Weed Risk Assessment for *Myriophyllum spicatum* L. (Haloragaceae) – Eurasian watermilfoil

Michigan Department of Agriculture and Rural Development

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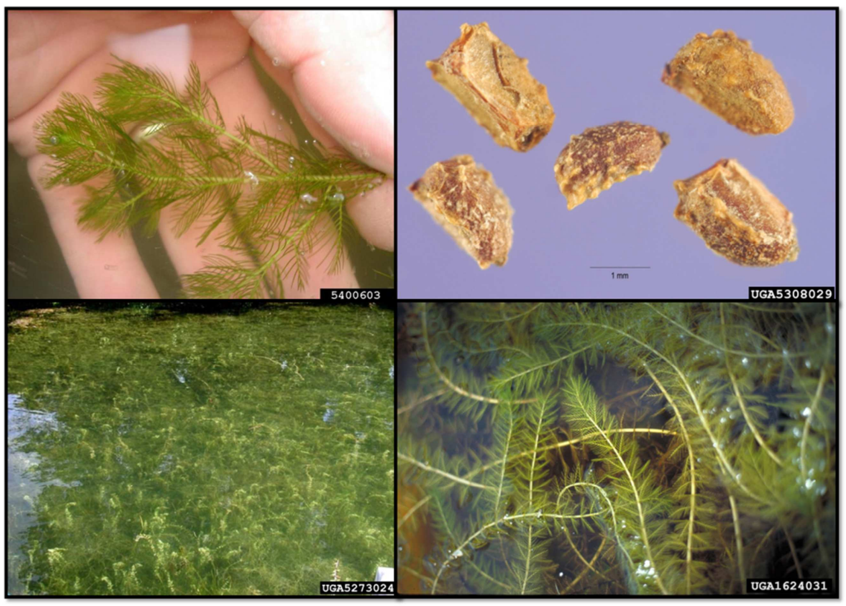
Version 1



Top left: *Myriophyllum spicatum* growth form (source: Graves Lovell, Alabama Department of Conservation and Natural Resources, Bugwood.org). Top right: *Myriophyllum spicatum* seeds (source: Steve Hurst, USDA NRCS PLANTS Database, Bugwood.org). Bottom left: Dense *M. spicatum* growth (source: Leslie J. Mehrhoff, University of Connecticut, Bugwood.org). Bottom right: Entangled *M. spicatum* growth contributes to mat density (source: Alison Fox, University of Florida, 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 list to ensure that the list is 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). At the core of the process is a 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.

	***Myriophyllum spicatum* L. – Eurasian watermilfoil**
Species Information	Family: Haloragaceae (Johnson and Blossey, 2002; Ring et al., 2002; NGRP, 2016). Synonyms: No synonyms were found in the literature search. The Plant List (2015) lists no synonyms for this species. Common names: Eurasian watermilfoil (Eiswerth et al., 2000). Botanical description: *Myriophyllum spicatum* is a submerged perennial with finely dissected leaves (Smith and Barko, 1990). It has a branching leafy shoot, 0.5-7.0 m long, and is found most commonly in water l-3 m deep (Aiken et al., 1979). For a full botanical description, see Ghazanfar (2011). 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 and review this species. Foreign distribution: *Myriophyllum spicatum* is native to Europe, Asia, Northern Africa, and South Africa (White et al., 1993; Johnson and Blossey, 2002; Weyl et al., 2016). It has been introduced to and naturalized in North America, including Canada and Mexico (GBIF, 2015; Ring et al., 2002; NSW Department of Primary Industry, 2014). U.S. distribution and status: *Myriophyllum spicatum* has been present in the United States since the 1940s, and may have been introduced into the Chesapeake Bay area as early as the 1880s (although this may have been a misidentification) (Madsen et al., 1991). An examination of more than 15,000 watermilfoil specimens in 173 herbariums showed that the introduction of Eurasian watermilfoil into North America dates to a Washington, DC pond in 1942 (Engel, 1995). *Myriophyllum spicatum* has naturalized throughout the United States. As of 2003, 45 states in the United States reported the presence of *M. spicatum* (Indiana Department of Natural Resources, 2009). We found no evidence that this species is sold at any level in the United States, nor does it appear to be cultivated to any extent. It was previously sold as a popular aquarium plant. It is now the most widely managed aquatic weed in the United States (Moody and Les, 2007). This species is currently regulated as a state noxious weed in Alabama, Alaska, Colorado, Connecticut, Florida, Idaho, Indiana, Maine, Michigan, Mississippi, Montana, Nebraska, Nevada, New Hampshire, New Mexico, North Carolina, Oregon, South Carolina, South Dakota, Texas, Vermont, and Washington (National Plant Board, 2015). WRA area[1]: Entire United States, including territories.

[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).

1. *Myriophyllum spicatum* analysis

Establishment/Spread Potential *Myriophyllum spicatum* is an aquatic plant that can survive shady conditions; low light conditions stimulate shoot and canopy growth of this species (Smith and Barko, 1990). This species grows vigorously and its populations are dense enough to allow waterfowl to walk over the water surface (Aiken et al., 1979). *Myriophyllum spicatum* produces viable seed (Smith and Barko, 1990; Riemer and Ilnicki, 1968) and it exhibits a typical annual growth pattern (Smith and Barko, 1990; Ring et al., 2002; Johnson and Blossey, 2002). This plant can be spread as a contaminant (Maki and Galatowitsch, 2004) and through human activities (Johnson and Blossey, 2002; New York Invasive Species Information, 2016). Natural methods of dispersal include via water (Southeastern Wisconsin Invasive Species Consortium, Inc., 2016; Invasive Species Council of Manitoba, 2016), birds (Holm et al., 1997; Barrat-Segretain, 1996; DiTomaso and Healy, 2003) and epizoochory (Southeast Exotic Pest Plant Council, 2016). We had average uncertainty for this element.Risk score = 22 Uncertainty index = 0.16

Impact Potential Large stands of *M. spicatum* can lower the temperature of water (Eiswerth et al., 2000) by up to 10 degrees Celsius (Aiken et al., 1979). Plant sloughing and leaf turnover, as well as the decomposition of high biomass at the end of the growing season, increase the concentration of phosphorus and nitrogen in the water column (Madsen et al., 1991; Eiswerth et al., 2000). In Lake Opinicon, Ontario, *M. spicatum* invaded areas which had for the most part been unvegetated (Smith and Barko, 1990). Madsen et al. (1991) found that in Lake George, NY, *M. spicatum* increased from 15% of the plant community to 95% within two years, and reduced dense-rooted, submerged plant beds to just a few stems under a dense canopy of *M. spicatum*. *Myriophyllum spicatum* creates a human safety issue because its long stems entangle swimmers (White et al., 1993). In Canada, this plant clogs power generation water intakes (Ring et al., 2002) and drinking water supply systems, and it affects flow metering devices used in flood control (Aiken et al., 1979). It also clogs agricultural and industrial water intakes (Ring et al., 2002) and impacts irrigation by clogging dam trash racks and intake pipes (Washington Department of Ecology, 2016). We had average uncertainty for this risk element.
Risk score = 4.7 Uncertainty index = 0.14

Geographic Potential Based on three climatic variables, we estimate that about 92 percent of the United States is suitable for the establishment of *M. spicatum* (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 *M. spicatum* represents the joint distribution of Plant Hardiness Zones 3-11, areas with 0-100+ inches of annual precipitation, and the following Köppen-Geiger climate classes: steppe, desert, Mediterranean, humid subtropical, marine west coast, humid continental warm summers, humid continental cool summers, and subarctic.

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. *Myriophyllum spicatum* has been observed in waters as deep as 8 m; it prefers eutrophic conditions, but can survive in oligotrophic areas (Aiken et al., 1979).

Entry Potential We did not assess the entry potential of *M. spicatum* because it is already present in the United States (Madsen et al., 1991; Engel, 1995).

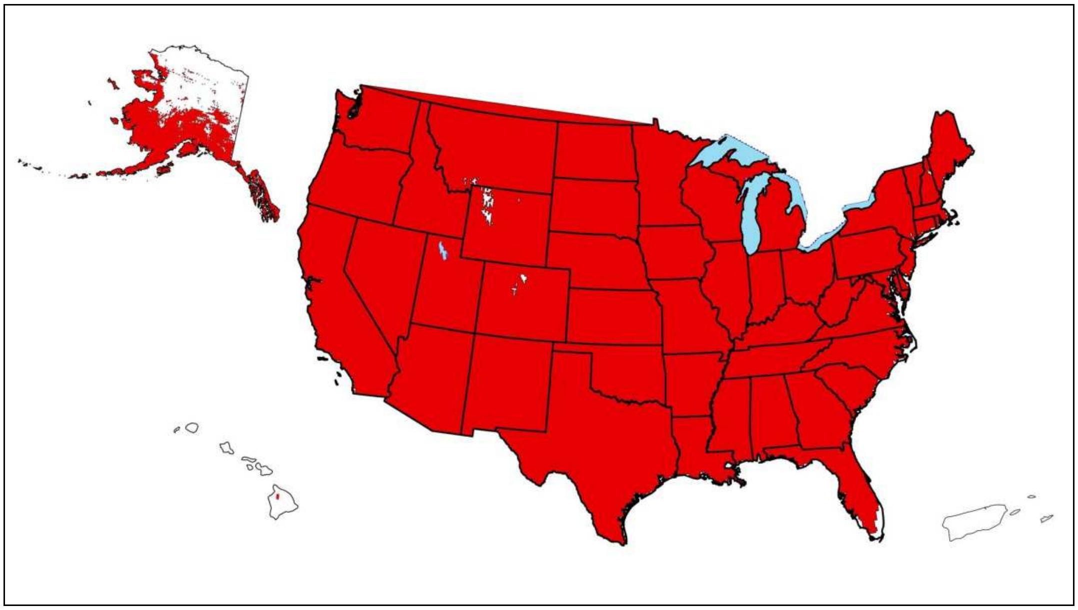

Figure 1. Predicted distribution of *M. spicatum* in the United States. Map insets for Alaska, Hawaii, and Puerto Rico are not to scale.

2. Results

Model Probabilities: P(Major Invader) = 98%
P(Minor Invader) = 2%
P(Non-Invader) = 0%

Risk Result = High Risk

Secondary Screening = Not applicable

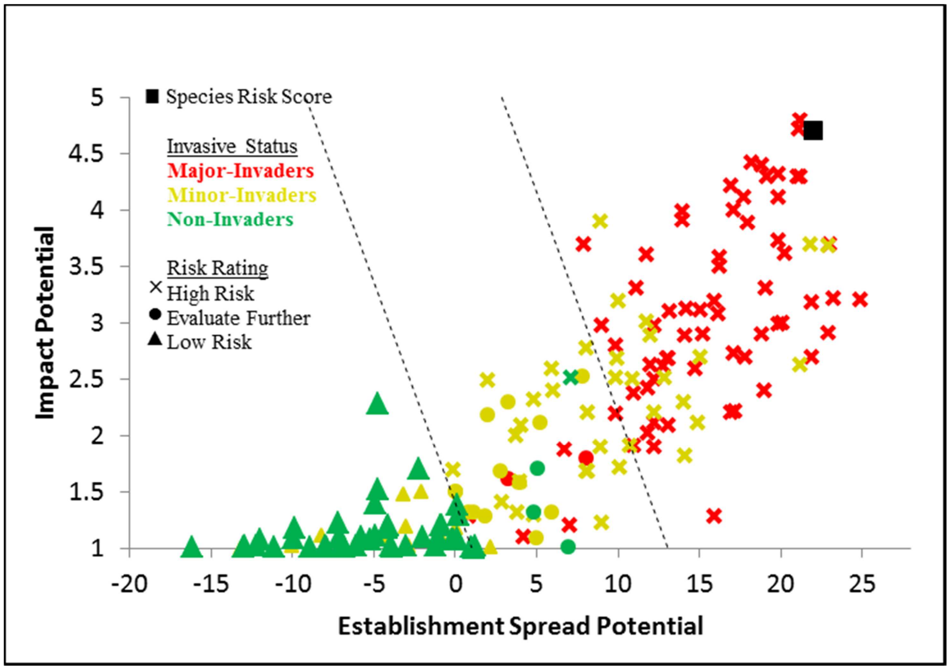

Figure 2. *Myriophyllum spicatum* risk score (black box) relative to the risk scores of species used to develop and validate the PPQ WRA model (other symbols). See Appendix A for the complete assessment.

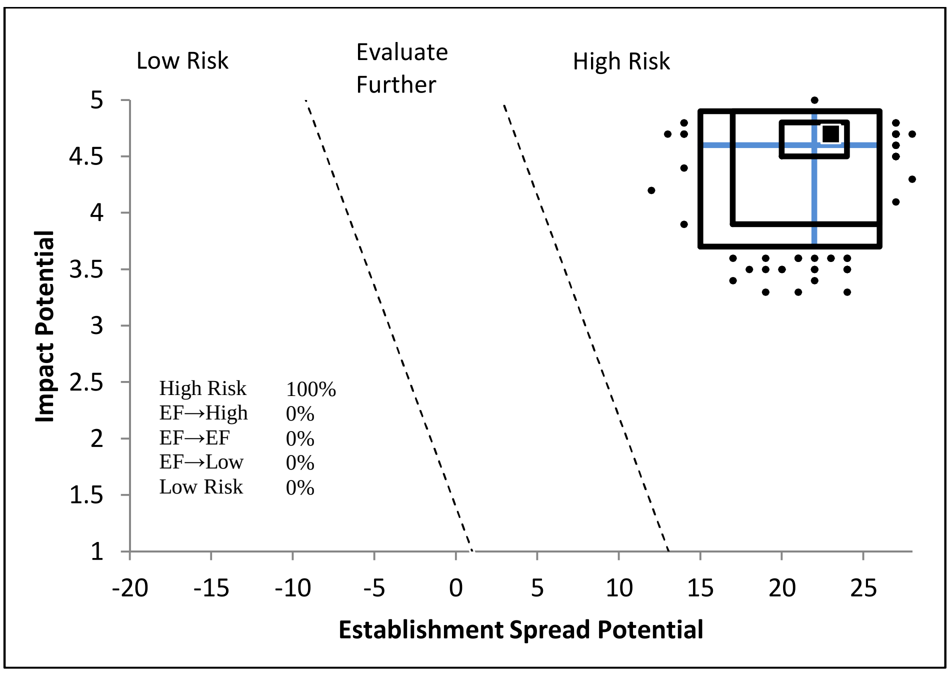

Figure 3. Model simulation results (N=5,000) for uncertainty around the risk score for *M. spicatum*. The blue "+" symbol represents the medians of the simulated outcomes. The smallest box contains 50 percent of the outcomes, the second 95 percent, and the largest 99 percent.

3. Discussion

The result of the weed risk assessment for *M. spicatum* is High Risk. When compared with the species of known weeds used to validate the WRA model, this species ranked amongst other High Risk weeds (Fig. 2). *Myriophyllum spicatum* was one of the species used to validate the WRA model, and our results here are consistent with the original results. Our categorization of "High Risk" is well supported by the uncertainty analysis (Fig. 3). *Myriophyllum spicatum* continues to be the most important waterweed in the continental United States with millions of dollars spent nationwide for control efforts. Stagnant water created by Eurasian watermilfoil mats provides good breeding grounds for mosquitoes. In New York state alone, annual control costs are estimated at US$500,000 (Johnson and Blossey, 2002). In Shuswap Lake in 1985, 38.8 ha were treated at a cost of Can$4500/ha, and in Cultus Lake in 1985, 4.7 ha were treated at Can$4000/ha (Ring et al., 2002). In Washington, private and government sources spend about US$1,000,000 per year on Eurasian watermilfoil control (Washington Department of Ecology, 2016). A control program for *M. spicatum* was initiated in British Columbia in the 1970s; control measures used were primarily manual/mechanical and were initiated when plants had spread to eight lakes in the Okanagan Valley. The program cost over $6 million between 1972 and 1990 (Ference Weicker & Company, 1991) and is still ongoing with additional operating costs of over US$4 million between 1990 and 2001 (Wilson et al., 2007).

Myriophyllum spicatum is known to hybridize with the native *M. sibiricum* in the northern United States (Moody and Les, 2007), further compounding the difficulty of management strategies for this species. Plant hybridization has been linked to aggressive and invasive traits in plants, and can produce novel phenotypes with ecological tolerances that differ from those of the parents (Moody and Les, 2007); these hybrid watermilfoil populations could be better suited to the northern United States and are more competitive than *M. spicatum* stands (LaRue et al., 2013). The hybrid watermilfoil is capable of reproducing both vegetatively and sexually (LaRue et al., 2013). LaRue et al. (2013) demonstrated that several populations of hybrid watermilfoil in Michigan produced seed that successfully germinated under laboratory conditions. These hybrids are difficult to manage, as herbivory of hybrid populations is altered, biocontrol may be less effective (Moody and Les, 2007), and they exhibit tolerance to several popular aquatic herbicides (Berger et al., 2015). Further research is necessary to determine the best method of management for these hybrid watermilfoil populations. We address here the issue of hybrid watermilfoil to alerate managers and policy makers to a major concern with *M. spicatum* outside of its own biological traits.

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Appendix A. Weed risk assessment for *Myriophyllum spicatum* L. (Haloragaceae). 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	*Myriophyllum spicatum* is native to Europe, Asia, and Northern Africa (White et al., 1993; Johnson and Blossey, 2002). There has been some confusion regarding the native status of *M. spicatum* within South Africa; Weyl et al. (2016) have shown through genetic testing and comparison that the South African population is genetically distinct from the European population, and therefore *M. spicatum* is native to South Africa as well (Weyl et al., 2016). *Myriophyllum spicatum* has been introduced to Canada (GBIF, 2015; Ring et al., 2002; NSW Department of Primary Industry, 2014), the United States (GBIF, 2015; NSW Department of Primary Industry, 2014; White et al., 1993), and Mexico (GBIF, 2015). As of 2003, 45 states in the United States reported the presence of *M. spicatum* (Indiana Department of Natural Resources, 2009). *Myriophyllum spicatum* has now spread to every state except Montana, Wyomin, and Kansas (Kartesz, 2015). *Myriophyllum spicatum* was first reported in Minnesota in 1987, and now occupies over 120 water bodies throughout the state (Minnesota Sea Grant, 2004). It was first reported in the state of Washington in 1965, and by the mid-1970s *M. spicatum* became established in central British Columbia and had traveled downstream to Lake Osoyoos and the Okanogan River in central Washington (Washington Department of Ecology, 2016). It is now found in the Columbia, Okanogan, Snake, and Pend Oreille Rivers and in many nearby lakes (Washington Department of Ecology, 2016). Of the approximately 616 lakes and reservoirs in the northern one-third of Indiana, Eurasian watermilfoil infested at least 175 of them as of the late 1990's. Throughout Indiana, approximately 126,000 acres of lakes and impoundments contain some level of Eurasian watermilfoil (Indiana Department of Natural Resources, 2009). In Currituck Sound in North Carolina, *M. spicatum* was first discovered in 1965 when about 40 ha were heavily infested and 200 to 400 ha were lightly infested. One year later, 3,200 ha were heavily infested at this location, and nine years later, more than 32,000 ha were infested (Eiswerth et al., 2000). The rapid spread of Eurasian watermilfoil has been documented at a number of sites in several other states (Eiswerth et al., 2000). Alternate answers for the Monte Carlo simulation are both "e".
ES-2 (Is the species highly domesticated)	n - low	0	We found no evidence that this species is highly domesticated or has been bred to reduce traits associated with weed potential.
ES-3 (Weedy congeners)	y - negl	1	The genus *Myriophyllum* contains 68 species (Moody & Les, 2010). Randall (2012) lists several species as environmental

Question ID	Answer - Uncertainty	Score	Notes (and references)
			weeds (i.e. *Myriophyllum papillosum*, *M. propinquum*, *M. quitense*, *M. exalbescen*, and *M. verrucosum*). Among the most serious weeds in this genus are *M. aquaticum* and *M. heterophyllum*. *Myriophyllum aquaticum* is native to South America and is "the dominant invasive species in Europe" (Sheppard et al., 2005). It is a problem across all systems, as it forms dense monotypic mats (Smith, 2008; Orr & Resh, 1989) that can entirely cover the surface of the water in shallow lakes and other waterways, shading the water column below (Bossard et al., 2000), preventing boating, swimming, and other activities (Kelly & Maguire, 2009; Bossard et al., 2000), and clogging irrigation canals (Haberland, 2014). *Myriophyllum heterophyllum* is native in the southeastern United States, but is considered invasive in the northern United States (Thum et al., 2012) and is considered a serious environmental weed (Brunel et al., 2010; Bohren et al., 2011; EPPO, 2012).
ES-4 (Shade tolerant at some stage of its life cycle)	y - negl	1	Low light conditions stimulate shoot and canopy growth (Smith and Barko, 1990). Seeds exposed to dark treatments showed an average of 40% germination. It has been shown before that some seeds of *M. spicatum* will germinate in the dark, regardless of light treatment, given the proper temperature and pretreatment conditions (Hartleb et al., 1993). High shade conditions produce little stress response, with no significant change in length per plant or biomass (Abernathy et al., 1996).
ES-5 (Plant a vine or scrambling plant, or forms tightly appressed basal rosettes)	n - negl	0	This species is neither a vine nor forms tightly appressed basal rosettes; *M. spicatum* is an aquatic herb (Johnson and Blossey, 2002).
ES-6 (Forms dense thickets, patches, or populations)	y - negl	2	*Myriophyllum spicatum* grows and spreads rapidly, creating dense mats on the water surface (Bossard et al., 2000). Vigorous growth forms dense thickets that are so thick waterfowl can walk over the water surface (Aiken et al., 1979), and its dense growth contributes to human drowning issues (Ring et al., 2002).
ES-7 (Aquatic)	y - negl	1	All Haloragaceae species are herbs submersed in quiet waters or rooted on muddy shores (Johnson and Blossey, 2002). *Myriophyllum spicatum* is a submersed aquatic plant (Bossard, 2000). Submerged macrophyte (Xiao et al., 2010).
ES-8 (Grass)	n - negl	0	This plant is a member of the family Haloragaceae (Johnson and Blossey, 2002; Ring et al., 2002; NGRP, 2016) and is therefore not a grass.
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; Ring et al., 2002; NGRP, 2016). *Myriophyllum spicatum* is an aquatic herb (Johnson and Blossey, 2002).
ES-10 (Does it produce viable seeds or spores)	y - negl	1	*Myriophyllum spicatum* produces viable seed (Smith and Barko, 1990; Riemer and Ilnicki, 1968). Seeds require a temperature higher than 10 °C before they begin to show significant germination rates (Hartleb et al., 1993). Germination percentage of *M. spicatum* was 71.3% at 0 cm burial depth, but decreases to 5.0% and to 2.5% at depths of

Question ID	Answer - Uncertainty	Score	Notes (and references)
			1 cm and 2 cm, respectively (Xiao et al., 2010).
ES-11 (Self-compatible or apomictic)	? - max	0	We were unable to find any information regarding self-compatibility for *M. spicatum*. Stigmas on individual flowers ripen well before the stamens, favoring cross-pollination (Aiken et al., 1979).
ES-12 (Requires specialist pollinators)	n - negl	0	Pollination is likely via wind, but some insect pollination does occur (Holm et al., 1997). Flowers generally are wind-pollinated (Bossard, 2000).
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 - negl	1	*Myriophyllum spicatum* exhibits a typical annual growth pattern. (Smith and Barko, 1990). Plants overwinter rooted in the sediment and grow rapidly once favorable temperatures are reached (Johnson and Blossey, 2002). Shoots grow from root crowns early in spring and summer (Ring et al., 2002). When shoots reach the water's surface, they branch profusely and may flower. After this period of surface growth and/or flowering, stems naturally fragment (Smith and Barko, 1990). These fragments settle in sediments, producing new plants (Bossard, 2000). Depending on how long it takes for populations to reach the surface of the water and go through the branching/fragmentation process, a second period of branching/fragmentation may occur (Smith and Barko, 1990). Roots occur on both lower (buried) and upper portions of stems (which fragment after reaching the water's surface) (Smith and Barko, 1990). Alternate answers for the Monte Carlo simulation are both "a", as it seems more likely that rooted fragments may grow and re-fragment within one growing season, than the species not fragmenting and spreading for 2 to 3 years.
ES-14 (Prolific seed producer)	y - mod	1	Reports of total seed set vary within the literature: Aiken et al. (1979) report that flowering spikes produce 12-40 seeds under favorable conditions, while Hartleb et al. (1993) report that the total possible seed set is 112 seeds per stalk. *Myriophyllum spicatum* stem densities can exceed 300/m^2 in shallow water (New York Invasive Species Information, 2016). Without more information regarding seed set per flower, we are assuming that each stem sets seed, and germination is 71% per observations by Xiao et al. (2010). Given this information, seed production would be between 2,556 and 23,856/m^2.
ES-15 (Propagules likely to be dispersed unintentionally by people)	y - low	1	Human activities, such as motor boating and mechanical weed harvesting, produce and distribute stem fragments, increasing propagation (Johnson and Blossey, 2002; New York Invasive Species Information, 2016). Vegetative propagules adhere to boats and can contaminate fish bait (Holm et al., 1997).
ES-16 (Propagules likely to disperse in trade as contaminants or hitchhikers)	y - high	2	*Myriophyllum spicatum* was previously used for packing material for earthworms in some areas (Holm et al., 1997). Species of *Myriophyllum* often contaminate shipments of ornamental aquatic plants (Maki and Galatowitsch, 2004). *Myriophyllum* species are very similar in foliage and may be difficult to differentiate (Aiken, 1981), and so it is possible for species to be misidentified and/or mislabeled. We are answering yes, with high uncertainty, because although we

Question ID	Answer - Uncertainty	Score	Notes (and references)
			were unable to find direct evidence of contamination by this species, the genus is a known contaminant. The difficulty in identifying this species may contribute to the lack of direct evidence of contamination.
ES-17 (Number of natural dispersal vectors)	3	2	Fruit and seed information used for ES-17a through ES-17e: Each female flower produces four small, nutlike fruits (2 to 3 mm) (Johnson and Blossey, 2002). Fruit is a hard, segmented capsule containing four seeds (National Park Service, 2010). The seed is a "trigonal nutlet" 2.2x1.5 mm with a "smooth epicarp and mesocarp and a hard endocarp", having two flat sides and an outer convex side (Wani and Arshid, 2013).
ES-17a (Wind dispersal)	n - mod		We found no evidence of wind dispersal of propagules, and this method of propagule dispersal is uncommon in aquatic plants (Barrat-Segretain, 1996).
ES-17b (Water dispersal)	y - negl		Plant fragments break off and are carried by water to new locations (Southeastern Wisconsin Invasive Species Consortium, Inc., 2016). Fruit can also float for long distances in water (Holm et al., 1997). Plant fragments grow roots, stems and leaves as they float (Invasive Species Council of Manitoba, 2016).
ES-17c (Bird dispersal)	y - negl		Vegetative plant fragments adhere to feet and feathers of birds, and seeds are also consumed and dispersed by birds (Holm et al., 1997; Barrat-Segretain, 1996). Seeds are consumed by waterfowl and may disperse great distances with migrating birds (DiTomaso and Healy, 2003).
ES-17d (Animal external dispersal)	y - high		Plant fragments can attach to objects in the water such as animals and be moved from one body of water to another (Southeast Exotic Pest Plant Council, 2016). As it seems likely that fragments can be dispersed via external dispersal, we are answering yes, with high uncertainty.
ES-17e (Animal internal dispersal)	n - mod		We found no evidence that this species is dispersed internally by animals.
ES-18 (Evidence that a persistent (>1yr) propagule bank (seed bank) is formed)	y - low	0	*Myriophyllum spicatum* produces some long-viable, often dormant seed (Bossard, 2000); seeds exhibit delayed germination and can remain dormant for several years (Patten, 1955). *Myriophyllum spicatum* has a strong potential to develop a large seed bank (Hartleb et al., 1993).
ES-19 (Tolerates/benefits from mutilation, cultivation or fire)	y - negl	1	*Myriophyllum spicatum* responds positively to disturbances like mechanical harvesting and cutting (Abernathy et al., 1996; Smith and Barko, 1990). Cutting plants allows fragments to float away and then colonize new areas (Holm et al., 1997).
ES-20 (Is resistant to some herbicides or has the potential to become resistant)	n - low		We found no evidence this species is resistant to herbicides. Furthermore, it is not listed by Heap (2013) as resistant. Diquat and 2,4,D butoxyethenol ester, 20 percent attaclay are non-selective herbicides that are effective at controlling *M. spicatum*. Fluridone may also be effective (Bossard, 2000).
ES-21 (Number of cold hardiness zones suitable for its survival)	9	0	
ES-22 (Number of climate types suitable for its survival)	7	2	
ES-23 (Number of precipitation	11	1	

Question ID	Answer - Uncertainty	Score	Notes (and references)
bands suitable for its survival)			
IMPACT POTENTIAL			
General Impacts			
Imp-G1 (Allelopathic)	? - max		A culture solution of *M. spicatum* released four polyphenols that inhibited growth of algae (Nakai et al., 2000). *Myriophyllum spicatum* tissue is known to contain algae-inhibiting polyphenols; however, field tests have been inconclusive as to how quickly these allelochemicals metabolize when released, and therefore, their effectiveness (Gross, 2003). Therefore, we are answering unknown.
Imp-G2 (Parasitic)	n - negl	0	We found no evidence that this species is parasitic. Furthermore, *M. spicatum* does not belong to a family known to contain parasitic plants (Heide-Jorgensen, 2008; NGRP, 2016).
Impacts to Natural Systems			
Imp-N1 (Changes ecosystem processes and parameters that affect other species)	y - negl	0.4	Large stands of *M. spicatum* can lower the temperature of water (Eiswerth et al., 2000) by up to 10 degrees Celsius (Aiken et al., 1979). Plant sloughing and leaf turnover, as well as the decomposition of high biomass at the end of the growing season, increase the concentration of phosphorus and nitrogen in the water column (Madsen et al., 1991; Eiswerth et al., 2000). Dense mats alter water quality by raising pH, decreasing oxygen under the mats, and increasing temperature (Washington Department of Ecology, 2016; Eiswerth et al., 2000). These dense mats also inhibit water circulation, reduce levels of dissolved oxygen, and enable nutrients to accumulate in the water column (Minnesota Sea Grant, 2004).
Imp-N2 (Changes habitat structure)	y - negl	0.2	In Canada, *M. spicatum* increases the density of plant communities by growing so thickly that waterfowl can walk over the water surface (Aiken et al., 1979). In Lake Opinicon, Ontario, *M. spicatum* invaded areas which had for the most part been unvegetated (Smith and Barko, 1990). Madsen et al. (1991) found that in Lake George, NY, *M. spicatum* increased from 15% of the plant community to 95% within two years, and reduced dense-rooted, submerged plant beds to just a few stems under a dense canopy of *M. spicatum*.
Imp-N3 (Changes species diversity)	y - negl	0.2	In Canada *M. spicatum* outcompetes and shades out other native aquatic plant species, and can completely displace entire plant communities within 2-3 years (Aiken et al., 1979) Eurasian watermilfoil beds contain significantly fewer macroinvertebrates than native macrophyte communities (including benthic invertebrates) and have a reduced abundance of native fish species (Johnson and Blossey, 2002). The negative effect of *M. spicatum* on salmonids is much greater than for other species, because the plant reduces spawning success by covering spawning gravels (Smith and Barko, 1990). Madsen et al. (1995) found the *M. spicatum* dominance significantly decreases plant diversity, and in the study location, *M. spicatum* reduced the number of native plant species from 5.5 to 2.2 species per 3 m2 quadrat in the span of 2 years.
Imp-N4 (Is it likely to affect	y - low	0.1	In Canada, *M. spicatum* outcompetes *Potamogeton* species

Question ID	Answer - Uncertainty	Score	Notes (and references)
federal Threatened and Endangered species?)			(Aiken et al., 1979), so *M. spicatum* could pose a threat to the endangered *Potamogeton clystocarpus* and other endangered aquatic species that occur in the United States (USFWS, 2015). Given the impacts discussed in Imp-N1-N3, we expect that *M. spicatum* will shade out T&E species and alter ecosystems in a way that will make them uninhabitable for T&E species.
Imp-N5 (Is it likely to affect any globally outstanding ecoregions?)	y - negl	0.1	*Myriophyllum spicatum* is already present in counties in Alabama, Arizona, California, Florida, Mississippi, Oregon, and Washington (Kartesz, 2015) that are designated as globally outstanding ecoregions (Ricketts et al., 1999). As reviewed under Imp-N1 and Imp-N3, *M. spicatum* negatively impacts ecosystems processes, habitat structure, and species diversity. Therefore, we are answering yes.
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	*Myriophyllum spicatum* is considered one of the worst weeds in Ohio natural areas by the Ohio Invasive Plant Council (OIPC, 2016). The Minnesota Department of Natural Resources (DNR) Invasive Species Program includes a specific program to curb the spread and manage the growth of Eurasian watermilfoil, specifically targeting protection of natural areas and native species (Minnesota Department of Natural Resources, 2016). The Minnesota DNR has spent approximately $120,000 for maintenance management of Eurasian watermilfoil in 1999 (Minnesota Sea Grant, 2004). While mechanical harvesting is not practical in managing this species, water drawdowns, biological control, and herbicides can be utilized to manage *M. spicatum* populations in natural areas (DiTomaso et al., 2013). Alternate answers for the Monte Carlo simulation are both "b".
Impact to Anthropogenic Systems (cities, suburbs, roadways)			
Imp-A1 (Negatively impacts personal property, human safety, or public infrastructure)	y - negl	0.1	*Myriophyllum spicatum* creates a human safety issue as its long stems entangle swimmers (White et al., 1993). In Canada this plant clogs power generation water intakes (Ring et al., 2002) and drinking water supply systems, and it affects flow metering devices used in flood control (Aiken et al., 1979). A 10% reduction in values of lakefront property due to heavy weed infestation amounts to a loss in value of at least Can$3.7 million for the entire Okanagan basin (Ring et al., 2002). *Myriophyllum spicatum* increases boat repair and maintenance costs; one boat owner in Vermont spent US$800 repairing his boat when the motor intake became clogged with *M. spicatum* (Minnesota Sea Grant, 2004).
Imp-A2 (Changes or limits recreational use of an area)	y - negl	0.1	*Myriophyllum spicatum* interferes with recreational activities such as swimming, boating, fishing and water skiing (Washington Department of Ecology, 2016). Large pieces of *M. spicatum* can wash onto beaches after storms, and this decaying plant matter reduces the quality of beaches. Dense thickets of the plant can also limit recreational boat activity and swimming in lakes and ponds (Aiken et al., 1979) In some areas motorboats, sailboats with keels, and water skiing were curtailed until *M. spicatum* was removed or controlled. Shore-based angling was also adversely affected (Ring et al., 2002).

Question ID	Answer - Uncertainty	Score	Notes (and references)
Imp-A3 (Affects desirable and ornamental plants, and vegetation)	n - mod	0	We found no evidence that this species affects ornamental plants and vegetation. We are using moderate uncertainty as its biology is such that it is likely to affect these plants if introduced into an ornamental setting.
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	Because *M. spicatum* seems to prefer habitats frequented by humans, or areas modified for public use, it is often perceived as a major threat to water use (Ring et al., 2002). Localized control (in swimming areas and around docks) can be achieved by covering the sediment with an opaque fabric which blocks light from the plants, like bottom barriers or screens (Washington Department of Ecology, 2016). The Tennessee Valley Authority tested control methods within its reservoirs to determine the efficacy of treatments, and determined that water drawdowns and the herbicide butoxyethanol ester of 2,4-D in 20% granular form were the most effective methods of treatment (Smith et al., 1967). Managers of reservoirs and some lake systems may have the ability to lower the water level as a method of managing aquatic plants (Washington Department of Ecology, 2016). To deal with this invasive weed in the vicinity of the Tahoe Keys marina, an association of property owners has purchased two mechanical harvesters that cost approximately $75,000 apiece. In addition to these capital costs, the association spent $75,000 in operating costs in 1998 to harvest *M. spicatum* (Eiswerth et al., 2000). Alternate answers for the Monte Carlo simulation are both "b".
Impact to Production Systems (agriculture, nurseries, forest plantations, orchards, etc.)			
Imp-P1 (Reduces crop/product yield)	y - mod	0.4	*Myriophyllum spicatum* competes with rice in China, the Philippines, and Portugal (Holm et al., 1997). Mid-lake trawlers encounter mats of floating milfoil that entangle their fishing lines (Ring et al., 2002), and this may reduce catch. Commercial fishing also becomes impossible in areas infested with *M. spicatum* (Gangstad, 1992). Its typically dense growth habit make *M. spicatum* beds poor spawning areas for fish and may lead to populations of small-sized specimens, and reduces expansion and vigor of warm-water fisheries (Getsinger et al., 2005). We are using moderate uncertainty here because we did not have direct, quantitative evidence of reduced yield.
Imp-P2 (Lowers commodity value)	y - mod	0.2	*Myriophyllum spicatum* decreases the profitability of agricultural production by clogging ditches, canals, farm ponds, and irrigation equipment used in agriculture. Such negative effects on irrigation have occurred, for example, in eastern Washington (Eiswerth et al., 2000). This in turn can impose additional costs on producers to control the weed, keep waterways clear and flowing, provide clean, functional equipment, and ensure weed-free products for sale (Eiswerth et al., 2000).
Imp-P3 (Is it likely to impact trade?)	y - high	0.2	Australia and Nauru require phytosanitary certificates declaring trade shipments to be free of *M. spicatum* (APHIS, 2016), and *M. spicatum* is banned from import in Canada (Aiken et al., 1979). This species is also regulated in trade by Alabama, Alaska, Colorado, Connecticut, Florida, Idaho,

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			Illinois, Indiana, Maine, Michigan, Mississippi, Montana, Nebraska, Nevada, New Hampshire, New Mexico, North Carolina, Oregon, South Carolina, South Dakota, Texas, Vermont, Washington, and Wisconsin (National Plant Board, 2016). Species of *Myriophyllum* can be dispersed as contaminants through the aquarium trade (Maki and Galatowitsch, 2004), and species are difficult to differentiate (Aiken, 1981). Although the genus *Myriophyllum* has been reported to be a trade contaminant (Maki and Galatowitsch, 2004) we did not have direct evidence of this species being a contaminant. Thus, we used high uncertainty.
Imp-P4 (Reduces the quality or availability of irrigation, or strongly competes with plants for water)	y - negl	0.1	*Myriophyllum spicatum* blocks irrigation systems in Saudi Arabia (Holm et al., 1997) and limits the use of irrigation canals in Yugoslavia (Gangstad, 1992). It clogs agricultural and industrial water intakes (Ring et al., 2002) and impacts irrigation by clogging dam trash racks and intake pipes (Washington Department of Ecology, 2016).
Imp-P5 (Toxic to animals, including livestock/range animals and poultry)	n - low	0	We found no evidence that this species is toxic. This species is well-studied, so we are using low uncertainty.
Imp-P6 [What is the taxon's weed status in production systems? (a) Taxon not a weed; (b) Taxon a weed but no evidence of control; (c) Taxon a weed and evidence of control efforts]	c - mod	0.6	*Myriophyllum spicatum* is targeted for control in irrigation and drainage systems in Canada (Aiken et al., 1979). Prather et al. (2007) provide guidance for irrigation delays when applying herbicides in water bodies used for irrigation purposes, indicating that this species is targeted for control in production systems. It is considered a weed of rice in Bangladesh, India, and Vietnam (Moody, 1989). Alternate answers for the Monte Carlo simulation are both "b". We are using moderate uncertainty because it is more difficult to find evidence of control specifically in production systems for this species.
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 this species exists in or could survive in this plant hardiness zone.
Geo-Z2 (Zone 2)	n - low	N/A	We found no evidence that this species exists in or could survive in this plant hardiness zone.
Geo-Z3 (Zone 3)	y - low	N/A	Canada, Finland, and the United States: Minnesota.
Geo-Z4 (Zone 4)	y - negl	N/A	Canada, Finland, Japan, Pakistan, and the United States: Minnesota and Wisconsin.
Geo-Z5 (Zone 5)	y - negl	N/A	Afghanistan, Austria, Canada, Japan, and the United States: Idaho, New Mexico, and Washington.
Geo-Z6 (Zone 6)	y - negl	N/A	Canada, Japan, and the United States: Idaho, Illinois, Indiana, Kansas, Michigan, Missouri, New Mexico, and Washington.
Geo-Z7 (Zone 7)	y - negl	N/A	The United States: Alabama, Arizona, Connecticut, Idaho, Kentucky, Maryland, Missouri, New Mexico, Oregon, Tennessee, and Washington.
Geo-Z8 (Zone 8)	y - negl	N/A	Canada, Japan, South Korea, and the United States: Alabama, Arizona, North Carolina, Oregon, Texas, and Washington.
Geo-Z9 (Zone 9)	y - negl	N/A	Japan, South Africa, South Korea, and the United States: Alabama, Arizona, California, Texas, and Washington.

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Geo-Z10 (Zone 10)	y - negl	N/A	Botswana, Mexico, South Africa, and the United States: Arizona, California, Florida, and Louisiana
Geo-Z11 (Zone 11)	y - low	N/A	Chad, Ecuador, South Africa, and Sudan.
Geo-Z12 (Zone 12)	n - low	N/A	We found no evidence that this species exists in or could survive in this plant hardiness zone.
Geo-Z13 (Zone 13)	n - negl	N/A	We found no evidence that this species exists in or could survive in this plant hardiness zone.
Köppen -Geiger climate classes			
Geo-C1 (Tropical rainforest)	n - high	N/A	Three points in Cameroon, however we found no evidence in the literature that this species could survive in this climate class, therefore we are answering "no".
Geo-C2 (Tropical savanna)	n - high	N/A	One point in Cameroon, however we found no evidence in the literature that this species could survive in this climate class, therefore we are answering "no".
Geo-C3 (Steppe)	y - negl	N/A	Afghanistan, Botswana, Mexico, Namibia, Pakistan, South Africa, and the United States: Idaho.
Geo-C4 (Desert)	y - low	N/A	Afghanistan, Pakistan, and the United States: Arizona and California.
Geo-C5 (Mediterranean)	y - negl	N/A	Ecuador, Israel, South Africa, Syria, and the United States: Arizona, California, Oregon, and Washington.
Geo-C6 (Humid subtropical)	y - negl	N/A	China, Japan, South Africa, and the United States: Alabama, Florida, Kentucky, Louisiana, Missouri, Tennessee, and Texas.
Geo-C7 (Marine west coast)	y - negl	N/A	China, France, Ireland, Spain, South Africa, the United Kingdom, and the United States: New Mexico and Washington.
Geo-C8 (Humid cont. warm sum.)	y - negl	N/A	Georgia, Japan, South Korea, and the United States: Connecticut, Illinois, Indiana, Kansas, Missouri, South Dakota, and Wisconsin.
Geo-C9 (Humid cont. cool sum.)	y - negl	N/A	Canada, China, and the United States: Connecticut, Idaho, Michigan, Minnesota, New Mexico, Washington, and Wisconsin.
Geo-C10 (Subarctic)	y - negl	N/A	Finland, Germany, Norway, Russia, and Sweden.
Geo-C11 (Tundra)	n - low	N/A	We found no evidence that this species exists in or could survive in this climate class.
Geo-C12 (Icecap)	n - negl	N/A	We found no evidence that this species exists in or could survive in this climate class.
10-inch precipitation bands			
Geo-R1 (0-10 inches; 0-25 cm)	y - low	N/A	Botswana, South Africa, and the United States: Arizona and California.
Geo-R2 (10-20 inches; 25-51 cm)	y - negl	N/A	Botswana, South Africa, and the United States: Arizona, California, New Mexico, Washington.
Geo-R3 (20-30 inches; 51-76 cm)	y - negl	N/A	Canada, Chad, South Africa, Sudan, and the United States: Arizona, California, Idaho, New Mexico, Oregon, Utah, and Washington.
Geo-R4 (30-40 inches; 76-102 cm)	y - negl	N/A	Canada, China, South Africa, and the United States: California, Missouri, Texas, Washington, and Wisconsin.
Geo-R5 (40-50 inches; 102-127 cm)	y - negl	N/A	China, South Africa, South Korea, and the United States: Idaho, Illinois, Indiana, Louisiana, Missouri, and Washington.
Geo-R6 (50-60 inches; 127-152	y - negl	N/A	China, South Korea, and the United States: Alabama,

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cm)			Connecticut, Florida, Kentucky, Oregon, Tennessee, and Washington.
Geo-R7 (60-70 inches; 152-178 cm)	y - negl	N/A	China, Finland, Ireland, Japan, the United Kingdom, and the United States: Alabama and Oregon.
Geo-R8 (70-80 inches; 178-203 cm)	y - negl	N/A	Cameroon, China, Japan, the United Kingdom, and the United States: Oregon.
Geo-R9 (80-90 inches; 203-229 cm)	y - negl	N/A	China, Japan, the United Kingdom, and the United States: Oregon and Washington.
Geo-R10 (90-100 inches; 229-254 cm)	y - low	N/A	China and Japan.
Geo-R11 (100+ inches; 254+ cm)	y - low	N/A	Cameroon, China, Ecuador, and Japan.
ENTRY POTENTIAL			
Ent-1 (Plant already here)	y - negl	1	*Myriophyllum spicatum* has been present in the United States since the 1940s, and may have been introduced into the Chesapeake Bay area as early as the 1880s (although this may have been a misidentification) (Madsen et al., 1991). An examination of more than 15,000 watermilfoil specimens in 173 herbariums revealed that authentic Eurasian watermilfoil in North America dates to a Washington, DC, pond in 1942 (Engel, 1995).
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	