes (and references)
ES-17 (Number of natural dispersal vectors)	3	2	Turions produced in leaf axils are dark green, cylindrical in shape, 0.25 inch long. Subterranean turions are yellowish and resemble potatoes; they are about 0.5 inch in diameter (Ramey, 2001). The fruits are 1.0-1.7 cm long and branch-shaped with tapering ends. The seeds inside are situated in a row; they are 2-3 mm long and are released when the fruit decays (Lal and Gopal, 1993).
ES-17a (Wind dispersal)	n - low		We found no evidence for this dispersal method, and the fruits and seeds have no adaptations for wind dispersal.
ES-17b (Water dispersal)	y - negl		Stem fragments break from the mats and float to new locations (CABI, 2020; Madsen and Smith, 1999; Sousa, 2011). Axillary turions also allow for intermediate-distance dispersal within a body of water (Madsen and Smith, 1999).
ES-17c (Bird dispersal)	y - low		Plants are eaten by waterfowl, which can then spread fragments, and subterranean turions can survive being eaten and regurgitated (Langeland, 1996).
ES-17d (Animal external dispersal)	y - low		Fragments can be carried externally on animals (Sousa, 2011).
ES-17e (Animal internal dispersal)	n - low		We found no evidence for this dispersal method.
ES-18 (Evidence that a persistent (>1yr) propagule bank (seed bank) is formed)	y - low	1	Tubers of monecious *H. verticillata* plants remained viable in sediment for up to four years (Van and Steward, 1990). Turions in the soil allow the population to renew itself after control methods have been applied (Netherland, 1997).
ES-19 (Tolerates/benefits from mutilation, cultivation or fire)	y - negl	1	The use of chopping machines can break the plant into fragments and assist in its dispersal (Ramey, 2001). Madsen and Smith (1999) found that while fragmentation was unlikely to occur naturally, the species responded to fragmentation by developing new plants from the fragments. Fifty percent of fragments with one whorl of leaves are able to sprout and begin new populations (Langeland, 1996). Fragments can settle and re-root, growing into entire new plants (Cornell Cooperative Extension, 2019). *Hydrilla verticillata* also stores carbohydrates in underground roots and tubers, which allows it to re-sprout if the photosynthetic material is cut back (Sousa, 2011).

Question ID	Answer - Uncertainty	Score	Notes (and references)
ES-20 (Is resistant to some herbicides or has the potential to become resistant)	y - negl	1	Some U.S. populations are resistant to fluridone (Benoit et al., 2019; Heap, 2020), including three different biotypes in Florida (Michel et al., 2004). Subterranean turions can survive the application of herbicide (Langeland, 1996).
ES-21 (Number of cold hardiness zones suitable for its survival)	12	1	
ES-22 (Number of climate types suitable for its survival)	10	2	
ES-23 (Number of precipitation bands suitable for its survival)	11	1	
IMPACT POTENTIAL			
General Impacts			
Imp-G1 (Allelopathic)	y - high	0.1	It has shown allelopathy against *Ceratophyllum* spp. in both natural settings and laboratory experiments (Kulshreshtha and Gopal, 1983). We have high uncertainty because we found only one fairly old source for this information.
Imp-G2 (Parasitic)	n - negl	0	*Hydrilla verticillata* is not reported to be parasitic and is not in any of the families known to have parasitic plants (Heide-Jorgensen, 2008).
Impacts to Natural Systems			
Imp-N1 (Changes ecosystem processes and parameters that affect other species)	y - mod	0.4	Dense infestations can alter water chemistry (Canfield Jr. et al., 1983). The process of photosynthesis depletes carbon dioxide from the water and raises the pH during the day. Respiration depletes oxygen and lowers the pH at night (Sousa, 2011). Gordon-Bradley et al. (2015) found that *H. verticillata* altered the bacterial community of the invaded area, which could lead to shifts in nutrient cycling. Barko et al. (1988) found that *H. verticillata* altered the sediment availability of nitrogen and phosphorous. We have moderate uncertainty because some of these effects may be typical of aquatic plants in general.
Imp-N2 (Changes habitat structure)	y - negl	0.2	It can grow until it fills a body of water, eliminating other vegetation layers (Ramey, 2001). By forming dense mats in the upper portion of the water column, it intercepts most of the sunlight and prevents the development of submerged vegetation (Langeland, 1996).

Question ID	Answer - Uncertainty	Score	Notes (and references)
Imp-N3 (Changes species diversity)	y - negl	0.2	It shades and outcompetes important native plants (Colle and Shireman, 1980; Hofstra and Clayton, 2014; Mullin et al., 2000; Ramey, 2001), though Herschner and Havens (2008) indicate that native plants were not eliminated in the Chesapeake Bay despite 40 percent or greater abundance of *H. verticillata* and that waterfowl abundance increased. Several species of fish grow smaller in waters infested with *H. verticillata* (Colle and Shireman, 1980). Colon-Gaud et al. (2004) found a significantly lower number of gastropods in habitat dominated by *H. verticillata* than by the native *Ceratophyllum demersum*. *Hydrilla verticillata* reduces habitat quality for wildlife (Hofstra and Clayton, 2014) and may facilitate the establishment of the invasive mussel *Limnoperna fortunei* (Michelan et al., 2014).
Imp-N4 (Is it likely to affect federal Threatened and Endangered species?)	y - low	0.1	Because *H. verticillata* can prevent the growth of submerged vegetation (Langeland, 1996) and outcompete native plants (Ramey, 2001), and because it has spread into many watersheds, it is likely to affect endangered aquatic plants. It may also threaten the endangered Florida snail kite (*Rostrhamus sociabilis*) by facilitating the growth of the toxic cyanobacterium *Aetokthonos hydrillicola*, allowing for food chain accumulation of the toxin (Dodd et al., 2016).
Imp-N5 (Is it likely to affect any globally outstanding ecoregions?)	y - negl	0.1	It has been discovered in Wakulla Springs, FL, which is listed as a national treasure (Gordon-Bradley et al., 2015). Since it is present in every drainage basin in Florida (Langeland, 1996), it can impact globally significant ecoregions in that state (Ricketts et al., 1999).

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	*Hydrilla verticillata* is considered one of the worst aquatic weeds worldwide (Hofstra and Clayton, 2014). The state of Florida spends millions of dollars each year on control efforts (Ramey, 2001), and eradication programs have been implemented in California and Washington (Mullin et al., 2000). As of 2000, the annual management cost in the United States was $25 million (Mullin et al., 2000). Managers in New Zealand have used mechanical, chemical, and biological control methods (Hofstra and Clayton, 2014). Researchers are investigating species for biocontrol (Bownes, 2018; Purcell et al., 2019) and developing new ways to monitor the species (Kumar et al., 2019). The herbicide endothall is used to control it (Ortiz et al., 2019). Our 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)	y - negl	0.1	It can reduce the capacity of storage ponds (Yeo et al., 1984), and in cooling reservoirs, it disrupts the flow patterns that allow the water to cool (Langeland, 1996). Large mats clog canals and water pumping stations, causing flooding and damage (Langeland, 1996; Ramey, 2001). It affects drinking water supplies and hydroelectric power generation (Kumar et al., 2019; Sousa, 2011). It can harbor mosquito larvae and increase the potential for the spread of mosquito-borne illnesses (Dodson et al., 2015).
Imp-A2 (Changes or limits recreational use of an area)	y - negl	0.1	It interferes with boating, swimming, and fishing (Ramey, 2001; Yeo et al., 1984). Infestations in the Wakulla Springs in Florida have made boating tours impossible and have caused direct economic losses (Gordon-Bradley et al., 2015). Fishing gear can be weighed down by loose masses of *H. verticillata* (Sousa, 2011).
Imp-A3 (Affects desirable and ornamental plants, and vegetation)	y - low	0.1	An online discussion of pond gardens included the comment that *H. verticillata* will take over if introduced (Garden Web, 2009).
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	Mechanical, chemical, and biological methods have been used to control it in canals, reservoirs, and waterways (Center, 1993; Manuel et al., 2013; Sutton, 1996). Our alternate answers for the uncertainty simulation were both "b."

Question ID	Answer - Uncertainty	Score	Notes (and references)
Impact to Production Systems (agriculture, nurseries, forest plantations, orchards, etc.)			
Imp-P1 (Reduces crop/product yield)	n - low	0	We found no evidence of this impact.
Imp-P2 (Lowers commodity value)	n - low	0	We found no evidence of this impact.
Imp-P3 (Is it likely to impact trade?)	y - low	0.2	It is listed as a harmful organism by Chile (PCIT, 2020) and can be a contaminant of aquatic plant commodities (CABI, 2020).
Imp-P4 (Reduces the quality or availability of irrigation, or strongly competes with plants for water)	y - negl	0.1	It can clog irrigation channels and pumps, reducing water flow (Sousa, 2011; Yeo et al., 1984). During the 1970s, it affected 500 miles of irrigation channels in California (Mullin et al., 2000).
Imp-P5 (Toxic to animals, including livestock/range animals and poultry)	n - low	0	*Hydrilla verticillata* can harbor a strain of cyanobacteria that produces a neurotoxin which has been shown to kill waterfowl, bald eagles, and possibly snail kites (Bidigare et al., 2009; Dodd et al., 2016; Wilde et al., 2005; Wiley et al., 2009). It may also affect turtles (Mercurio et al., 2014). Because the cyanobacteria are not consistently associated with the plant, however, and because we found no evidence of the plant itself being toxic, we answered “no.”
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 - low	0.6	It is a weed of rice in southeastern Asia (CABI, 2020). Research has been conducted on the use of grass carp to control it in irrigation channels in California (Stocker and Hagstom, 1986). Our answers for the uncertainty simulation were both "b."
GEOGRAPHIC POTENTIAL			Unless otherwise indicated, the following evidence represents geographically referenced points obtained from the Global Biodiversity Information Facility (GBIF Secretariat, 2020).
Plant hardiness zones			
Geo-Z1 (Zone 1)	n - mod	N/A	2 points in Russia, but we answered “no” because these are close to zone 2 and we found no other evidence of presence in this zone.
Geo-Z2 (Zone 2)	y - mod	N/A	10 points in Russia. Langeland (1996) reports that it has been found as far as 50 degrees north latitude in Poland and Russia. The 50-degree latitude line intercepts Zones 2-5.
Geo-Z3 (Zone 3)	y - low	N/A	12 points in Russia. Langeland (1996) reports that it has been found as far as 50 degrees north latitude in Poland and Russia. The 50-degree latitude line intercepts Zones 2-5.

Question ID	Answer - Uncertainty	Score	Notes (and references)
Geo-Z4 (Zone 4)	y - low	N/A	3 points in Russia, 2 in the United States (Wisconsin). Langeland (1996) reports that it has been found as far as 50 degrees north latitude in Poland and Russia. The 50-degree latitude line intercepts Zones 2-5.
Geo-Z5 (Zone 5)	y - low	N/A	12 points in Latvia, some in the United States (few in Maine close to zone 6, few in Indiana, 3 in Wisconsin). Langeland (1996) reports that it has been found as far as 50 degrees north latitude in Poland and Russia. The 50-degree latitude line intercepts Zones 2-5.
Geo-Z6 (Zone 6)	y - negl	N/A	Many points in the eastern United States, some in South Korea, 4 in China, 1 in Lithuania.
Geo-Z7 (Zone 7)	y - negl	N/A	South Korea, eastern United States, few points in Japan, 7 in China.
Geo-Z8 (Zone 8)	y - negl	N/A	South Korea, eastern United States, some points in Japan, few in China, 4 in Australia.
Geo-Z9 (Zone 9)	y - negl	N/A	South Korea, many points in Australia and on the U.S. Gulf Coast, some in Japan and China.
Geo-Z10 (Zone 10)	y - negl	N/A	Australia, United States (Florida), some points in Japan and Mexico, 3 in India, 2 in China.
Geo-Z11 (Zone 11)	y - negl	N/A	Australia, many points in the United States (Florida), 3 in Thailand, 2 in India and Honduras, 1 in El Salvador.
Geo-Z12 (Zone 12)	y - negl	N/A	Australia, 4 points in Thailand, 3 in Taiwan, 1 in El Salvador.
Geo-Z13 (Zone 13)	y - negl	N/A	Some points in Indonesia, few in Australia, 8 in Panama, 2 in Papua New Guinea, Malaysia, Costa Rica, and the United States (Puerto Rico.
Köppen -Geiger climate classes			
Geo-C1 (Tropical rainforest)	y - negl	N/A	Some points throughout Malesia, in Australia, and in the United States (Florida); few in Central America.
Geo-C2 (Tropical savanna)	y - negl	N/A	Australia, some points in the United States (Florida), few in Central America, 9 in Thailand, 5 in Myanmar, 4 in India.
Geo-C3 (Steppe)	y - negl	N/A	Australia, few points in the United States (5 in Arizona, 2 in California), 9 in Mexico, 2 in South Africa.
Geo-C4 (Desert)	y - low	N/A	Some points in the United States (few in Arizona and southern California) (EDDMapS, 2020; Kartesz, 2015).
Geo-C5 (Mediterranean)	y - negl	N/A	Some points in the United States (California) (EDDMapS, 2020).

Question ID	Answer - Uncertainty	Score	Notes (and references)
Geo-C6 (Humid subtropical)	y - negl	N/A	Australia, southeastern United States, many points in China, some in Japan and South Korea.
Geo-C7 (Marine west coast)	y - negl	N/A	Some points in the United Kingdom, 8 in Australia, 6 in China, 1 in India, Germany, and the United States (Washington).
Geo-C8 (Humid cont. warm sum.)	y - negl	N/A	South Korea, some points in the United States, 12 in Japan.
Geo-C9 (Humid cont. cool sum.)	y - negl	N/A	Some points in Russia and the northern United States, 12 in Latvia, 3 in Poland, 1 in Lithuania and Germany.
Geo-C10 (Subarctic)	y - mod	N/A	11 points in Russia, most within 100 miles of the humid continental cool summer class; 1 point in the United States (Maine) on the edge of the humid continental cool summer class.
Geo-C11 (Tundra)	n - negl	N/A	We found no evidence of presence in this climate class.
Geo-C12 (Icecap)	n - negl	N/A	We found no evidence of presence in this climate class.
10-inch precipitation bands			
Geo-R1 (0-10 inches; 0-25 cm)	y - low	N/A	12 points in the United States (California and Arizona).
Geo-R2 (10-20 inches; 25-51 cm)	y - negl	N/A	Some points in Australia, few in China, 13 in the United States, 7 in Mexico.
Geo-R3 (20-30 inches; 51-76 cm)	y - negl	N/A	Many points in Australia, some in Russia and the United States (some in Texas, 2 in California), few in China, 1 in Italy.
Geo-R4 (30-40 inches; 76-102 cm)	y - negl	N/A	Australia, the United States (Texas), some points in Latvia and the United Kingdom, few in Russia.
Geo-R5 (40-50 inches; 102-127 cm)	y - negl	N/A	South Korea, eastern United States, some points in Australia and the United Kingdom. The species is present in Japan, which generally receives 40-100+ inches of annual precipitation.
Geo-R6 (50-60 inches; 127-152 cm)	y - negl	N/A	South Korea, United States (Florida), some points in the United Kingdom. The species is present throughout Japan, Melanesia, and southeastern Asia, which generally receive 50-100+ inches of annual precipitation.
Geo-R7 (60-70 inches; 152-178 cm)	y - negl	N/A	United States (Florida); few points in Central America, which generally receives 60-100+ inches of annual precipitation; 2 points in South Korea. The species is present throughout Japan, Melanesia, and southeastern Asia, which generally receive 50-100+ inches of annual precipitation.

Question ID	Answer - Uncertainty	Score	Notes (and references)
Geo-R8 (70-80 inches; 178-203 cm)	y - negl	N/A	United States (Florida); few points in Central America, which generally receives 60-100+ inches of annual precipitation. The species is present throughout Japan, Melanesia, and southeastern Asia, which generally receive 50-100+ inches of annual precipitation.
Geo-R9 (80-90 inches; 203-229 cm)	y - negl	N/A	United States (Florida); few points in Central America, which generally receives 60-100+ inches of annual precipitation. The species is present throughout Japan, Melanesia, and southeastern Asia, which generally receive 50-100+ inches of annual precipitation.
Geo-R10 (90-100 inches; 229-254 cm)	y - negl	N/A	Few points in Central America, which generally receives 60-100+ inches of annual precipitation. The species is present throughout Japan, Melanesia, and southeastern Asia, which generally receive 50-100+ inches of annual precipitation.
Geo-R11 (100+ inches; 254+ cm)	y - negl	N/A	Few points in Central America, which generally receives 60-100+ inches of annual precipitation. The species is present throughout Japan, Melanesia, and southeastern Asia, which generally receive 50-100+ inches of annual precipitation.
ENTRY POTENTIAL			
Ent-1 (Plant already here)	y - negl	1	Because *Hydrilla verticillata* is present throughout the United States (Langeland, 1996; Ramey, 2001), we did not evaluate its entry potential.
Ent-2 (Plant proposed for entry, or entry is imminent)	-	N/A	
Ent-3 [Human value & cultivation/trade status: (a) Neither cultivated or positively valued; (b) Not cultivated, but positively valued or potentially beneficial; (c) Cultivated, but no evidence of trade or resale; (d) Commercially cultivated or other evidence of trade or resale]	-	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	

Question ID	Answer - Uncertainty	Score	Notes (and references)
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	