Hydrilla (*Hydrilla verticillata*) - monoecious biotype

Ecological Risk Screening Summary – Great Lakes Basin

U.S. Fish and Wildlife Service, Web Version – 9/13/2017

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1 Native Range and Status in the Great Lakes Basin

Native Range

From Jacono et al. (2011):

"Korea appears the likely origin for the monoecious type (Madeira et al. 1997)."

Status in the Great Lakes Basin

Hydrilla verticillata was found in a 15 mile stretch the Erie Canal in Tonawanda, NY in September 2012 (USACOE 2014).

Means of Introductions in the Great Lakes Basin

There is no conclusive information on means of introduction to the Great Lakes Basin.

Remarks

From CABI (2015):

"*H. verticillata* is a submerged plant that has rapid growth and a highly effective survival strategy that makes it one of the most troublesome aquatic weeds of water bodies in the world. It forms dense masses, outcompeting native plants and interfering with many uses of waterways. It can be spread by water flow, waterfowl and recreational activities and is sold as an aquarium plant. In the USA it has been listed as Federal Noxious Weed since 1976; its import is prohibited in Western Australia and Tasmania, and it is on the EPPO alert list."

From NANSP (2013):

"Langeland (1996) suggested that monoecious hydrilla could spread as far north as southern Canada, based on its range in Europe. Les et al. (1997) compiled the northernmost hydrilla distributions worldwide and Balciunas and Chen (1993) provided a comparison of January temperatures in North America to those in Asia where hydrilla has been documented. Based on reported worldwide hydrilla distribution and climate patterns, there are vast areas in North America at risk of invasion by hydrilla (Figure 3)."

2 Biology and Ecology

Taxonomic Hierarchy and Taxonomic Standing

From ITIS (2015):

"Kingdom Plantae
  Subkingdom Viridiplantae
    Infrakingdom Streptophyta
      Superdivision Embryophyta
        Division Tracheophyta
          Subdivision Spermatophytina
            Class Magnoliopsida
              Superorder Lilianae
                Order Alismatales
                  Family Hydrocharitaceae
                    Genus *Hydrilla*
                      Species *Hydrilla verticillata* (L. f.)Royle"

"Taxonomic Status: Current Standing: accepted"

Size, Weight, and Age Range

From Jacono et al. (2011):

"Stems grow up to 9 m in length; leaves are 6-20 mm long and 2-4 mm wide."

Environment

From GISD (2011):

"*H. verticillata* is found in freshwater but can tolerate salinities of up to 7% salinity of seawater. It has been found in springs, lakes, marshes, ditches, rivers, and tidal zones. It can grow in relatively low light and CO2 conditions."

From CABI (2015):

"In the tropics, *H. verticillata* is described as tolerant of a wide variety of water conditions, from acidic and oligotrophic to eutrophic or brackish; it thrives on many kinds of pollution and tolerates a great deal of disturbance (Cook and Lüönd, 1982), although increasing salinity appears to limit its dispersal (Rout et al., 1998; Mataraza et al., 1999; Rout and Shaw, 2001). Due to its tolerance of low light conditions (White et al., 1996), it is capable of growing in water up to 7 m deep (Yeo et al., 1984). […] In temperate regions, it grows in alkaline, moderately calcareous, mesotrophic or slightly eutrophic waters (Preston and Croft, 1997), richer in SO4, but generally poorer in Na, K and Cl than those of Elodea canadensis (Klosowski and Tomaszewicz, 1997). It also appears to occur more often as scattered stands within more diverse aquatic plant communities (Klosowski and Tomaszewicz, 1997; Balevicius, 1998)."

Climate/Range

From GISD (2011):

"*H. verticillata* prefers temperatures between 20 and 27 degrees Celsius."

From NANSP (2013):

"Optimal growth and survival for the dioecious type is found in warmer climates, while the monoecious form is better suited for more temperate climates with lower temperatures and shorter growing seasons (Ames et al. 1986; Van 1989; Madeira et al. 2000; Netherland 1997; Steward et al. 1987). Dioecious hydrilla typically thrives all year in the warm waters of the southern US, while monoecious hydrilla dies back completely in the winter and acts as a herbaceous perennial (Harlan et al. 1985)."

Distribution Outside the United States

Native

From Jacono et al. (2011):

"Korea appears the likely origin for the monoecious type (Madeira et al. 1997)."

From CABI (2015):

"It is thought to be native but is relatively rare in Europe (Preston and Croft, 1997), sufficiently so that it is protected in Lithuania (Balevicius, 1998). It occurs in certain areas in Poland and Belarus, and has been found in solitary lakes in Ireland (Preston and Croft, 1997)."

Introduced

From GISD (2011):

"The dioecious and the monoecious plant are now found on every continent except Antarctica."

From Zhuang (2013):

"Introduced:
Austria; Germany; Hungary; Italy; Spain (Canary Is., Spain (mainland)); United States
Present - origin uncertain:
Latvia; Poland"

From CABI (2015):

"On the African continent it occurs around Lake Victoria and Lake Tanganyika in the Rift Valley of East Africa, while it has also been reported from Mozambique and a few isolated places in West Africa and, in 2006, from South Africa."

Means of Introduction Outside the United States

From GISD (2011):

"Floating vegetation/debris: Plant fragments dispersed by river flow.
Ignorant possession: Shipments of water lilies have been found contaminated with Hydrilla.
Pet/aquarium trade: Sold as an aquarium plant."

Short Description

From Jacono et al. (2011):

"Submersed perennial herb. Rooted, with long stems that branch at the surface where growth becomes horizontal and dense mats form. Small, pointed leaves are arranged in whorls of 4 to 8. Leaves have serrated margins and one or more sharp teeth under the midrib (see Godfrey and Wooten 1979). Development of these features may vary with location, age, and water quality (Kay 1992)."

From CABI (2015):

"*H. verticillata* is a submerged, monoecious or dioecious perennial. Its stems are branched, about 1 mm thick and up to 3 m long; the internodes are 3 to 50 mm long. The sessile leaves are formed in whorls at the nodes; there are 3-8, sometimes up to 12 leaves in a whorl. The leaves

are 7-40 mm long, linear to lanceolate, with a conspicuous midrib. They have sharply toothed margins and spines on the vein on the lower side of the leaves; a few teeth may also be formed on this vein. These leaf characteristics are commonly used to distinguish *H. verticillata* from similar submerged plants in the Hydrocharitaceae, like *Egeria* and *Elodea* spp.

The inflorescences are unisexual, arising from spathes situated in the leaf axils, each flower has three sepals and three petals. All six perianth parts are clear or translucent green (the sepals usually slightly reddish).The male spathe is about 1.5 mm long, solitary in the leaf axils, somewhat spiny. The female spathe is about 5 mm long, solitary in the leaf axils. There are three petals, three stamens and three styles. The ovary is cylindrical to narrowly conical and is enclosed in the base of a hypanthium; the style is as long as the hypanthium and there are three stigmas. For further information, see Cook et al. (1974) and Aston (1977).

The fruit is cylindrical, about 7 mm long and 1.5 mm wide. It contains 2-7 oblong-elliptic seeds. For further information, see Cook and Lüönd (1982); Swarbrick et al. (1981); and Yeo et al. (1984)."

Biology

From GISD (2011):

"*H. verticillata* reproduces mostly by asexual vegetative fragmentation (from stem fragments), but it also grows new plants from tubers and underground tubers and reproduces sexually with flowers. One *H. verticillata* tuber can lead to the production of 5,000 new tubers per square m. It spreads faster in flowing water habitats because the fragments are more efficiently dispersed.

Tubers and turions can survive ice cover, drying, ingestion, and regurgitation by waterfowl. Tubers may remain viable in the sediment for several years."

From CABI (2015):

"*H. verticillata* is a submerged plant which is rooted by means of filiform, adventitious roots. The stems, which consist of distinct nodes and internodes, are branched and approach or touch the surface of the water. The internodes tend to elongate in flowing water. The flowers are unisexual, arising from spathes situated in the leaf axils, each flower has three sepals and three petals. All six perianth parts are clear or translucent green (the sepals usually slightly reddish). The ovary is enclosed in the base of a hypanthium, the style is as long as the hypanthium and there are three stigmas. Due to an elongation of the hypanthium, the female flower ascends to the surface of the water. The perianth segments remain closed over the stigmas during this movement and retain a bubble of air above them. The perianth segments open to form a wide funnel which floats with its rim just at the water surface, its walls holding back the water and preventing wetting of the stigmas. The male flower becomes detached from the plant and subsequently rises to the surface of the water where the perianth segments uncurl. The anthers dehisce explosively and spread pollen for some 20 cm around the open flower. Pollination occurs via the air.

H. verticillata spreads horizontally by means of branches which grow over the bottom of a waterbody. Vertical branches and roots are produced at nodes on these runners. Vegetative multiplication is also possible by means of fragmentation, i.e. pieces of branches which have become detached are able to form new, rooted plants, if they come into contact with a favourable substratum. In the USA, hydrilla grows optimally at 20-27°C.

It is capable of surviving conditions unfavourable for growth, by producing two types organ capable of remaining dormant for extended periods. These structures are respectively formed in the axil of a leaf (generally described as axillary turions, turions or green turions) and at the tip of branches which grow into the hydrosoil (generally described as subterranean turions, brown turions or tubers). (Turions can be defined as short, specialized shoots of aquatic plants in which food material is stored and which eventually become detached from the parent plant). The axillary turions are stalked and cylindrical or slightly conical in shape. The subterranean turions are boat-shaped and covered by whorls of tough and fleshy scale leaves. For further information on these turions, see the Description section. As many as 1000 (Pieterse, 1981) to 6000 (USDA, 2011) subterranean turions may be produced per square metre in one growing season and remain viable for over 4 years (USDA, 2011). In Florida, USA, the average number of subterranean turions varies from 36 to 207 per m^2 and the average number of axillary turions from 5 to 90 per m^2 (Sutton and Portier, 1985). In areas where *H. verticillata* dies during the winter, the formation of turions occurs mainly in the autumn. Axillary turions are frequently formed on free-floating fragments. The formation of subterranean turions is stimulated by short days (Steward and Van, 1987).

There have been numerous studies into the biology of turion production; the most useful of these is a comprehensive review (Netherland, 1997). Additional studies have dealt with the effects of photperiod on turion development (Steward, 1997; Steward, 2000); factors affecting turion formation (Langeland et al., 1996); the size of turions (Spencer and Ksander, 1995); and the timing of plant development from turions (Spencer and Ksander, 1995; Spencer and Ksander, 1997).

H. verticillata may be either monoecious or dioecious. Its rapid vegetative growth and, as a consequence, the formation of large clones, questions whether strains which produce only male or female flowers are able to reproduce effectively by sexual means. In California and the Gulf States of the USA, and in Europe, there is no seed formation because only female flowers are produced."

From NANSP (2013):

"Pesacreta (1990) examined carbohydrate allocation in monoecious hydrilla and found that the majority of starch accumulation occurred in plant shoots when exposed to short photoperiods. Starch levels in tubers were found to decrease mostly in the first two weeks after sprouting (Pesacreta 1990). Pesacreta (1990) also found that monoecious hydrilla displayed enhanced fragmentation after 8 weeks of high temperatures (32° C)."

"Monoecious hydrilla tubers have a very high germination rate in laboratory trials, often greater than 90% (Harlan et al. 1985, Van and Steward 1990, personal experience). However, while

monoecious hydrilla tubers readily germinate when removed from sediment, when left undisturbed in situ the germination rate is much lower (Van and Steward 1990). Carter et al. (1987) found that monoecious hydrilla tubers require a chilling period prior to sprouting which may prevent sprouting the same year of formation. Monoecious hydrilla tubers have been shown to remain in undisturbed soil for more than 4 years after production (Van and Steward 1990), and six year tubers have still been viable in North Carolina (unpublished data). There appears to be an environmental factor imposed dormancy which prevents depletion of tuber populations. Axillary turions will germinate within one year or not at all (Van and Steward 1990). Nawrocki et al. (2011) also found that monoecious hydrilla tubers have multiple axillary buds preformed within dormant tubers that can produce secondary shoots, even after terminal shoot removal."

From Jacono et al. (2011):

"Freshwater lakes, ponds, rivers, impoundments and canals."

Human Uses

From GISD (2011):

"Pet/aquarium trade: Sold as an aquarium plant."

From Zhuang (2013):

"A dried powder from the plant has be [sic] used as detergent in the treatment of abscesses, burns and wounds. It has been used as an ornamental plant."

Diseases

From CABI (2015):

"Epiphytic cyanobacteria found on hydrilla are thought to be the agents producing a toxin that causes avian vacuolar myelinopathy (AVM) a disease that has killed at least 100 bald eagles (*Haliaeetus leucocephalus*) and thousands of American coots (*Fulica americana*) since 1994 in locations from Texas to North Carolina, USA (Wilde et al., 2005). The incidence of AVM is likely to increase as *H. verticillata* spreads."

Threat to Humans

From CABI (2015):

"It can also result in reduced water flow and stagnant pools which become habitats for mosquito larvae. A case study on the social impact of invasion of a lake in Guatemala by hydrilla has been produced by Binemelis et al. (2007)."

From GISD (2011):

"Apart from interfering with fishing, boat motors can become tangled with them and swimming areas choked. *H. verticillata* often slows or clogs rivers, irrigation ditches, and flood control

canals, creating stagnant water that is prime mosquito breeding habitat. Dense stands can even cause flooding, alter water quality by decreasing oxygen levels and increasing pH and water temperature."

3 Impacts of Introductions

From Jacono et al. (2011):

"Once established, hydrilla results in an array of ecosystem disruptions. Changes often begin with its invasion of deep, dark waters where most plants can not grow. Hydrilla grows aggressively and competitively, spreading through shallower areas and forming thick mats in surface waters that block sunlight penetration to native plants below (van Dijk 1985). In the southeast, hydrilla effectively displaces beneficial native vegetation (Bates and Smith 1994) such as wild-celery (*Vallisneria americana*) and coontail (*Ceratophyllum demersum*) (van Dijk 1985; Rizzo et al. 1996).

It has been shown to alter the physical and chemical characteristics of lakes. Colle and Shireman (1980) found sportfish reduced in weight and size when hydrilla occupied the majority of the water column, suggesting that foraging efficiency was reduced as open water space and natural vegetation gradients were lost. Stratification of the water column (Schmitz et al. 1993; Rizzo et al. 1996), decreased oxygen levels (Pesacreta 1988), and fish kills (Rizzo et al. 1996) have been documented. Changes in water chemistry may also be implicated in zooplankton and phytoplankton declines (Schmitz and Osborne 1984; Schmitz et al. 1993).

Hydrilla seriously affects water flow and water use. Infestations in the Mobile Delta are reducing flow in small tidal streams and creating a backwater habitat (J. Zolcynski pers. comm. 1998). Its heavy growth commonly obstructs boating, swimming and fishing in lakes and rivers and blocks the withdrawl [sic] of water used for power generation and agricultural irrigation."

From GISD (2011):

"*H. verticillata* competes with native plants by growing to the water surface and forming dense mats that totally exclude sunlight from other plants, which in turn can significantly reduce aquatic plant and animal biodiversity. Large populations of *H. verticillata* may affect fish size and population levels where predatory fish cannot hunt effectively within the thick mats. The dense mats also affect recreational activities. Apart from interfering with fishing, boat motors can become tangled with them and swimming areas choked. *H. verticillata* often slows or clogs rivers, irrigation ditches, and flood control canals, creating stagnant water that is prime mosquito breeding habitat. Dense stands can even cause flooding, alter water quality by decreasing oxygen levels and increasing pH and water temperature."

From CABI (2015):

"*H. verticillata* poses a potential threat to areas outside its native habitats; this has been demonstrated in the USA and the Panama Canal area. As *H. verticillata* is introduced to the New World as an aquarium plant, legislative measures should be taken worldwide to restrain this trade."

“Due to its rapid growth and a highly effective survival strategy, *H. verticillata* is one of the most troublesome aquatic weeds in the world. It rapidly outcompetes other plant species and forms dense masses, which may completely fill the volume of waterbodies. Consequently, the often multifunctional use of canals, rivers and lakes becomes seriously hampered by infestations of the weed.

Harmful effects of *H. verticillata* include: impeding the movement of irrigation and drainage water; hindering navigation and recreational use of the water; physical interference with hydro-electric schemes and fisheries; competition with native plants; impacts on native fauna; reductions in size and weight of sport fish (Colle and Shireman, 1980 in Jacono et al., 2011); and the creation of favourable habitats for organisms which cause or transmit disease.

Although it is increasingly troublesome in its original habitat in South-East Asia and Australia, particularly in man-made lakes and irrigation canals, its impact is most significant where it is introduced. This applies, in particular, to the USA, where it was introduced in Florida in the early 1950s (Schardt, 1995). The costs of controlling *H. verticillata* in Florida were reported to be $200 per ha per year (Haller, 1995) when an area of more than 12,000 ha were heavily infested in the state. Useful summaries of economic and ecological costs due to *H. verticillata* are provided by the Northeast Aquatic Nuisance Species Panel (for the USA) and by Hofstra and Champion (2006; for New Zealand).”

“Epiphytic cyanobacteria found on hydrilla are thought to be the agents producing a toxin that causes avian vacuolar myelinopathy (AVM) a disease that has killed at least 100 bald eagles (*Haliaeetus leucocephalus*) and thousands of American coots (*Fulica americana*) since 1994 in locations from Texas to North Carolina, USA (Wilde et al., 2005). The incidence of AVM is likely to increase as *H. verticillata* spreads.”

From NANSP (2013):

“Monoecious hydrilla is an extremely tolerant and competitive plant. It can establish and then displace native plants. Monoecious hydrilla can persist alone and competitively with *Elodea canadensis* (Michx.) in flowing systems like streams and waterways in New Zealand (Hofstra et al. 2010). Spencer and Ksander (2000) showed the strong competitive ability of monoecious hydrilla mixed with American pondweed, and Meadows and Richardson (2012) found that monoecious hydrilla out-competed four other submersed aquatic plants (Eurasian watermilfoil (*Myriophyllum spicatum* L.; invasive), curly leaf pondweed [*Potamogeton crispus* L.; (invasive), *Elodea canadensis* Michx. (native), and *Vallisneria americana* Michx. (native)] in a mesocosm trial.”

4 Global Distribution

Figure 1. Known global distribution of both biotypes of *Hydrilla verticillata*. Map from GBIF (2013).

5 Distribution Within the United States

Distribution within the Great Lakes Basin

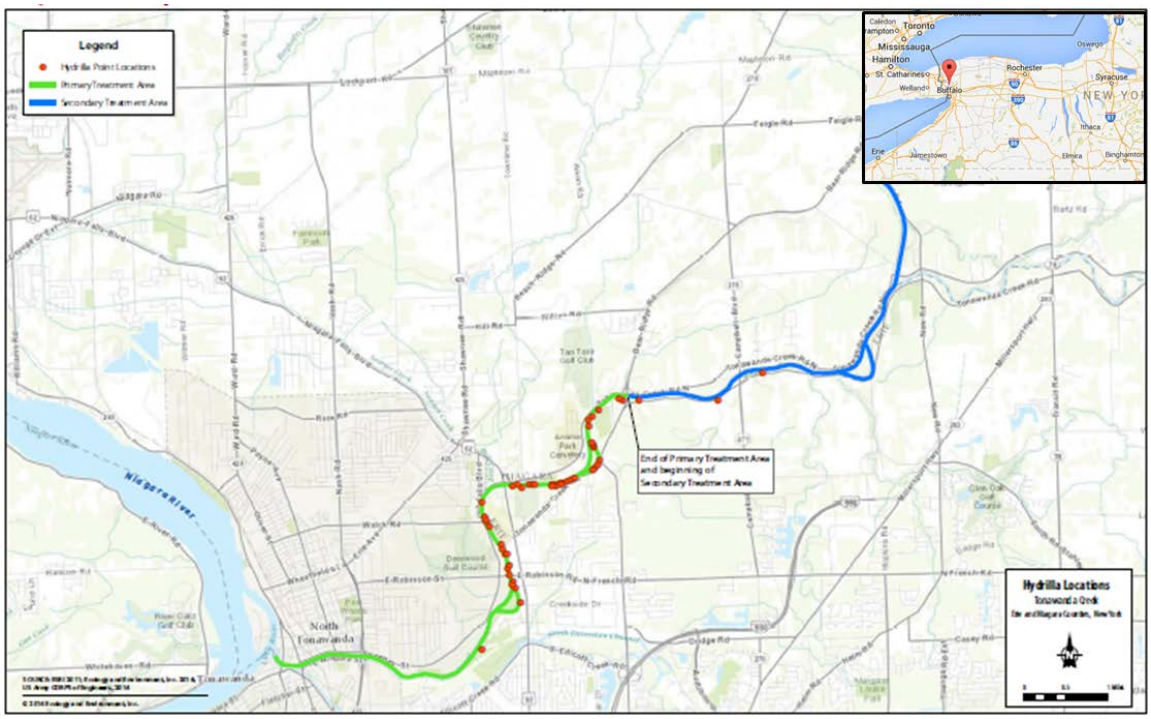

Figure 2. Distribution of monecious *Hydrilla verticillata* in the Great Lakes Basin. Inset map shows location of population in New York. Map from USACOE (2014).

Distribution in the continental United States

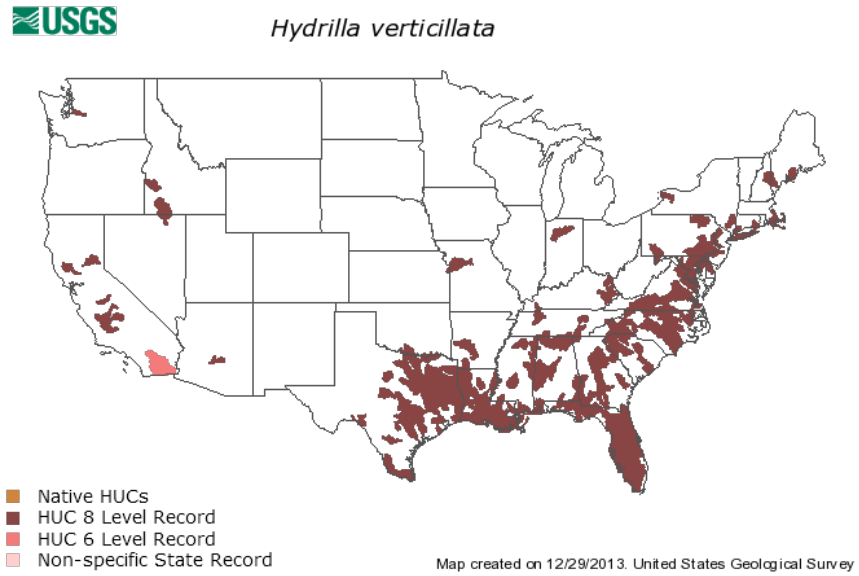

Figure 3. Continental U.S. distribution of both biotypes of *Hydrilla verticillata*. Map from Jacono et al. (2011).

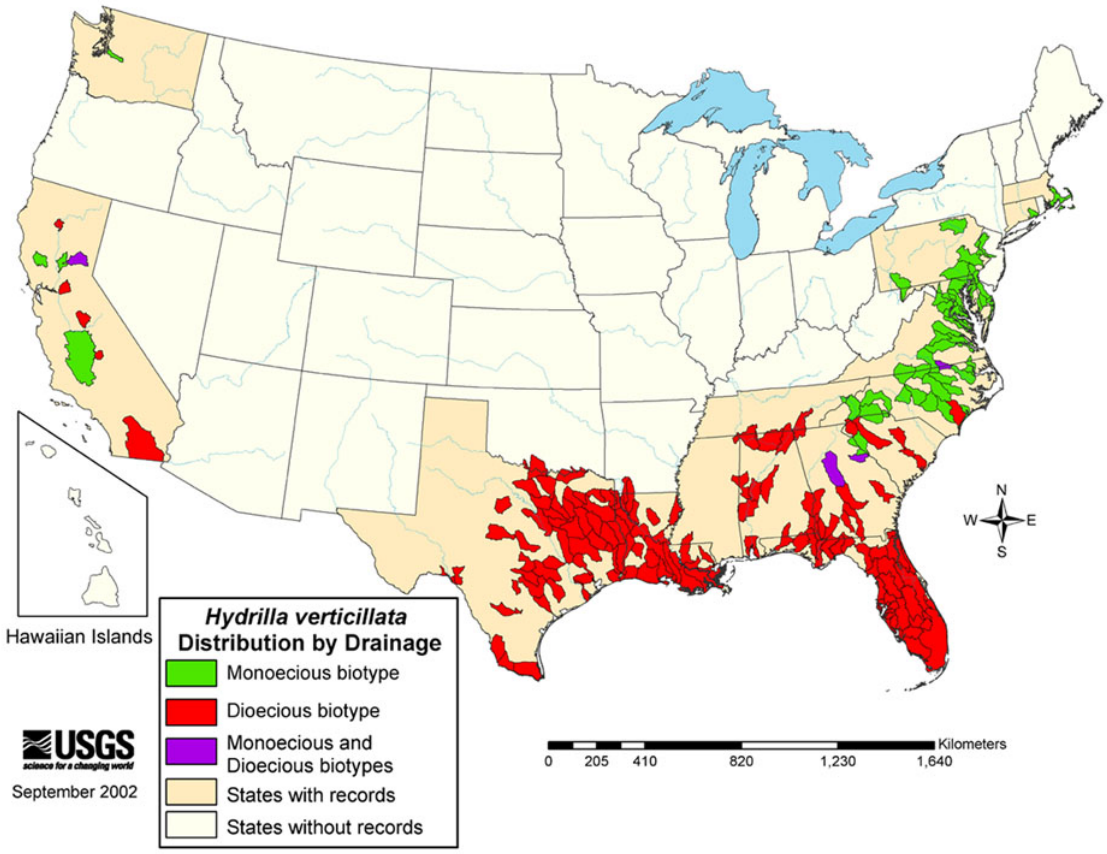

Figure 4. Distribution of the two different biotypes of *Hydrilla verticillata* in the continental U.S. Map from Jacono et al. (2011).

6 Climate Matching

Summary of Climate Matching Analysis

The climate match for monoecious *Hydrilla verticillata* was high for most of the basin and medium for northern Michigan and Wisconsin. The Climate 6 score (Sanders et al. 2014; 16 climate variables; Euclidean distance) for the Great Lakes Basin was 0.923, high.

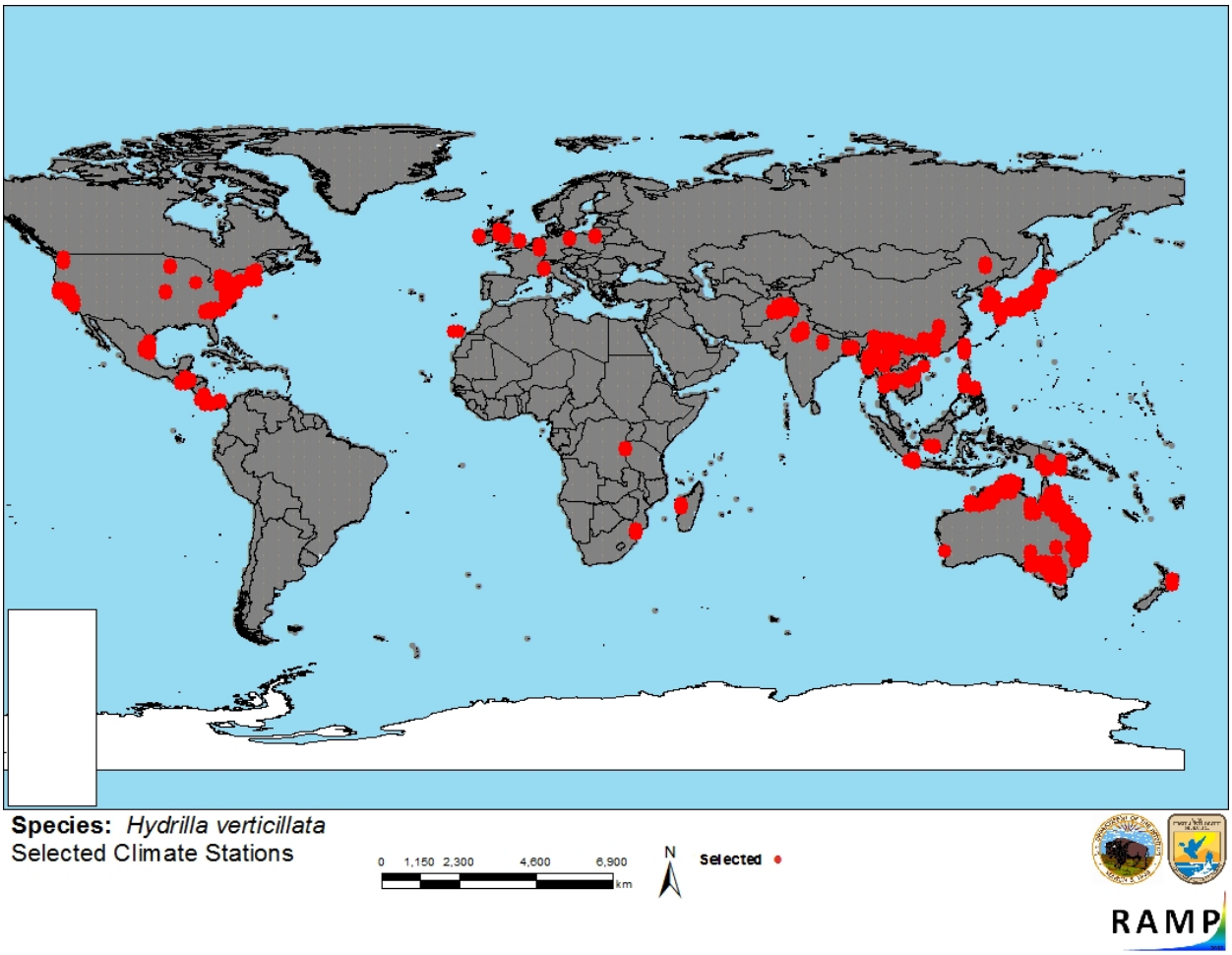

Figure 5. RAMP (Australian Bureau of Rural Sciences 2010) source map showing weather stations selected as source locations (red) and non-source locations (grey) for monoecious *Hydrilla verticillata* climate matching. Locations known to pertain to the dioecious biotype were not included. Other than original biotype source populations, specific biotype locations were only available for the continental U.S. Source locations from Jacono et al. (2011), GBIF (2013), and USACOE (2014).

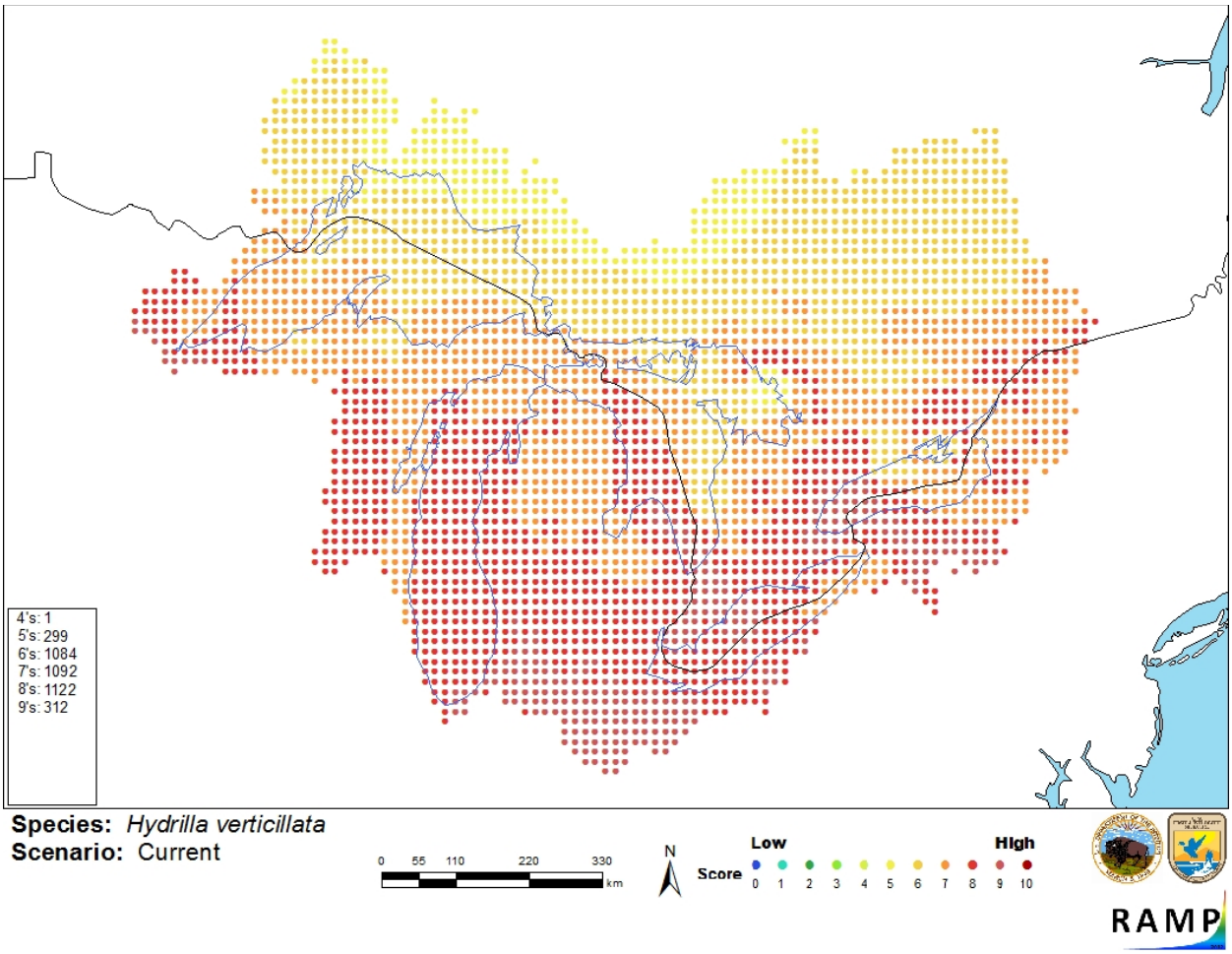

Figure 6. Map from RAMP (Sanders et al. 2014) of a current climate match for monoecious biotype of *Hydrilla verticillata* in the Great Lakes Basin based on source locations reported by Jacono et al. (2011), GBIF (2013), and USACOE (2014). 0 = Lowest match, 10 = Highest match.

The High, Medium, and Low Climate match Categories are based on the following table:

Climate 6: Proportion of (Sum of Climate Scores 6-10) / (Sum of total Climate Scores)	Climate Match Category
$0.000 \leq X \leq 0.005$	Low
$0.005 < X < 0.103$	Medium
≥ 0.103	High

Future Climate Matches

Climate matches for monoecious *Hydrilla verticillata* using Representative Concentration Pathways (RCPs) for predicting future climates based on human produced greenhouse gases (IPCC 2014). RCP2.6 predicts a scenario where emission of greenhouse gasses is reduced, RCP4.5 predicts continued levels of emission from present, and RCP8.5 predicts a future climate

based on rising levels of emissions. Climate matches for each RCP were modeled at two generational time steps, 2050 and 2070.

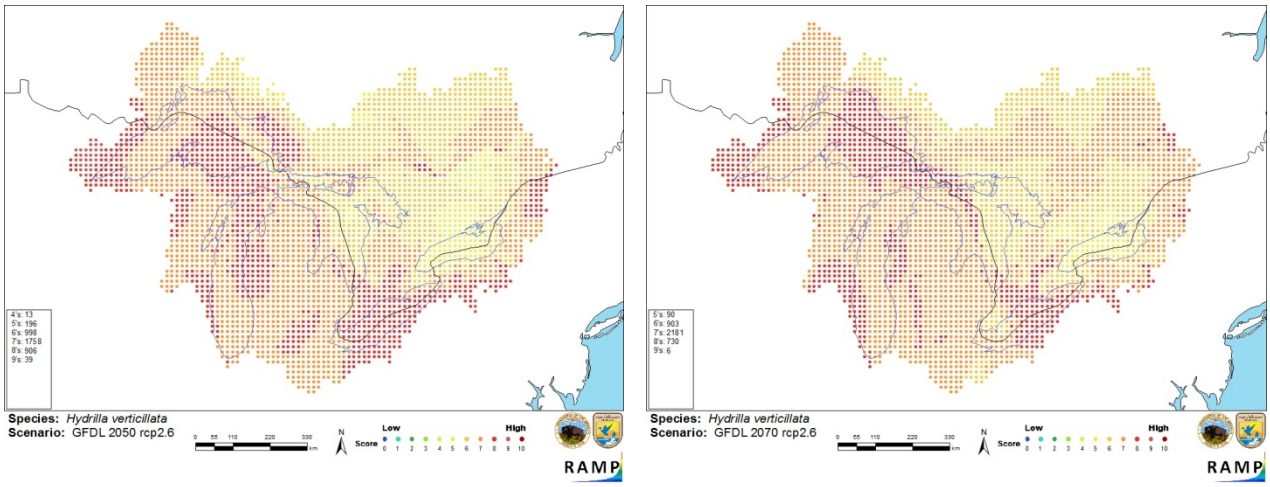

Figure 7. RAMP (Sanders et al. 2014) climate match using RCP2.6 at the 2050 and 2070 time steps. Climate 6 score for 2050 is 0.947 and for 2070 is 0.977.

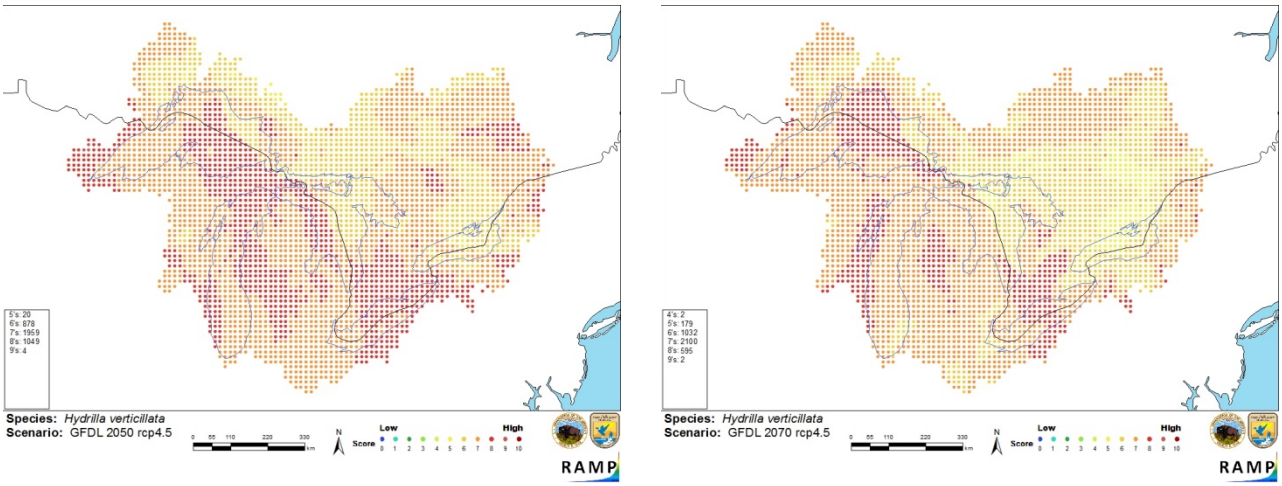

Figure 8. RAMP (Sanders et al. 2014) climate match using RCP4.5 at the 2050 and 2070 time steps. Climate 6 score for 2050 is 0.995 and for 2070 is 0.954.

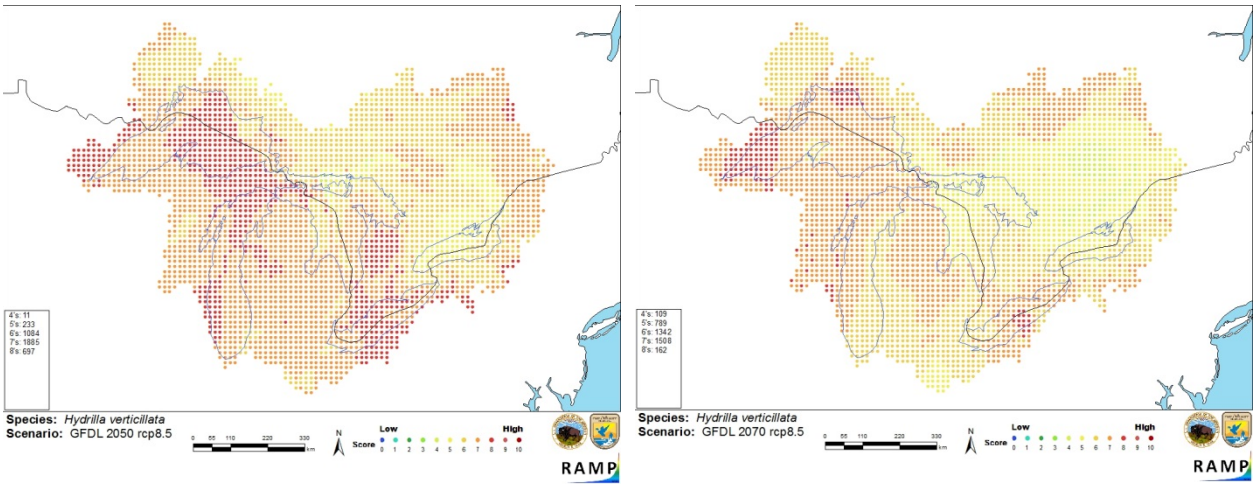

Figure 9. RAMP (Sanders et al. 2014) climate match using RCP8.5 at the 2050 and 2070 time steps. Climate 6 score for 2050 is 0.938 and for 2070 is 0.770.

7 Certainty of Assessment

The certainty of this assessment is high. There is a wealth of information available about *Hydrilla verticillata* in general. There is some information about the distribution of the two different biotypes in the continental U.S. Distributions of the different biotypes around the world were not available. There is a possibility that the climate match would change if a more specific distribution of the biotypes was known. The information provided above states that the two biotypes have different optimal temperatures. It is the author's opinion that any change in source locations for the climate match would still result in a high climate match for monoecious *Hydrilla verticillata* in the Great Lakes Basin.

8 Risk Assessment

Summary of Risk to the Contiguous United States

The history of invasiveness is high. *Hydrilla verticillata* is found on virtually every continent with adverse impacts. The climate match is high. The climate match for the current climate conditions and for all future scenarios resulted in a very high match. The certainty of assessment is high. The overall risk assessment is high.

Assessment Elements

- **History of Invasiveness (Sec. 3): High**
- **Climate Match (Sec. 6): High**
- **Certainty of Assessment (Sec. 7): High**
- **Remarks/Important additional information** Monoecious hydrilla is already present in the basin. Risk of spreading is high; the Erie Canal has high recreational traffic.
- **Overall Risk Assessment Category: High**

9 References

Note: The following references were accessed for this ERSS. References cited within quoted text but not accessed are included below in Section 10.

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10 References Quoted But Not Accessed

Note: The following references are cited within quoted text within this ERSS, but were not accessed for its preparation. They are included here to provide the reader with more information.

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