Weed Risk Assessment for *Myriophyllum aquaticum* Vell. Verdc. (Haloragaceae) – Parrot's feather

Michigan
Department of
Agriculture and
Rural Development

December 04, 2015

Version 1

Left: Emergent and submergent leaves (source: Leslie J. Mehrhoff, University of Connecticut, Bugwood.org) Top right: *Myriophyllum aquaticum* growth (source: Graves Lovell, Alabama Department of Conservation and Natural Resources, Bugwood.org) Bottom right: *Myriophyllum aquaticum* cutting with emergent and submergent leaves (source: Graves Lovell, Alabama Department of Conservation and Natural Resources, 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.

Myriophyllum aquaticum Vell. – Parrot's feather

Species Information

Family: Haloragaceae (Smith, 2008; NGRP 2015)

Synonyms: *Enydria aquatica* Vell.; *Myriophyllum brasiliense* Cambess.; *Myriophyllum proserpinacoides* Gillies ex Hook. & Arn. (Wunderlin & Hansen, 2008; The Plant List, 2015). These synonyms were accepted as *M. aquaticum* during the literature search.

Common names: Parrotfeather (Jacot Guillarmod, 1979), parrot's feather (Wersal & Madsen, 2011), Brazilian water-milfoil, thread-of-life, and water-feather (NGRP, 2015).

Botanical description: *Myriophyllum aquaticum* is an herbaceous aquatic macrophyte (Wersal & Madsen, 2011) with stems that grow to six and a half feet in length, which resemble bright green bottlebrushes emerging from the water (Bossard et al., 2000). Emergent leaves are feather-like and grayish green, stiff, and grow in whorls around the emergent shoot. These leaves have stomata, a thick waxy cuticle, and short cylindrical leaflets. Submersed leaves are typically orange to red, lack both stomata and a leaf cuticle, and grow in whorls around shoots (Wersal & Madsen, 2013). For a full botanical description, see SEINet (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). USDA Plant Epidemiology and Risk Analysis Laboratory's (PERAL) Weed Team worked with MDARD to evaluate and review this species.

Foreign distribution: This species is native to South America (Xie et al., 2013): Argentina, Bolivia, Brazil, Chile, Ecuador, Paraguay, and Peru (NGRP, 2015). It is naturalized in Australia, India (NGRP, 2015), Japan (Kadono, 2004; NGRP, 2015), New Zealand (Groves et al., 2001; NGRP, 2015), Taiwan, Thailand, and Vietnam (NGRP, 2015).

U.S. distribution and status: *Myriophyllum aquaticum* is naturalized in the United States in Alabama, Arizona, Arkansas, California, Connecticut, Delaware, Florida, Georgia, Idaho, Kansas, Kentucky, Louisiana, Maryland, Massachusetts, Mississippi, Missouri, Montana, New Jersey, New Mexico, New York, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, South Carolina, Tennessee, Texas, Virginia, Washington, and West Virginia (BONAP, 2015; NGRP, 2015). It is regulated as a noxious weed in Alabama, Connecticut, Idaho, Illinois, Indiana, Maine, Michigan, Nebraska, New Hampshire, New Mexico, Oregon, Vermont, Washington, and Wisconsin (National Plant Board, 2015). *Myriophyllum aquaticum* is readily available from both retail and wholesale nurseries (Lilypons Water Gardens, 2015; AAA Pond Supply, 2015; LiveAquaria, 2015). *Myriophyllum aquaticum* is widely controlled in the United States using chemical and mechanical means (Washington Department of Ecology, 2015a; Haberland, 2014).

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

1. *Myriophyllum aquaticum* analysis

Establishment/Spread Potential *Myriophyllum aquaticum* is an emergent aquatic macrophyte with both submersed and emergent growth forms (Wersal & Madsen, 2013). When stems of *M. aquaticum* reach the water's surface, they continue to grow horizontally and vertically (Xie et al., 2013), creating thick mats that completely cover the surface (Smith, 2008; Bossard et al., 2000). *Myriophyllum aquaticum* has a very short generation time, often with multiple generations per year, because its stems readily fragment (Orchard, 1981) and generate more plants (Xie et al., 2010; Xie et al., 2013). This ability to survive and tolerate mutilation makes *M. aquaticum* a successful hitchhiker, spreading via boats and trailers (Smith, 2008; Bossard et al., 2000) and through transport of contaminated materials (Jacot Guillarmod, 1979). We had average uncertainty for this element.

Risk score = 15 Uncertainty index = 0.16

Impact Potential Floating mats of *Myriophyllum aquaticum* create anoxic conditions throughout the water column (Moreira et al., 1999); because most of the photosynthesis happens in emergent leaves while senescing plant material uses up oxygen in the water column (Hussner, 2009). Furthermore, shading by *M. aquaticum* stems at the water surface reduces the density of photosynthetic algae in the water column (Washington Department of Ecology, 2015a) and removes the submersed vegetation layer, decreasing the abundance of many native species (Moreira et al., 1999). The dense surface growth of *M. aquaticum* provides shelter for *Anopheles* (mosquito) larvae (Orr & Resh, 1989) which in turn facilitates the spread of disease-bearing organisms (Macdonald et al., 2003), a notable human health hazard. Mats of *M. aquaticum* clog waterways, making areas unusable for recreation (Bossard et al., 2000); the thick mats also prevent boating, swimming, and other activities, and decrease the lakeshore aesthetic value (Kelly & Maguire, 2009). In agricultural systems, this plant causes flooding along

[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).

irrigation channels (Bossard et al., 2000).We had a low amount of uncertainty for this risk element.
Risk score = 3.8 Uncertainty index = 0.06

Geographic Potential Based on three climatic variables, we estimate that about 44.5 percent of the United States is suitable for the establishment of *Myriophyllum aquaticum* (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 *Myriophyllum aquaticum* represents the joint distribution of Plant Hardiness Zones 7-13, areas with 0-100+ inches of annual precipitation, and the following Köppen-Geiger climate classes: tropical rainforest, tropical savanna, steppe, desert, Mediterranean, humid subtropical, marine west coast, humid continental warm summers, humid continental cool summers.

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. *Myriohpyllum aquaticum* can colonize a diverse range of habitats and tolerates disturbances to these habitats (Wersal et al., 2011). Growth initiates when water temperatures reach 8 °C (Moreira et al., 1999). Depths of less than 100 cm are optimal (Moreira et al., 1999), but *M. aquaticum* has been observed growing in waters up to 2 m deep (Wersal et al., 2011). *Myriophyllum aquaticum* can survive in coastal waters where frequent inundation by salt water occurs (Wersal et al., 2011).

Entry Potential We did not assess the entry potential of *Myriophyllum aquaticum* because it is already present in the United States (GBIF, 2015; Washington Department of Ecology, 2015a). In North America, the first record of *M. aquaticum* was in New Jersey in 1890 (GLANSIS, 2015), and has now naturalized in the United States in 31 states (BONAP, 2015; NGRP, 2015).

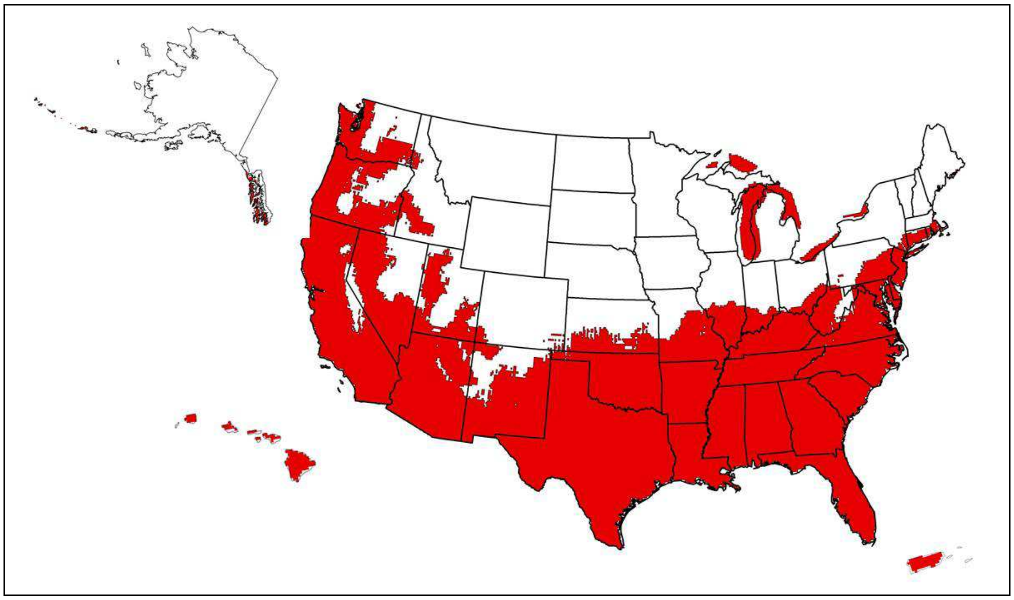

Figure 1. Predicted distribution of *Myriophyllum aquaticum* in the United States. Map insets for Alaska, Hawaii, and Puerto Rico are not to scale.

2. Results

Model Probabilities: P(Major Invader) = 84.4%
P(Minor Invader) = 15.1%
P(Non-Invader) = 0.6%

Risk Result = High Risk

Secondary Screening = Not applicable

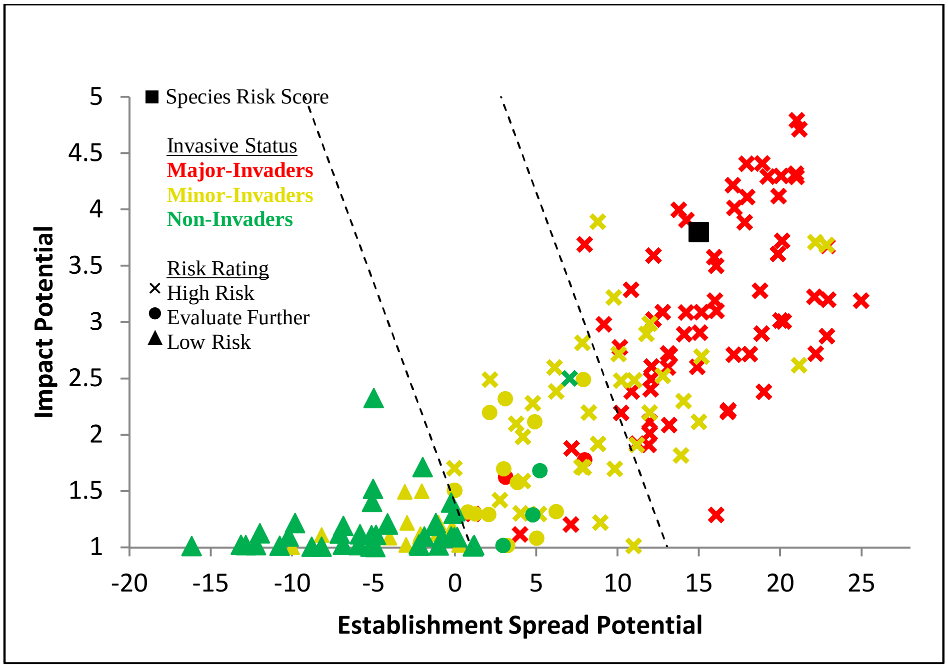

Figure 2. *Myriophyllum aquaticum* risk score (black box) relative to the risk scores of species used to develop and validate the PPQ WRA model (other symbols). See Appendix A for the complete assessment.

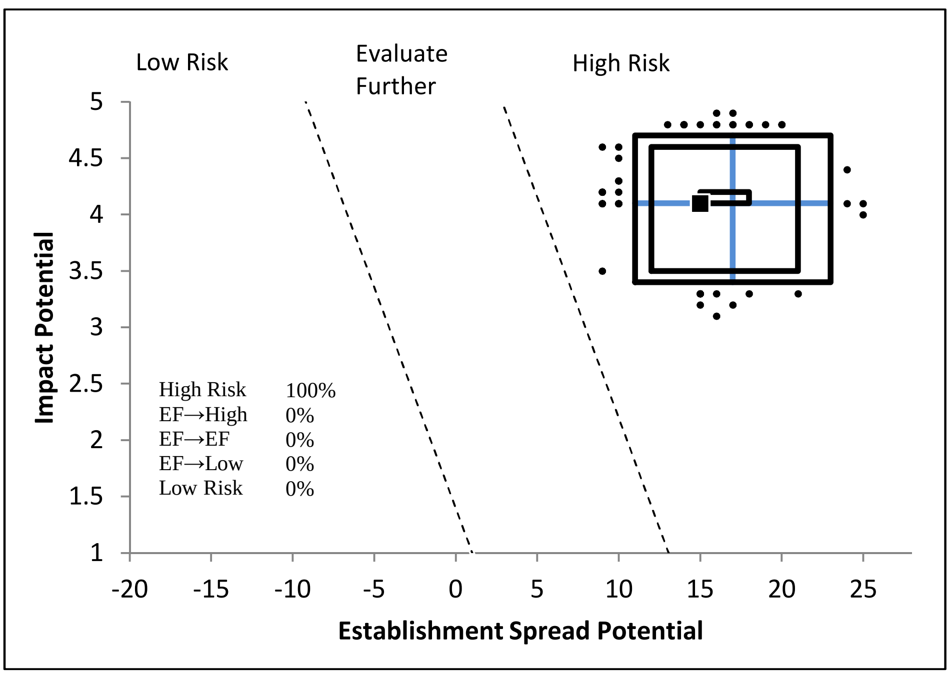

Figure 3. Model simulation results (N=5,000) for uncertainty around the risk score for *Myriophyllum aquaticum*. The blue "+" symbol represents the medians of the simulated outcomes. The smallest box contains 50 percent of the outcomes, the second 95 percent, and the largest 99 percent.

3. Discussion

The result of the weed risk assessment for *Myriophyllum aquaticum* is High Risk (Figure 2). The uncertainty analysis of this assessment shows that 100% of the 5,000 alternate outcomes for the assessment are High Risk (Figure 3), indicating that our result is robust. Control of this species can be very costly. In Washington, the Longview Diking District spends $50,000 annually to remove *Myriophyllum aquaticum* from its drainage ditches, most effectively by dredging (Washington Department of Ecology, 2015a). In Ireland, it is expected that the cost of eradicating a *M. aquaticum* population from a single lake would be £50,000 - 100,000, and would utilize a combination of mechanical, herbicidal, and shading control methods (Kelly & Maguire, 2009). Removal of this species is a very intensive process, so heavy emphasis on prevention efforts should be the focus of management plans in areas that do not currently have a *M. aquaticum* infestation (Kelly & Maguire, 2009). To control this species, the State of Washington uses mechanical harvesters specially designed to pluck out individual plants and not fragment them (Bossard et al., 2000).

4. Literature Cited

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Appendix A. Weed risk assessment for *Myriophyllum aquaticum* Vell. (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 - low	5	Native to South America (Xie et al., 2013): Argentina, Bolivia, Brazil, Chile, Ecuador, Paraguay, and Peru (NGRP, 2015). Naturalized in much of Europe (GBIF, 2015), as well as Australia, India (NGRP, 2015), Japan (Kadono, 2004; NGRP, 2015), New Zealand (Groves et al., 2001; NGRP, 2015), Taiwan, Thailand, and Vietnam (NGRP, 2015). Naturalized in the United States in 31 states (BONAP, 2015; NGRP, 2015). *Myriophyllum aquaticum* has spread widely in the main river systems and impoundments of South Africa (Jacot Guillarmod, 1979). In California, *M. aquaticum* has infested over 500 surface acres and nearly 600 acres of waterways (Sytsma, 1992). Given the extent of naturalization and ability to spread, we are answering f. Alternate answers 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 weeds (i.e. *Myriophyllum papillosum*, *M. propinquum*, *M. quitense*, *M. exalbescen*, and *M. verrucosum*). Among the most serious weeds in this genus are *M. spicatum* and *M. heterophyllum*. *Myriophyllum spicatum* is considered "one of the worst invasive aquatic weed problems" (Cuda et al., 2008) due to its "aggressive" growth (Moody & Les, 2010). It is a problem across all systems, as it spreads rapidly, crowds out native species, clogs waterways, and blocks sunlight and oxygen from penetrating the water column (Washington Department of Ecology, 2015b). *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	*Myriophyllum aquaticum* is adapted to a wide variety of conditions, from full sun to partial shade (Smith, 2008) and its growth form is adapted to shady environments (Wersal et al., 2011). In a study conducted by Xie et al. (2013), growth parameters (i.e. total biomass, number of new shoots, and total stem length) were unaffected between shaded and unshaded growth plots. Field studies conducted by Wersal and Madsen (2013) found that optimal growth occurred at intermediate light intensities, particularly 30% shade. *Myriophyllum aquaticum* also thrived in full sunlight and survived in 70% shade (Wersal & Madsen, 2013).

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	This species is neither a vine nor forms tightly appressed basal rosettes; *Myriophyllum aquaticum* is an aquatic herb (Wersal & Madsen, 2011).
ES-6 (Forms dense thickets, patches, or populations)	y - negl	2	*Myriophyllum aquaticum* forms dense monotypic mats (Smith, 2008) that can entirely cover the surface of the water in shallow lakes and other waterways (Bossard et al., 2000). Once *M. aquaticum* stems reach the surface, vertical as well as horizontal stem growth allows this plant to quickly cover the water surface (Xie et al., 2013).
ES-7 (Aquatic)	y - negl	1	*Myriophyllum aquaticum* is a stout aquatic perennial (Bossard et al., 2000). It is a semi-submersed freshwater aquatic macrophyte (Xie et al., 2013; Smith, 2008).
ES-8 (Grass)	n - negl	0	This plant is a member of the family Haloragaceae (Smith, 2008; NGRP 2015) 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; Smith, 2008; NGRP 2015). *Myriophyllum aquaticum* is an aquatic herb (Wersal & Madsen, 2011).
ES-10 (Does it produce viable seeds or spores)	? - max	0	No evidence was found regarding sexual reproduction of this species within its native range, which is the only reported area where the species sets seed (Orchard, 1981). Within its native range, where male plants occur, fruit set is "apparently very rare" (Orchard, 1981). In its non-native range, only female plants are present in the United States so the spread of *M. aquaticum* has resulted solely from vegetative reproduction (Smith, 2008). All non-native populations are pistillate (Sytsma, 1992). Therefore, we answered unknown, without any evidence about viable seed production.
ES-11 (Self-compatible or apomictic)	n - negl	-1	This species is dioecious (Orchard, 1981), with differing pistillate and staminate plants (Sytsma, 1992).
ES-12 (Requires specialist pollinators)	? - max		We found no evidence regarding the pollination mechanisms of this species. One source indicates that some members of the *Myriophyllum* genus are wind-pollinated (Cook, 1988), but does not specify which species those are. Therefore, we answered unknown.
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]	a - low	2	*Myriophyllum aquaticum* is an herbaceous aquatic perennial (Bossard et al., 2000; Wersal & Madsen, 2011). Growth is most rapid from March until September. In spring, shoots begin to grow rapidly from overwintering rhizomes as water temperature increases (Bossard et al., 2000). Stems are brittle and readily fragment (Orchard, 1981). Fragments are specially adapted for propagation (Xie et al., 2010) and both rhizomes and stem fragments have extremely high survival rates (Xie et al., 2010; Xie et al., 2013). In fall, the plants typically die back to the rhizomes (Bossard et al., 2000) and overwinter via these rhizomes (Sytsma & Anderson, 1993). We answered a, due to the species' ability to fragment and propagate during one season, with alternate answer for the Monte Carlo simulation both being b.
ES-14 (Prolific reproduction)	? - max	0	We found no information regarding seed production of

Question ID	Answer - Uncertainty	Score	Notes (and references)
			this species. Orchard (1981) notes that fruit set is "apparently very rare" within the species' native range, and *M. aquaticum* reproduces exclusively vegetatively within its introduced range (Smith, 2008). We also found no data about the rate of vegetative reproduction. Without additional information, we answered unknown.
ES-15 (Propagules likely to be dispersed unintentionally by people)	y - negl	1	Stems easily fragement and are readily spread by boats and trailers (Smith, 2008; Bossard et al., 2000). These fragments settle in sediments and produce new plants. (Bossard et al., 2000).
ES-16 (Propagules likely to disperse in trade as contaminants or hitchhikers)	y - low	2	*Myriophyllum aquaticum* was introduced into the Kariega River system in Africa after the area was stocked with fish fry that originated at a hatchery that was infested with *M. aquaticum* (Jacot Guillarmod, 1979). *Myriophyllum* species are very similar in foliage and may be difficult to differentiate (Aiken, 1981) and can be dispersed through the aquarium trade, as evidenced by Maki and Galatowitsch's 2004 study of trade contaminants.
ES-17 (Number of natural dispersal vectors)	1	-2	Information relevant for ES-17a through ES-17e: We found little evidence about *M. aquaticum* fruit and no evidence about *M. aquaticum* seed. Stems are brittle and readily fragment (Orchard, 1981) and have very high regenerative rates (Xie et al., 2010; Xie et al., 2013). Fruit: ovoid with four mericarps (Torres Robles et al., 2011), 1.7 mm long, 1.3-1.4 mm diameter. (Orchard, 1981).
ES-17a (Wind dispersal)	n - low		We found no evidence that this species is wind dispersed. Further, stem fragments and fruit do not appear to have mechanisms for wind dispersal.
ES-17b (Water dispersal)	y - negl		Fragments are capable of floating in the water column for weeks before settling and rooting (Xie et al., 2010), and are able to float for up to six months (Xie et al., 2013).
ES-17c (Bird dispersal)	? - max		It may be possible for fragments to be bird dispersed by sticking to feathers or in beaks. There has been no documentation of this type of transport, however, so we answered unknown.
ES-17d (Animal external dispersal)	? - max		It may be possible for fragments to be dispersed by water dwelling mammals by sticking to wet fur. There has been no documentation of this type of transport, however, so we answered unknown.
ES-17e (Animal internal dispersal)	n - low		We found no evidence that this species may be dispersed internally by other animals. Because seed production is uncommon, and because it is unlikely that vegetative fragements will survive gut passage, we used low uncertainty.
ES-18 (Evidence that a persistent (>1yr) propagule bank (seed bank) is formed)	n - mod	-1	We found no evidence that this species forms a persistent seed bank. While *Myriophyllum aquaticum* may be able to survive drawdown periods of up to nine months as long as the sediment remains saturated (Wersal & Madsen, 2011), once the sediment dries out fragments that are subjected to desiccation are no longer viable following 80% mass loss (Barnes et al., 2013).
ES-19 (Tolerates/benefits from mutilation, cultivation or fire)	y - negl	1	*Myriophyllum aquaticum* is tolerant of mechanical disturbance, and repeated cuttings favors dominance of the

Question ID	Answer - Uncertainty	Score	Notes (and references)
			species (Wersal & Madsen, 2011). Mechanical harvesting that cuts the plants only serves to fragment the species and potentially extend its range of distribution (Wersal & Madsen, 2011). Tough rhizomes of this species can survive being transported long distances in water (Smith, 2008). Fragments are specially adapted for propagation as they are capable of floating in the water column for weeks before settling and rooting (Xie et al., 2010) and both rhizomes and stem fragments have extremely high survival rates (Xie et al., 2010; Xie et al., 2013). Higher propagule supply (i.e. fragments) results in higher population survival rates and growth parameters (i.e. total biomass, number of new shoots, and total stem length) (Xie et al., 2013).
ES-20 (Is resistant to some herbicides or has the potential to become resistant)	n - low	0	We found no evidence this species is resistant to herbicides. Furthermore, it is not listed by Heap (2013) as resistant. Chemical control of *M. aquaticum* is challenging because a surfactant has to be used to permeate the waxy cuticle of emergent stems and leaves. Reports indicate that the weight of herbcide sprays often causes the emergent stem to collapse into the water, washing the chemical off before it is translocated into the rest of the plant. Some success at controlling *M. aquaticum* has been reported using 2,4-D diquat, diquat and complexed copper, endothall and complexed copper, endothall dipotassium salt, and fluridone (Smith, 2008).
ES-21 (Number of cold hardiness zones suitable for its survival)	7	0	
ES-22 (Number of climate types suitable for its survival)	9	2	
ES-23 (Number of precipitation bands suitable for its survival)	11	1	
IMPACT POTENTIAL			
General Impacts			
Imp-G1 (Allelopathic)	n - mod	0	We found no evidence that this species is allelopathic. Cheng et al. (2008) found that *Microcystis aeruginosa* was significantly inhibitied by *M. aquaticum* culture water, but as this is under unnatural conditions, we are answering no.
Imp-G2 (Parasitic)	n - negl	0	We found no evidence that this species is parasitic. Furthermore, *M. aquaticum* does not belong to a family known to contain parasitic plants (Heide-Jorgensen, 2008; Smith, 2008).
Impacts to Natural Systems			
Imp-N1 (Changes ecosystem processes and parameters that affect other species)	y - negl	0.4	Photosynthetic activity by both the emergent and submersed portions of the plant creates dissolved oxygen gradients within the water column, and anoxic conditions generally exist in water deeper than 15 cm. (Moreira et al., 1999). Shading by the floating weed mats reduces the oxygen content of the underlying water layers to <1 mg O_2/L (Hussner, 2009). Heavy infestations also result in high levels of suspended organic matter (Moreira et al., 1999).

Question ID	Answer - Uncertainty	Score	Notes (and references)
Imp-N2 (Changes habitat structure)	y - negl	0.2	*Myriophyllum aquaticum* 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). *Myriophyllum aquaticum* replaced the submerged vegetation layer in some river systems in Portugal (Moreira et al., 1999).
Imp-N3 (Changes species diversity)	y - negl	0.2	*Myriophyllum aquaticum* shades underlying water, with a consequential decrease in the local diversity of submerged macrophytes and a build-up of anoxic conditions in the infested waters (Hussner, 2009). Furthermore, this shading reduces the density of algae in the water column that "serve as the basis of the aquatic food web" (Washington Department of Ecology, 2015a). Dense growth of *M. aquaticum* provides a refuge for *Anopheles* (mosquitos), decreasing predation and increasing the survival of mosquito larvae (Orr & Resh, 1989). *Myriophyllum aquaticum* replaced the native species *Potamogeton fluitans*, *Potamogeton crispus*, *Ceratophyllum demersum*, and *Myriophyllum spicatum* in river systems in Portugal (Moreira et al., 1999).
Imp-N4 (Is it likely to affect federal Threatened and Endangered species?)	y - low	0.1	*Myriophyllum aquaticum* creates anoxic conditions (Hussner, 2009) and shades out plants and algae growing in the water column below its dense growth (Moreira et al., 1999; Washington Department of Ecology, 2015a). *Myriophyllum aquaticum* replaces native vegetation (Moreira et al., 1999), and may change habitat structure. Without the nutrients necessary for survival, and with decreased algae populations, aquatic food webs are likely to shift, severely impacting any T&E species.
Imp-N5 (Is it likely to affect any globally outstanding ecoregions?)	y - low	0.1	*Myriophyllum aquaticum* is already present as a noxious weed in much of the southeastern and Pacific coast United States (BONAP, 2014) that are listed as globally outstanding ecoregions (Ricketts et. al, 1999). This species severely limits photosynthetic activity and creates anoxic conditions below the dense mats it forms on the surface of water (Moreira et al., 1999; Hussner, 2009), and these dense mats also outcompete and replace native species (Smith, 2008; Orr & Resh, 1989; Moreira et al., 1999). This species is highly likely to affect United States globally outstanding ecoregions.
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 aquaticum* is listed as an environmental weed of New Zealand (Howell, 2008) and a weed in New Zealand protected natural areas (Timmins & Mackenzie, 1995). Because of its threat to wetlands, it is also included in the list of prioritized Invasive Aquatic Species of Nepal (Tiwari et al., 2005). The State of Washington uses mechanical harvesters specially designed to pluck out individual plants and not fragment them (Bossard et al., 2000). Alternate answers for the Monte Carlo simulation are both "b."
Impact to Anthropogenic Systems (cities, suburbs, roadways)			

Question ID	Answer - Uncertainty	Score	Notes (and references)
Imp-A1 (Negatively impacts personal property, human safety, or public infrastructure)	y - low	0.1	Dense mats of *M. aquaticum* growth clog waterways, making them unusable for navigation (Bossard et al., 2000). While this is not technically considered in this question, we think it is important to mention that dense growths of emergent stems serves as protection from predation for female *Anopheles* mosquitos and lead to increases in the number of eggs laid (Wersal et al., 2011; Orr & Resh, 1989), facilitating the spread of disease-bearing organisms (Macdonald et al., 2003).
Imp-A2 (Changes or limits recreational use of an area)	y - low	0.1	Thick mats prevent boating, swimming, and other activities, and decrease the lakeshore aesthetic value (Kelly & Maguire, 2009; Bossard et al., 2000).
Imp-A3 (Affects desirable and ornamental plants, and vegetation)	n - mod	0	We found no evidence that this species affects ornamental plants and vegetation.
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 - low	0.1	*Myriophyllum aquaticum* is listed as a weed of South Africa, as it can extend the range of disease bearing organisms (i.e. mosquitos) (Macdonald et al., 2003; Orr & Resh, 1989). It is listed as a weed of ornamental plants in Israel (Dufour-Dror, 2013). *Myriophyllum aquaticum* has been controlled in hydroelectric station reservoirs in North Carolina with grass carp grazing (Gardener et al., 2013) and in Georgia with herbicides (Broadwell, 1991). Alternate answers fo the Monte Carlo simulation are both "b."
Impact to Production Systems (agriculture, nurseries, forest plantations, orchards, etc.)			
Imp-P1 (Reduces crop/product yield)	n - low	0	We found no evidence that this species reduces crop or commodity yield.
Imp-P2 (Lowers commodity value)	n - low	0	We found no evidence that this species reduces commodity value.
Imp-P3 (Is it likely to impact trade?)	y - low	0.2	National Plant Pest Accord List New Zealand (MPI, 2012), an agreement that identifies pest plants that are prohibited from sale and commercial propagation and distribution.. Australia, Honduras, Nauru, Republic of Korea, and Taiwan require phytosanitary certificates declaring trade shipments to be free of *M. aquaticum* (APHIS, 2015). This species is also regulated in Alabama, Connecticut, Idaho, Illinois, Indiana, Maine, Michigan, Nebraska, New Hampshire, New Mexico, Oregon, Vermont, Washington, and Wisconsin. *Myriophyllum aquaticum* can be dispersed through the aquarium trade (Maki & Galatowitsch, 2004), and has been moved with fish fry that were cultivated in a tank containing *M. aquaticum* (Jacot Guillarmod, 1979). Because this species is regulated and is likely to move in trade, we answered yes.
Imp-P4 (Reduces the quality or availability of irrigation, or strongly competes with plants for water)	y - low	0.1	Monotypic stands of *M. aquaticum* clog irrigation canals (Rhode Island Department of Environmental Management, 2015; Haberland, 2014; Virginia Department of Conservation & Recreation, 2014).
Imp-P5 (Toxic to animals, including livestock/range	n - mod	0	We found no evidence that this species is toxic to animals.

Question ID	**Answer - Uncertainty**	**Score**	**Notes (and references)**
animals and poultry)			
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	Weed of rice in Indonesia and Kampuchea (Moody, 1989). Major weed of irrigation and drainage systems in Portugal (Moreira et al., 1999). Mechanical harvesting of the species in Portuguese irrigation canals left the roots intact and allowed the species to repopulate the channel. The most effective control occurred when the channel was dredged (Moreira et al., 1999). In Washington, the Longview Diking District estimates that it spends $50,000 a year on *M. aquaticum* control in drainage ditches (Washington Department of Ecology, 2015a). Alternate answers are both "b."
GEOGRAPHIC POTENTIAL			Unless otherwise indicated, the following evidence represents geographically referenced points obtained from the Global Biodiversity Information Facility (GBIF, 2015).
Plant hardiness zones			
Geo-Z1 (Zone 1)	n - negl	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z2 (Zone 2)	n - negl	N/A	We found no evidence that it occurs in this hardiness 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 - low	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z6 (Zone 6)	n - high	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z7 (Zone 7)	y - negl	N/A	The United States (AL, AR, CA, CT, MD, MO, NC, TN), France, and Germany.
Geo-Z8 (Zone 8)	y - negl	N/A	The United States (AL, CA, LA, MS, OR, SC, TX, WA), Australia, Japan, Canada, the United Kingdom, and France.
Geo-Z9 (Zone 9)	y - negl	N/A	The United States (AL, AZ, CA, FL, LA, OR, TX, WA), Mexico, France, South Africa, Japan, New Zealand, and Colombia.
Geo-Z10 (Zone 10)	y - negl	N/A	The United States (CA, OR, WA), Colombia, South Africa, New Zealand, Zimbabwe, Australia, Japan, and Brazil.
Geo-Z11 (Zone 11)	y - negl	N/A	The United States (CA), New Zealand, Australia, Thailand, China, South Africa, Mexico, Colombia, and Brazil.
Geo-Z12 (Zone 12)	y - negl	N/A	The United States (HI), Australia, China, Sri Lanka, Colombia, Ecuador, Peru, and Brazil.
Geo-Z13 (Zone 13)	y - negl	N/A	The United States (HI), Indonesia, Australia, and South Africa.
Köppen -Geiger climate classes			
Geo-C1 (Tropical rainforest)	y - negl	N/A	The United States (HI), Indonesia, Mexico, Colombia, and Brazil.
Geo-C2 (Tropical savanna)	y - negl	N/A	The United States (HI), Thailand, Australia, and Brazil.

Question ID	Answer - Uncertainty	Score	Notes (and references)
Geo-C3 (Steppe)	y - negl	N/A	The United States (AZ, CA), Australia, South Africa, Mexico, and Peru.
Geo-C4 (Desert)	y - low	N/A	The United States (CA) and Mexico.
Geo-C5 (Mediterranean)	y - negl	N/A	The United States (CA, OR, WA), Australia, South Africa, Canada, Ecuador, Portugal, and Spain.
Geo-C6 (Humid subtropical)	y - negl	N/A	The United States (AL, AR, FL, LA, MD, MO, MS, NC, SC, TN, TX), Australia, Japan, Thailand, Zimbabwe, and South Africa.
Geo-C7 (Marine west coast)	y - negl	N/A	New Zealand, Australia, Sri Lanka, South Africa, Canada, Mexico, Colombia, Brazil, Ireland, and the United Kingdom.
Geo-C8 (Humid cont. warm sum.)	y - low	N/A	A few points in the United States (MO).
Geo-C9 (Humid cont. cool sum.)	y - low	N/A	A few points in the United States (CT) and France.
Geo-C10 (Subarctic)	n - low	N/A	We found no evidence that it occurs in this climate class.
Geo-C11 (Tundra)	n - mod	N/A	A point in Colombia at high elevation, but this is likely an erroneous record.
Geo-C12 (Icecap)	n - negl	N/A	We found no evidence that it occurs in this climate class.
10-inch precipitation bands			
Geo-R1 (0-10 inches; 0-25 cm)	y - negl	N/A	The United States (AZ, CA) and Mexico.
Geo-R2 (10-20 inches; 25-51 cm)	y - negl	N/A	The United States (AZ, CA, HI), Australia, and South Africa.
Geo-R3 (20-30 inches; 51-76 cm)	y - negl	N/A	The United States (CA, HI, TX), New Zealand, Australia, South Africa, Peru, the United Kingdom, and Portugal.
Geo-R4 (30-40 inches; 76-102 cm)	y - negl	N/A	The United States (CA, HI, MO, TX), New Zealand, Australia, Japan, Zimbabwe, South Africa, the United Kingdom, and Ireland.
Geo-R5 (40-50 inches; 102-127 cm)	y - negl	N/A	The United States (AR, CA, CT, MD, MO), New Zealand, Australia, Japan, South Africa, Canada, and Mexico.
Geo-R6 (50-60 inches; 127-152 cm)	y - negl	N/A	The United States (AL, FL, LA, NC, OR, SC, WA), New Zealand, Australia, Japan, Canada, Mexico, and Colombia.
Geo-R7 (60-70 inches; 152-178 cm)	y - negl	N/A	The United States (AL, LA, MS, OR, WA), Brazil, New Zealand, Japan, China, and Brazil.
Geo-R8 (70-80 inches; 178-203 cm)	y - negl	N/A	The United States (OR, WA), Japan, China, and Mexico.
Geo-R9 (80-90 inches; 203-229 cm)	y - negl	N/A	The United States (WA), Japan, China, Australia, and Mexico, and Brazil.
Geo-R10 (90-100 inches; 229-254 cm)	y - negl	N/A	Japan, Mexico, Colombia, and Brazil.
Geo-R11 (100+ inches; 254+ cm)	y - negl	N/A	New Zealand, Japan, Thailand, China, Sri Lanka, Indonesia, Ecuador, and Colombia.
ENTRY POTENTIAL			
Ent-1 (Plant already here)	y - negl	1	In North America, the first record of *M. aquaticum* was in New Jersey in 1890 (GLANSIS, 2015), and has now naturalized in the United States in 31 states (BONAP, 2015; NGRP, 2015).
Ent-2 (Plant proposed for entry, or entry is imminent)	-	N/A	
Ent-3 (Human value & cultivation/trade status)	-	N/A	

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