# Weed Risk Assessment for *Potamogeton crispus* L. (Potamogetonaceae) – Curly leaf pondweed

Michigan Department of Agriculture and Rural Development

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Version 1


Top left: growth form (Leslie J. Mehrhoff, University of Connecticut, Bugwood.org), bottom left: *P. crispus* infestation (Chris Evans, University of Illinois, Bugwood.org), right: foliage close up with view of air bladders (Chris Evans, University of Illinois, 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.

***Potamogeton crispus* L. – Curly leaf pondweed**

**Species Information**

Family: Potamogetonaceae (NGRP, 2016; Haynes and Holm-Nielson, 2003).

Synonyms: Several synonyms are listed for this species, including *Buccaferrea crispata* Bubani, *Potamogeton austriacus* Gand., *Potamogeton concinnitus* A.Benn., *Potamogeton crenulatus* D.Don, *Potamogeton crispatus* Wallman ex Rchb., *Potamogeton hohenackeri* Gand., *Potamogeton hungaricus* Gand., *Potamogeton lactucaceum* Montandon, *Potamogeton leptophyllus* Gand., *Potamogeton macrorrhynchus* Gand., *Potamogeton notarisii* Gand., *Potamogeton pallidior* Gand., *Potamogeton rubricans* Gand., *Potamogeton rubrinaevus* Gand., *Potamogeton serrulatus* Opiz, and *Potamogeton tuberosus* Roxb. (The Plant List, 2013). However, none of these synonyms were found to be currently used in literature and were therefore not used in the literature search for this weed risk assessment.

Common names: Curly leaf pondweed (Snyder and Kaufman, 2004; Catling and Dobson, 1985), curled pondweed (Catling and Dobson, 1985), crisp pondweed (Stuckey, 1979), curly muckweed (Stuckey, 1979).

Botanical description: *Potamogeton crispus* is a submerged aquatic perennial herb (Stuckey, 1979; Haynes and Holm-Nielson, 2003) that can grow up to 100 cm long (Haynes and Hellquist, 2011). Leaves are spirally arranged and serrated (Haynes and Holm-Nielson, 2003). For a full botanical description, see Haynes and Hellquist (2011) or Haynes and Holm-Nielson (2003).

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: *Potamogeton crispus* is native to Africa, Asia, Australia, and Europe (Snyder and Kaufman, 2004; Atlas of Living Australia, 2016), and has been introduced to New Zealand and North

America (Bolduan et al., 1994). *Potamogeton crispus* is naturalized in New Zealand (New Zealand Plant Conservation Network, 2013), and is considered invasive and spreading in Canada (Catling and Dobson, 1985).

U.S. distribution and status: It is unclear how this species was introduced to the United States, however the first verifiable specimen of *P. crispus* was collected from Wilmington, Delaware, in 1859 (Nichols and Shaw, 1986; Stuckey, 1979). This species is now present in every state in the conterminous U.S. except South Carolina (Kartesz, 2015). It is regulated as a noxious weed in Connecticut, Illinois, Indiana, Maine, Michigan, Montana, Vermont, Washington, and Wisconsin (National Plant Board, 2014). *Potamogeton crispus* does not appear to be commercially cultivated or present in any botanical gardens in the United States, however it has been available through private aquarium hobbyists in the past (The Planted Tank, 2008), and may still be.

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

1. *Potamogeton crispus* analysis

**Establishment/Spread Potential** *Potamogeton crispus* can survive and grow at very low light levels (Tobiessen and Snow, 1984; Bolduan et al., 1994). Plant fragments are transported on aquatic equipment such as boats, trailers, motors, and fishing gear (Indiana DNR, 2009; Southeastern Wisconsin Invasive Species Consortium, 2016; Bruckerhoff et al., 2015), and long distance spread is associated with fish hatchery movement of contaminated water (Catling and Dobson, 1985; Bolduan et al., 1994). Natural dispersal mechanisms include water mediated dispersal (Haynes and Holm-Nielson, 2003; Mikulyuk and Nault, 2009) and dispersal by birds (Haynes and Holm-Nielson, 2003; Stuckey, 1979). Plants can reproduce by seed (Rogers and Breen, 1980; Ganie et al., 2008) and through fragmentation (Heidbüchel et al., 2016; Jiang et al., 2008). Stem fragments with at least one node have a high regeneration capacity (Heidbüchel et al., 2016; Bruckerhoff et al., 2015). We had an average amount of uncertainty for this risk element.

Risk score = 20 Uncertainty index = 0.16

**Impact Potential** *Potamogeton crispus* growth contributes to the depletion of water nutrients (Catling and Dobson, 1985; Mi et al., 2008) and affects the nutrient composition of a water body (Bolduan et al., 1994; Shen et al., 2014). *Potamogeton crispus* growth begins early in the spring, when water temperatures are still too cold for native species growth (Tobiessen and Snow, 1984; Bolduan et al., 1994). This creates a dense vegetative population before native species can create this layer (Tobiessen and Snow,

[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).

1984; GLANSIS, 2016). Dense mats of *P. crispus* disrupt boating, swimming, and fishing (Snyder and Kaufman, 2004) and severely restrict water-based recreation (Catling and Dobson, 1985). We had a low amount of uncertainty for this risk element.

Risk score = 3.3 Uncertainty index = 0.12

**Geographic Potential** Based on three climatic variables, we estimate that about 87 percent of the United States is suitable for the establishment of *Potamogeton crispus* (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 *Potamogeton crispus* represents the joint distribution of Plant Hardiness Zones 4-12, 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, 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. *Potamogeton crispus* invades calcareous, brackish, and freshwater systems, including rivers, canals, ditches, ponds, and reservoirs (Mikulyuk and Nault, 2009).

**Entry Potential** We did not assess the entry potential of *Potamogeton crispus* because it is already present in the United States (Kartesz, 2015). This species is now present in every state in the conterminous U.S. except South Carolina (Kartesz, 2015).

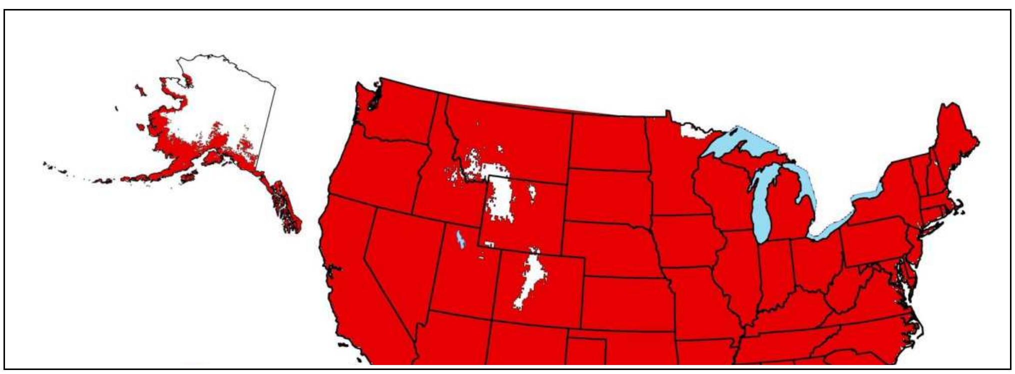

**Figure 1**. Predicted distribution of *Potamogeton crispus* in the United States. Map insets for Alaska, Hawaii, and Puerto Rico are not to scale.

2. Results

Model Probabilities: P(Major Invader) = 92.8%
P(Minor Invader) = 6.9%
P(Non-Invader) = 0.2%

Risk Result = High Risk

Secondary Screening = Not applicable

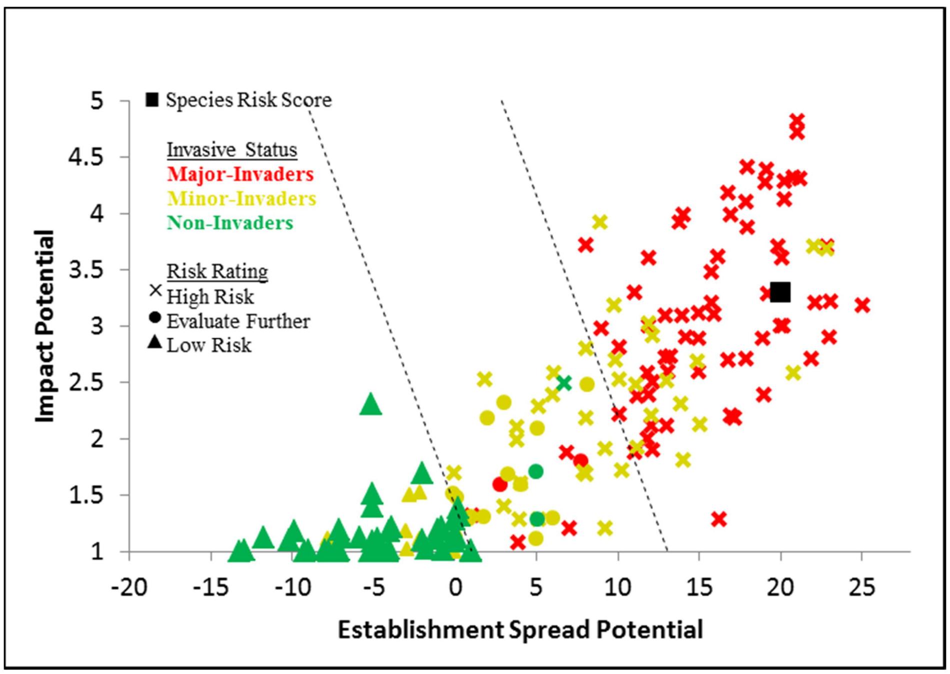


**Figure 2**. *Potamogeton crispus* risk score (black box) relative to the risk scores of species used to develop and validate the PPQ WRA model (other symbols). See Appendix A for the complete assessment.

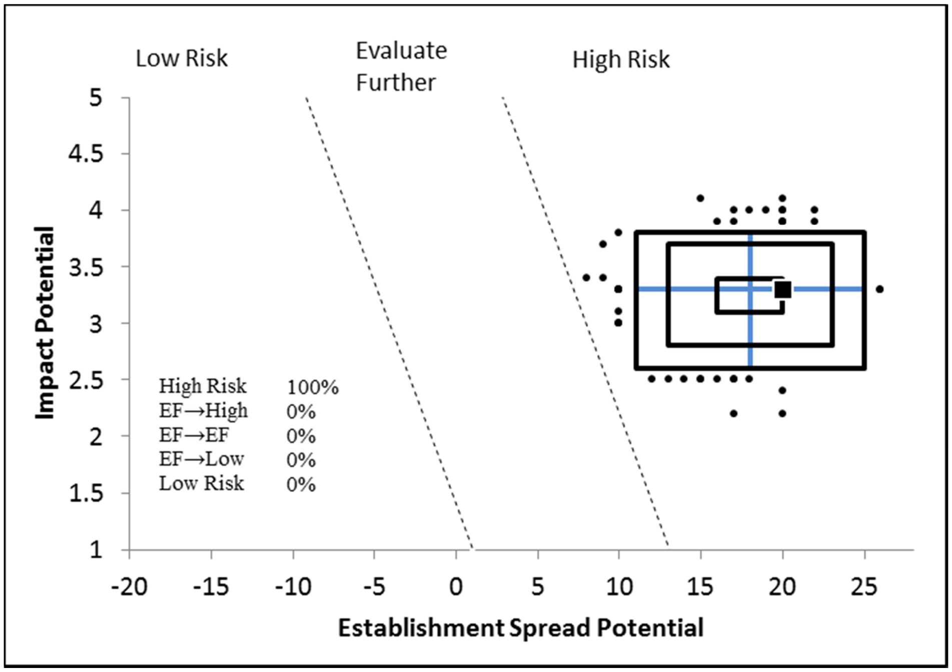


**Figure 3**. Model simulation results (N=5,000) for uncertainty around the risk score for *Potamogeton crispus*. The blue "+" symbol represents the medians of the simulated outcomes. The smallest box contains 50 percent of the outcomes, the second 95 percent, and the largest 99 percent.

3. Discussion

The result of the weed risk assessment for *Potamogeton crispus* 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). Our categorization of "High Risk" is well supported by the uncertainty analysis (Fig. 3). Although this plant is not listed as a federal noxious weed, its wide presence throughout the United States (Kartesz, 2015) and regulation by many of these states as a noxious weed (National Plant Board, 2015) has made this plant one of the more widely recognized invasive aquatic weeds. We were unable to find any evidence that this species is sold in the United States, pointing to the success of weed education and invasive species management. Control efforts are generally undertaken by individual lake and city organizations (Cedar Lake Improvement District, 2014; City of Plymouth, 2005) rather than large-scale treatment efforts by state organizations, as these treatments are only useful to control a population, rather than eradicate it (Indiana DNR, 2009). The Cedar Lake Improvement District (2014) is currently implementing a treatment plan to control *P. crispus* with funding from the Minnesota Department of Natural Resources grant program and the Scott Watershed Management Organization. This funding contributed to the herbicide treatment of 100 acres in 2012 and 200 acres in 2013 and cost just over $20,000 each year. The City of Plymouth, Minnesota, implemented a three year control program for Medicine Lake, MN, where over 300 acres were treated each year at a cost of about $105,000 per year.

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**Appendix A**. Weed risk assessment for *Potamogeton crispus* L. (Potamogetonaceae). 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 | *Potamogeton crispus* is native to Africa, Asia, Australia, and Europe (Snyder and Kaufman, 2004; Atlas of Living Australia, 2016), and has been introduced to New Zealand and North America (Bolduan et al., 1994). *Potamogeton crispus* is naturalized in New Zealand (New Zealand Plant Conservation Network, 2013). The first specimen of *P. crispus* in the United States was collected in Delaware, in 1859 (Nichols and Shaw, 1986). By 1900, the species was reported as far west as western Pennsylvania, as far south as Virginia, and as far north as the Canadian side of Lake Ontario (Nichols and Shaw, 1986). By the 1930s it had spread to eastern Minnesota (Stuckey, 1979), and since that time it has spread to nearly every state in the lower 48 United States and the southern regions of the Canadian provinces from Ontario eastward and to the extreme west coastal region (Stuckey, 1979; Kartesz, 2015). Given the spread of this species in North America, we are answering "f", with alternate answers for the Monte Carlo simulation of "e". |
| ES-2 (Is the species highly domesticated) | n - low | 0 | We found no evidence that this species has been domesticated. |
| ES-3 (Weedy congeners) | y - mod | 1 | The genus *Potamogeton* is comprised of 95 species (Haynes and Holm-Nielson, 2003). *Potamogeton distinctus* is considered a serious weed in China and a principle weed in Korea, where it can be a very dominant species in shallow water, such as that found in rice crops (Holm et al., 1979 in WSSA, 2016). We are answering yes for this question due to the Holm et al. (1979) designation as a serious and principle weed. |
| ES-4 (Shade tolerant at some stage of its life cycle) | y - negl | 1 | *Potamogeton crispus* can survive and grow at very low light levels (less than 1% of the surface irradiance) (Tobiessen and Snow, 1984). It also grows in very low light under ice (10-1290 lux) (Bolduan et al., 1994). |
| ES-5 (Plant a vine or scrambling plant, or forms tightly appressed basal rosettes) | n - negl | 0 | This species is neither a vine nor does it form tightly appressed basal rosettes; *P. crispus* is an herbaceous, submerged aquatic plant (Stuckey, 1979; Haynes and Holm-Nielson, 2003). |
| ES-6 (Forms dense thickets, patches, or populations) | y - negl | 2 | This species forms dense beds (Snyder and Kaufman, 2004; GLANSIS, 2016). Images of this species' growth show high density beds (Chris Evans, University of Illinois, Bugwood.org; Graves Lovell, Alabama Department of Conservation and Natural Resources, Bugwood.org). |
| ES-7 (Aquatic) | y - negl | 1 | *Potamogeton crispus* is a submersed, rooted perennial aquatic plant (Stuckey, 1979) that can occupy a range of aquatic habitats (Snyder and Kaufman, 2004). It grows best in alkaline or eutrophic water (Snyder and Kaufman, 2004; Haynes and Holm-Nielson, 2003) and can survive well in brackish areas (Haynes and Holm-Nielson, 2003). |

| Question ID | Answer - Uncertainty | Score | Notes (and references) |
|---|---|---|---|
| ES-8 (Grass) | n - negl | 0 | This species is not a grass, but is a member of the family Potamogetonaceae (NGRP, 2016; Haynes and Holm-Nielson, 2003). |
| 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; NGRP, 2016; Haynes and Holm-Nielson, 2003). *Potamogeton crispus* is an aquatic herb (Stuckey, 1979; Haynes and Holm-Nielson, 2003). |
| ES-10 (Does it produce viable seeds or spores) | y - high | 1 | Seeds observed in lakes in the Pongolo River flood plain of South Africa exhibited germination rates of 0.001%, where 4 of the 1450 seeds observed germinated (Rogers and Breen, 1980). Seeds did not germinate in laboratory tests of dormancy (Muenscher, 1938). Ganie et al. (2008) obtained laboratory germination rates of 4%, but seeds that germinated did develop into seedlings. Germination of *P. crispus* seeds has not been well-studied, and field germination rates are unknown (Nichols and Shaw, 1986). Given the information we were able to find, we are answering yes, with high uncertainty, because although germination rates and viability may be low, it is apparent that seeds are capable of developing. |
| ES-11 (Self-compatible or apomictic) | ? - max | 0 | We found no evidence regarding self-compatibility. Sexual reproduction mechanisms for this species have not been well reviewed, so we are answering unknown. |
| ES-12 (Requires specialist pollinators) | n - negl | 0 | Inflorescences of species in the genus *Potamogeton* are borne above the surface of the water (DiTomaso et al., 2013), and most species in the genus *Potamogeton* are wind pollinated (Catling and Dobson, 1985; Haynes and Holm-Nielson, 2003; DiTomaso et al., 2013). While we did not find direct evidence of *P. crispus* being wind pollinated on a species level, this plant is well-studied and we found no evidence that it requires specialist pollinators. |
| 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 | *Potamogeton crispus* is a perennial species (Catling and Dobson, 1985) that reproduces sexually via seed and vegetatively via turions (DiTomaso et al., 2013) and fragments (Heidbüchel et al., 2016).Turions and fruits develop in early spring and drop to the bottom of the water and lie dormant throughout summer (Tobiessen and Snow, 1984). Fruits and turions germinate in the fall (Bolduan et al., 1994; Catling and Dobson, 1985). Young plants overwinter and grow rapidly in the spring (Bolduan et al., 1994), and die back in early summer (Catling and Dobson, 1985). Fragments will naturally detach from the parent stem due to herbivory or flow velocity, and these fragments will quickly regenerate (Heidbüchel et al., 2016). Alternate answers for the Monte Carlo simulation are both "c" for seed production, as this plant is a perennial. |
| ES-14 (Prolific reproduction) | n - low | -1 | Reports of seed production are highly variable. Hunt and Lutz (1959) report that plants produce 1110-1394 seeds/$m^2$. Seed production in a South African lake was 561/$m^2$ (Rogers and Breen, 1980). A single plant can produce up to 960 seeds (Yeo, 1966). Regardless of variability, no reports meet the threshold of 5000 seeds / $m^2$ to be considered prolific production, so we are answering no. |
| ES-15 (Propagules likely to be | y - negl | 1 | Plant fragments are transported on aquatic equipment such as |

| Question ID | Answer - Uncertainty | Score | Notes (and references) |
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| dispersed unintentionally by people) | | | boats, trailers, motors, and fishing gear (Indiana DNR, 2009; Southeastern Wisconsin Invasive Species Consortium, 2016; Bruckerhoff et al., 2015). |
| ES-16 (Propagules likely to disperse in trade as contaminants or hitchhikers) | y - mod | 2 | *Potamogeton crispus* occurs in aquaculture facilities and could be moved in contaminated water with fry (Catling and Dobson, 1985). Long distance spread is associated with fish hatchery movement of contaminated water; early reports of specimens from Missouri, Minnesota, Iowa, Oklahoma, and North Carolina came from waters associated with fish hatcheries (Bolduan et al., 1994). Without direct evidence of movement, we are answering yes, but with moderate uncertainty. |
| ES-17 (Number of natural dispersal vectors) | 3 | 2 | Fruit, seed, and propagules traits for questions ES-17a through ES-17e. Fruits are oval shaped, red to reddish brown, and 6 mm x 2.5 mm in size (Haynes and Holm-Nielson, 2003). We were unable to find seed traits for this species, and they are not reviewed in any floras that we accessed. Based on the available literature, it appears as though seedlings sprout directly from fruit and the seed is not shed prior to germination. Turions are stem buds developed in the leaf axils and consist of several reduced, overlapping leaves (DiTomaso et al., 2013). |
| ES-17a (Wind dispersal) | n - mod | | We found no evidence that this species is dispersed by wind. However, with minimal information available regarding seed traits, we are using moderate uncertainty. |
| ES-17b (Water dispersal) | y - negl | | Fruits are released in water and may float for up to 18 months (Haynes and Holm-Nielson, 2003). Turions are distributed passively via water flow (Mikulyuk and Nault, 2009). |
| ES-17c (Bird dispersal) | y - negl | | Birds eat the seeds (Catling and Dobson, 1985), and seeds ingested by birds retain their endocarp and have high germination rates after passing through the digestive tract (Haynes and Holm-Nielson, 2003). Ducks are responsible for much of the spread of *P. crispus* throughout the United States (Stuckey, 1979). |
| ES-17d (Animal external dispersal) | y - high | | Fruit and turions can become caught in animal feet and be dispersed to new water bodies (Michigan DEQ, 2016; DiTomaso et al., 2013). This form of dispersal is not well-reviewed in the literature, and the cases in which it is discussed, the mechanisms of attachment are not fully explored. Therefore, we are using high uncertainty without further evidence of dispersal. |
| ES-17e (Animal internal dispersal) | n - mod | | DiTomaso et al. (2013) note that seeds are ingested by wildlife and may be spread in this manner, however they do not specify if wildlife refers to birds or other animals as well. No other sources mention this as a potential dispersal mechanism, so we are answering no. |
| ES-18 (Evidence that a persistent (>1yr) propagule bank (seed bank) is formed) | ? - max | 0 | Rogers and Breen (1980) determined that *P. crispus* produced 561 seeds/m2, and found in the sediment 1960 seeds/m2, indicating a seed bank consisting of about four years' worth of seeds. This species also forms turion banks (Indiana DNR, 2009; James, 2008). We were unable to determine if the turion banks persist for more than a year. We are answering unknown for this question because seed banks are not a well-reviewed source of seedling production. |
| ES-19 (Tolerates/benefits from | y - negl | 1 | Mechanical control will spread fragments that can resprout |

| Question ID | Answer - Uncertainty | Score | Notes (and references) |
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| mutilation, cultivation or fire) | | | elsewhere (DiTomaso et al., 2013). Stem fragments with at least one node have a high regeneration capacity (Heidbüchel et al., 2016). Fragment lengths of 2 cm, 4 cm, and 6 cm each resprouted successfully and showed no difference in regeneration ability (Jiang et al., 2008), and fragments weighing 1.4 g were able to resprout after 12 hours of drying (Bruckerhoff et al., 2015). |
| ES-20 (Is resistant to some herbicides or has the potential to become resistant) | n - low | 0 | We found no evidence that this species is resistant to herbicides, and it is not listed by Heap (2013) as a weed that is resistant to herbicides. Herbicides that have been found to be effective to manage *P. crispus* include 6-benzyladenine, acrolein, diquat, endothall, gibberilic acid, flumioxazin, fluridone, and imazamox (Michigan DEQ, 2016). |
| ES-21 (Number of cold hardiness zones suitable for its survival) | 9 | 0 | |
| 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) | ? - max | 0.1 | Pakdel et al. (2013) found an inhibitory effect of *P. crispus* shoots on the growth of the cyanobacteria *Anabaena variabilis* Kützing. However, Nakai et al. (1999) found no evidence of allelopathy toward three blue-green algae (*Microcyctis aeruginosa*, *Anabaena flos-aquae*, and *Phormidium tenue*). Allelopathy has not been well studied in this species; therefore we are answering unknown. |
| Imp-G2 (Parasitic) | n - negl | 0 | We found no evidence that this species is parasitic. Furthermore, *P. crispus* does not belong to a family known to contain parasitic plants (Heide-Jorgensen, 2008; NGRP, 2015; Haynes and Holm-Nielson, 2003). |
| **Impacts to Natural Systems** | | | |
| Imp-N1 (Changes ecosystem processes and parameters that affect other species) | y - low | 0.4 | *Potamogeton crispus* growth contributes to the depletion of water nutrients (Catling and Dobson, 1985) and affects the nutrient composition of a water body (Bolduan et al., 1994). When the spring foliage dies off in midsummer, the oxygen demand created by decomposition may severely deplete the levels of dissolved oxygen (Catling and Dobson, 1985). The massive anoxic degradation of *P. crispus* releases dimethyl sulfide, dimethyl disulfide, and dimethyl trisulfide, and greatly changes the cycling of iron, sulfur, and nutrients in the water column (Shen et al., 2014). In a laboratory study of *P. crispus* growth on nutrients in the water column and sediments, Mi et al. (2008) found that Ca, Mg, and Si concentrations in the water column were significantly lower, and P and Cu concentrations were significantly higher than in unplanted controls. |
| Imp-N2 (Changes habitat structure) | y - mod | 0.2 | *Potamogeton crispus* growth begins early in the spring, when water temperatures are still too cold for native species growth (Tobiessen and Snow, 1984; Bolduan et al., 1994). This creates a dense vegetative population before native species can create this layer (Tobiessen and Snow, 1984; GLANSIS, 2016). While |

| Question ID | Answer - Uncertainty | Score | Notes (and references) |
|---|---|---|---|
| | | | this doesn't necessarily create a new layer, it does create this layer sooner than the native population would. Therefore, we are answering yes, with moderate uncertainty. |
| Imp-N3 (Changes species diversity) | y - negl | 0.2 | *Potamogeton crispus* outcompetes native aquatics by shading them out (Snyder and Kaufman, 2004; Catling and Dobson, 1985) and decreases biodiversity (GLANSIS, 2016; Michigan DEQ, 2016). |
| Imp-N4 (Is it likely to affect federal Threatened and Endangered species?) | y- mod | | We found no evidence that this species currently affects federal T&E species, however, the Connecticut Department of Environmental Protection currently treats *P. crispus* in order to protect populations of *P. vaseyi*, a Connecticut state endangered species (Bugbee, 2009). However, because it forms dense patches (Snyder and Kaufman, 2004; GLANSIS, 2016), reduces biodiversity (see Imp-N3) and alters habitat structure (see Imp-N2), we think it is likely to affected T&E aquatic plant species if they co-occur. |
| Imp-N5 (Is it likely to affect any globally outstanding ecoregions?) | y - mod | 0.1 | *Potamogeton crispus* is already present in many counties in the states of Alabama, California, North Carolina, Oregon, Virginia, and Washington that are designated as globally outstanding ecoregions (Ricketts et al., 1999). We are answering yes based on the evidence of occurrence and effects discussed in Imp-N1 through Imp-N3, however given the moderate levels of uncertainty used for the previous questions; we are conservatively using moderate uncertainty for this question. |
| 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 - low | 0.6 | *Potamogeton crispus* is considered an environmental weed in New Zealand (Howell, 2008) and North America (DiTomaso et al., 2013; Michigan DEQ, 2016). Mechanical harvesting is not effective in controlling *P. crispus* in natural areas; weed harvesters will spread fragments that can resprout elsewhere, and drawdowns tend to be ineffective as plants can resprout from rhizomes (DiTomaso et al., 2013). Several herbicides are effective for use in natural areas, including penoxsulam, imazamox, fluridone, diquat, flumioxazin, acrolein, and endothall (DiTomaso et al., 2013). The Connecticut Department of Environmental Protection conducted herbicide treatments using diquat in order to control *P. crispus* growth in Crystal Lake, CT, and to protect populations of *P. vaseyi*, a Connecticut state endangered species (Bugbee, 2009). We are answering "c", and we are using low uncertainty. 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) | n - mod | 0 | We found no evidence of that *P. crispus* impacts personal property, human safety, or public infrastructure. |
| Imp-A2 (Changes or limits recreational use of an area) | y - negl | 0.1 | Dense mats of *P. crispus* disrupt boating, swimming, and fishing (Snyder and Kaufman, 2004) and severely restrict water-based recreation (Catling and Dobson, 1985). Dense colonies of *P. crispus* can restrict access to docks and fishing areas until July, when the plants die back (GLANSIS, 2016) |
| Imp-A3 (Affects desirable and ornamental plants, and | n - low | 0 | We found no evidence that this species affects ornamental plants and vegetation. |

| Question ID | Answer - Uncertainty | Score | Notes (and references) |
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| 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] | b - mod | 0.1 | In the United States there are many reports of curly-leaved pondweed becoming a serious weed problem in restricting water-based recreation (Catling and Dobson, 1985). In 2006, the Maine Department of Environmental Protection halted efforts to hand remove *P. crispus* in West Pond from property owner's lakefront areas because the populations were too dense (West Pond Association, 2006). The U.S. Army Corps of Engineers suggests the use of benthic barriers to control small, high use areas such as boat ramps and docks (Utah Division of Wildlife Resources, 2016). We were unable to find much evidence of control in this system; therefore we are answering "b", as it is likely, given the results of our literature search, that the majority of stakeholders do not control *P. crispus* in anthropogenic systems. Alternate answers for the Monte Carlo simulation are both "c". |
| **Impact to Production Systems (agriculture, nurseries, forest plantations, orchards, etc.)** | | | |
| Imp-P1 (Reduces crop/product yield) | n - low | 0 | We found no evidence that *P. crispus* reduces crop/commodity yield. |
| Imp-P2 (Lowers commodity value) | n - low | 0 | We found no evidence that *P. crispus* lowers commodity values. |
| Imp-P3 (Is it likely to impact trade?) | y - mod | 0.2 | *Potamogeton crispus* can be moved in the trade of aquaculture and fish hatcheries, as discussed in ES-16. Honduras, Indonesia, and Timor-Leste require phytosanitary certificates declaring trade shipments to be free of *P. crispus* (APHIS, 2016). Therefore, we believe this species is likely to impact trade and we are using moderate uncertainty to reflect our confidence levels in the pathway of trade. |
| Imp-P4 (Reduces the quality or availability of irrigation, or strongly competes with plants for water) | y - high | 0.1 | Profuse growth of *P. crispus* impedes water flow in irrigation canals (Catling and Dobson, 1985). Michigan's Status and Strategy Guide for *P. crispus* notes that that impact of *P. crispus* growth on water flow in irrigation systems has not been well-studied (Michigan DEQ, 2016), and we were unable to find any sources reviewing the impact of *P. crispus* that cited a source other than Catling and Dobson (1985). We are answering yes, but using high uncertainty without further independent sources reviewing the impact of *P. crispus* on irrigation canals. |
| Imp-P5 (Toxic to animals, including livestock/range animals and poultry) | n - negl | 0 | We found no evidence that this species is toxic. The seeds and vegetative parts of curly-leaved pondweed are eaten by both dabbling and diving ducks and by coots (Catling and Dobson, 1985) |
| 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] | b - low | 0.2 | *Potamogeton crispus* is a weed in fish hatcheries (Catling and Dobson, 1985) and a weed of rice in Bangladesh and India (Moody, 1989). However, we found no evidence that this species is controlled in production systems. Alternate answers for the Monte Carlo simulation are both "a". |
| **GEOGRAPHIC POTENTIAL** | | | Unless otherwise indicated, the following evidence represents geographically referenced points obtained from the Global |

| Question ID | Answer - Uncertainty | Score | Notes (and references) |
|---|---|---|---|
| | | | Biodiversity Information Facility (GBIF, 2015). |
| **Plant hardiness zones** | | | |
| Geo-Z1 (Zone 1) | n - negl | N/A | We found no evidence that this species occurs in this plant hardiness zone. |
| Geo-Z2 (Zone 2) | n - low | N/A | One point each in India and Tajikistan. We are answering "no" as these may be erroneous and the literature does not provide any evidence that this species would be capable of surviving in this plant hardiness zone. |
| Geo-Z3 (Zone 3) | n - mod | N/A | One point in Canada. We are answering "no" because this point may be erroneous and the literature does not provide any evidence that this species would be capable of surviving in this plant hardiness zone. |
| Geo-Z4 (Zone 4) | y - low | N/A | Canada and the United States: Colorado, New York, Vermont, and Wisconsin. |
| Geo-Z5 (Zone 5) | y - negl | N/A | Austria, Canada, Norway, and the United States: Illinois, Iowa, New York, South Dakota, Washington, and Wisconsin. |
| Geo-Z6 (Zone 6) | y - negl | N/A | Austria, Canada, Germany, and the United States: Connecticut, Kansas, Massachusetts, Michigan, Missouri, and Washington. |
| Geo-Z7 (Zone 7) | y - negl | N/A | Canada, India, and the United States: Alabama, Arizona, Idaho, Maryland, Michigan, Nevada, Oregon, and Washington. |
| Geo-Z8 (Zone 8) | y - negl | N/A | Australia, Canada, New Zealand, Pakistan, Spain, and the United States: Alabama, California, Oregon, and Washington. |
| Geo-Z9 (Zone 9) | y - negl | N/A | Australia, New Zealand, Pakistan, South Africa, Spain, and the United States: Alabama, Arizona, California, Louisiana, South Carolina, and Washington. |
| Geo-Z10 (Zone 10) | y - negl | N/A | Australia, Costa Rica, Mexico, New Zealand, South Africa, Spain, and the United States: Arizona and California. |
| Geo-Z11 (Zone 11) | y - negl | N/A | Australia, Colombia, Mauritania, Mexico, New Zealand, South Africa, Spain, and the United States: California. |
| Geo-Z12 (Zone 12) | y - mod | N/A | Australia and New Zealand. |
| Geo-Z13 (Zone 13) | n - high | N/A | Four points in Mexico and Costa Rica, but we are answering "no" because we do not have convincing evidence, either from the geographic data or the literature, that this species could survive in this plant hardiness zone. |
| **Köppen -Geiger climate classes** | | | |
| Geo-C1 (Tropical rainforest) | y - mod | N/A | Colombia and Costa Rica. |
| Geo-C2 (Tropical savanna) | y - low | N/A | Australia, Costa Rica, and Mexico. |
| Geo-C3 (Steppe) | y - negl | N/A | Australia, Spain, and the United States: Arizona, California, Idaho, Oregon, and Washington. |
| Geo-C4 (Desert) | y - mod | N/A | Australia and the United States: Arizona, California, and Nevada. |
| Geo-C5 (Mediterranean) | y - negl | N/A | Australia, France, Portugal, Spain, and the United States: California, Oregon, and Washington. |
| Geo-C6 (Humid subtropical) | y - negl | N/A | Australia, China, Mexico, and the United States: Alabama, Louisiana, Maryland, Missouri, South Carolina, and Tennessee. |
| Geo-C7 (Marine west coast) | y - negl | N/A | Australia, Canada, France, Mexico, New Zealand, Spain, and the United States: Washington. |
| Geo-C8 (Humid cont. warm sum.) | y - negl | N/A | Japan, South Korea, and the United States: Connecticut, Illinois, Iowa, Kansas, Massachusetts, Missouri, Nebraska, Pennsylvania, Utah, and Wisconsin. |
| Geo-C9 (Humid cont. cool | y - negl | N/A | Canada, France, and the United States: Colorado, Connecticut, |

| Question ID | Answer - Uncertainty | Score | Notes (and references) |
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| sum.) | | | Michigan, New York, Utah, Vermont, Washington, and Wisconsin. |
| Geo-C10 (Subarctic) | y - negl | N/A | Austria, Finland, France, Germany, and Norway. |
| Geo-C11 (Tundra) | n - low | N/A | We found no evidence that this species exists or could survive in this climate class. |
| Geo-C12 (Icecap) | n - negl | N/A | We found no evidence that this species exists or could survive in this climate class. |
| **10-inch precipitation bands** | | | |
| Geo-R1 (0-10 inches; 0-25 cm) | y - mod | N/A | Mexico and South Africa. |
| Geo-R2 (10-20 inches; 25-51 cm) | y - negl | N/A | Australia, Mexico, Spain, and South Africa. |
| Geo-R3 (20-30 inches; 51-76 cm) | y - negl | N/A | Australia, France, Mexico, New Zealand, and the United Kingdom. |
| Geo-R4 (30-40 inches; 76-102 cm) | y - negl | N/A | Australia, Canada, France, New Zealand, Portugal, South Africa, and Switzerland. |
| Geo-R5 (40-50 inches; 102-127 cm) | y - negl | N/A | Australia, Canada, France, New Zealand, Portugal, South Africa, and Spain. |
| Geo-R6 (50-60 inches; 127-152 cm) | y - negl | N/A | Canada, France, Germany, Ireland, New Zealand, Spain, and the United Kingdom. |
| Geo-R7 (60-70 inches; 152-178 cm) | y - negl | N/A | France, Ireland, Mexico, Norway, Spain, and the United Kingdom. |
| Geo-R8 (70-80 inches; 178-203 cm) | y - negl | N/A | Austria, China, France, Slovenia, Spain, and the United Kingdom. |
| Geo-R9 (80-90 inches; 203-229 cm) | y - negl | N/A | Austria, France, Japan, Mexico, Slovenia, and Switzerland. |
| Geo-R10 (90-100 inches; 229-254 cm) | y - negl | N/A | China, Costa Rica, France, and Japan. |
| Geo-R11 (100+ inches; 254+ cm) | y - negl | N/A | China, Costa Rica, Colombia, and Japan. |
| **ENTRY POTENTIAL** | | | |
| Ent-1 (Plant already here) | y - negl | 1 | The first verifiable specimen of *P. crispus* was collected from Wilmington, Delaware, in 1859 (Nicholas and Shaw, 1986; Stuckey, 1979). This species is now present in every state in the lower 48 except South Carolina (Kartesz, 2015). |
| 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 | - | N/A | |

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