2.2 Hydrilla

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Hydrilla verticillata (L.f.) Royle; submersed plant in the Hydrocharitaceae (frog's-bit) family
Derived from *hydr* (Greek: water) and *verticillus* (Latin: whorl) "water plant with whorls of leaves"

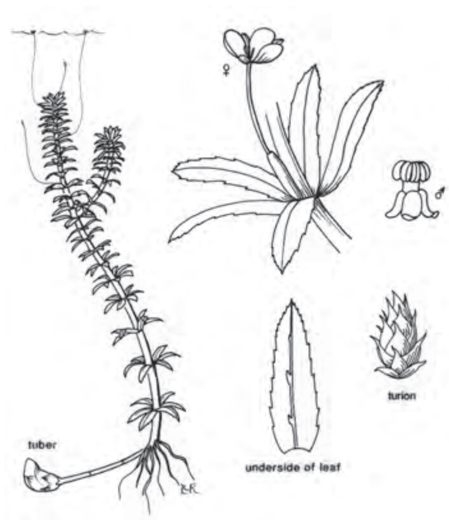
Dioecious introduced from Asia to Florida in the late 1950s
Monoecious introduced in 1970s in Mid-Atlantic states
Present throughout the southeast and north to New England and Wisconsin; west to California, Washington and Idaho

Introduction and spread

Hydrilla (*Hydrilla verticillata*) is the only recognized species in the genus *Hydrilla* but numerous biotypes occur in its Asian native range. Some biotypes are monoecious with separate pollen-bearing ("male") and seed-producing ("female") flowers on the same plant, whereas others are dioecious (each plant bears only "male" or "female" flowers). The monoecious and dioecious biotypes are almost identical and can be virtually impossible to tell apart. It appears that hydrilla was introduced to North America on at least two separate occasions which accounts for the two different biotypes present in the US. Hydrilla presently occurs in North America from Texas north to Wisconsin and eastward to Maine and in the west from Arizona north to Idaho. It was likely introduced through the aquaculture and aquarium trade. Hydrilla was added to the Federal Noxious Weed List in the late 1970s and is on many state prohibited lists as well. These listings prohibit interstate sale and shipment of the species, but hydrilla is readily available for purchase on the internet. It is easily spread by irresponsible boaters and others who move plants from one watershed to another, since the species reproduces and forms new colonies from small plant fragments that hitchhike on boats and other equipment. There is no direct evidence to suggest that hydrilla is spread by waterfowl or other aquatic fauna, but this type of transfer may occur between bodies of water that are in close proximity to one another. However, many confirmed initial infestations have occurred near public access points, suggesting that boaters continue to inadvertently transfer hydrilla on trailered boats.

Description of the species

Hydrilla is a rooted, submersed perennial monocot that grows in all types of bodies of freshwater, with growth limited only by water depth and velocity of flow. The stems of hydrilla are slender (about 1/32 of an inch in thickness), multi-branched and up to 25 feet in length – apical meristems can grow as much as an inch per day and there are dozens produced as the plant nears the water surface. Hydrilla forms dense underwater stands and often "tops out" to form dense canopies or mats on the surface of the water. All vegetative parts of hydrilla are submersed and the appearance of the species can vary drastically depending on growth conditions such as water pH, hardness and clarity.



Hydrilla has small (to 5/8 of an inch in length), strap-like, pointed leaves. The midrib on the underside of the leaf often has one or more sharp teeth along its length and leaf margins are distinctly saw-toothed, especially in hard water. Leaves are attached directly to the stem and are borne in whorls of four to eight around the stem, with a space of 1/8 to 2 inches between whorls. Healthy leaves are bright green, whereas leaves under stress from fungi, bacteria and sun-bleaching may be brown or yellow. Hydrilla is often confused with native elodea (*Elodea canadensis*) and exotic *Egeria densa* (commonly called egeria or Brazilian elodea) (Section 2.5). While these three species are very similar in appearance, leaves of native elodea are borne in whorls of three and those of egeria are arranged in whorls of four or five. In addition, only hydrilla has saw-toothed leaf margins; the leaf margins of the other species are smooth. It is often difficult – even for trained biologists – to tell hydrilla, native elodea and egeria apart. This makes early detection and rapid response efforts very difficult since by the time hydrilla is positively identified it has often produced reproductive tubers and turions. Plants can be positively identified as hydrilla by digging 3 to 4 inches into the soil and looking for the presence of tubers or turions among the roots, as hydrilla is the only one of these species to produce these reproductive structures.

Reproduction

Hydrilla is spread primarily by vegetative means (plant fragments) since each leaf node has axillary buds in the leaf axils capable of producing a new plant. Its spread by this method has been rapid and has increased the species' range throughout most of the southeastern US. Hydrilla produces two types of vegetative reproductive structures: turions and tubers. Turions are small (to 1/4 inch in diameter), cylindrical, dark green and borne in leaf axils, whereas tubers are larger (to 1/2 inch in diameter), potato-like, yellowish and attached to the tips of underground rhizomes 2 to 4 inches below the surface of the sediment. Dioecious hydrilla produces tubers and turions during winter short-day conditions in the southeastern US, whereas monoecious hydrilla behaves like a herbaceous perennial and produces these structures in mid to late summer in northern waters. Hydrilla is the only species in the Hydrocharitaceae family to produce tubers and turions, so the presence of these structures is considered confirmation that the plant in question is indeed hydrilla. Underground tubers can remain dormant for many years; this protects the species from management efforts such as drawdowns (Section 3.4) and allows plants to survive adverse conditions. Studies have shown that a single sprouting tuber of hydrilla planted in shallow water can produce several hundred tubers per square foot each year. Monoecious hydrilla is able to produce seeds, but their contribution to population development and expansion in thought to be negligible.

Problems associated with hydrilla

Hydrilla grows almost entirely underwater as a submersed aquatic plant and its growth potential is limited primarily by water clarity and depth of light penetration. Hydrilla has been reported at depths of 35 to 40 feet in crystal clear spring water and is commonly found at water depths of 15 to 20 feet in lakes with clear water. Hydrilla is uniquely adapted to grow under low light conditions, which allows it to colonize water that is deeper than most native submersed species can tolerate. For example, native submersed plants typically colonize the margins of shallow lakes where water depth is 6 to 8 feet. Hydrilla competes with native plants in these shallow areas, but also grows in much deeper water with little or no competition, which greatly extends the area of the vegetated littoral zone outward from the shoreline into deeper waters.

Hydrilla infestations often go unnoticed until the species tops out and reaches the surface of the water, where it forms hundreds of lateral branches due to the increased light intensity. This surface canopy or mat formed in the upper 1 to 2 feet of water comprises as much as 80% of the biomass of the plant on an area basis and limits light availability to lower-growing native submersed plants, which reduces species diversity over time. The ecological effects of this dense growth on the water surface include significant changes in water temperature, wave action, oxygen production, pH and other parameters, which reduce the suitability of infested waterways for use by aquatic fauna. Human activities are adversely affected as well – recreational use of water is limited, property values are diminished and there are increased public health and safety concerns (e.g., mosquito control, drowning, flooding). The severity of problems caused by hydrilla depends on the characteristics of the infested water body. An acre or two of hydrilla in a 100-acre lake may cause few problems; however, coves, bays or lakes with infestations of 80% or greater are significantly impacted by hydrilla.

Management options

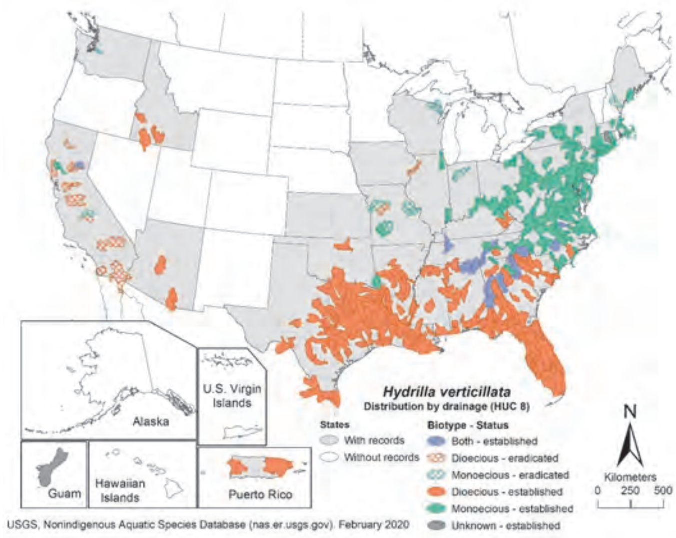
Clearly, preventing hydrilla from entering a water body is the best method to control this noxious species. Federal and state authorities have made it illegal to sell and transport hydrilla, which reduced this source of infestation. However, hydrilla still manages to increase its range and to colonize new bodies of water. Once hydrilla becomes established in a water body, control options are costly and generally must be employed on an annual basis.

Mechanical (Section 3.5) or physical (Section 3.4) control projects such as hand removal, benthic barriers or mechanical harvesters should be designed to prevent the spread of hydrilla fragments to other parts of the water body. Of course, if a lake is already extensively infested by hydrilla, there is less concern regarding plant fragmentation. Hand removal is labor-intensive and must take into consideration the presence of tubers and turions in and on the sediment, since failure to remove these structures virtually assures rapid reinfestation of the site. Mechanical harvesting can be expensive and most harvesters only cut to a water depth of 5 feet (although new deep-water harvesters are now available – see page 135). Since hydrilla meristems can grow an inch per day, control may only last for 2 to 3 months after mechanical harvesting. Another problem associated with mechanical harvesting is disposal of the harvested hydrilla. This vegetation has been evaluated for its potential as mulch, cattle feed, biofuel production and other uses, but its utility is very limited. Also, submersed plants do not produce much dry matter – a surface mat of hydrilla may weigh as much as 15 tons per acre, but contains only 5% (1,500 pounds) dry matter. As a result, harvested hydrilla is generally disposed of in a landfill due to its high water content (95% by weight) and low production of biomass. Drawdowns and freezing of hydrilla tubers and turions may provide temporary control in northern locations, but these measures provide only a season or partial season of control in the southeastern US. Thus, most hydrilla management programs rely on the use of biological control agents (grass carp) or herbicides.

Classical insect-based biocontrol of hydrilla has been studied for at least 50 years (Section 3.6.1). Researchers continue to seek possible biocontrol insects, pathogens and other agents in Asia and Africa. A few promising candidate insects have been discovered, studied and released to control hydrilla, but these insects have provided only localized and temporary reductions in hydrilla populations and are not considered to be viable biocontrol agents. In contrast, sterile triploid grass carp (Section 3.6.2) are widely used for hydrilla control in some states. Grass carp are released primarily in closed ponds or lakes and are sometimes used in conjunction with herbicides. Grass carp are not species-specific as required for the introduction of biocontrol insects; grass carp may prefer hydrilla but will consume most submersed and emergent aquatic plants. As a result, most states regulate the stocking and use of grass carp. Despite this challenge, grass carp continue to be the most effective method for biological control of hydrilla where their use is legal and practical.

Several herbicides (Section 3.7.1) can be used to effectively control hydrilla, but one of the most significant problems associated with chemical control of any submersed species is dilution. An acre of water that is one foot deep comprises 325,800 gallons of water, which results in tremendous dilution of herbicides. In addition, water flow or movement greatly reduces the amount of time hydrilla is exposed to the herbicide. These factors can make it difficult to control hydrilla using chemical methods, so treatments have to be designed to take dilution and water movement into consideration to achieve optimum results. See Section 3.7.1 for concentration/exposure requirements for aquatic herbicides.

Fast-acting contact herbicides – including copper, diquat, endothall, florpyrauxifen-benzyl and flumioxazin – are taken up quickly by hydrilla and usually cause plant death and decay in a few weeks. Most contact herbicides are applied at concentrations of 200 or greater ppb, but the fast-acting contact herbicide florpyrauxifen-benzyl is used at very low concentrations (2 to 48 ppb). Contact herbicides are generally used for spot treatments, strip treatments along shorelines and in areas where water movement would limit the use of slower-acting systemic herbicides that require much longer exposure times. Slow-acting systemic herbicides – including fluridone, imazamox, penoxsulam, bispyribac and topramezone – control hydrilla by inhibiting enzyme activity. These herbicides are usually applied as whole-lake treatments and provide control of hydrilla only when a long period of contact or exposure is possible. An advantage to systemic herbicides is that they are effective at low doses (usually concentrations of less than 25 to 50 ppb of fluridone, penoxsulam, bispyribac and topramezone). These herbicides slowly kill plants by starving them over a long period of time, but usually provide one to two years of control. Slow plant decay resulting from systemic herbicide treatments minimizes possible oxygen depletion, which reduces the potential for fish mortality. The disadvantage of systemic herbicides is that they generally require a whole-lake treatment, or at least treatment in coves, bays and other areas where water movement and dilution are reduced and there is little or no water exchange. Most states require permits to apply herbicides in public (and some private) waters, so contact your state water authority for further advice and information. An additional valuable source of information is the herbicide label, which is available on the manufacturer website or at www.cdms.net and describes the safety requirements, how the herbicide works, how much to apply and other useful information.



Eradication efforts

Conservation agencies and resource managers are very concerned about the rapid spread of hydrilla and eradication efforts are underway in several states. Hydrilla has been successfully eradicated in primarily small ponds in Wisconsin, Washington, Missouri, Iowa and Indiana. California has had an eradication program in place for nearly four decades and has spent millions of dollars stocking grass carp, dredging, draining and using herbicides in their aggressive control efforts. Other states with ongoing eradication programs include Maine, Massachusetts, Connecticut, New York, Idaho and possibly others. These expensive and time-consuming efforts are undertaken to contain and prevent hydrilla from spreading to other state waters, where infestations would cause both economic and recreational losses, possible flooding and negative ecological impacts that have occurred in other states.

Dioecious hydrilla

The USGS map of watersheds that host populations of the two hydrilla biotypes clearly shows that dioecious "female" plants spread from their initial 1950s introduction to Florida northeast to Kentucky, North Carolina and west to California. The Iowa population (farm pond) was likely introduced from Florida and was eradicated in the 1970s. Idaho provides a classic example of how humans move plants over large geographical distances. Blessed with many geothermal springs, Idaho is a primary producer of warm-water fish such as tilapia and tropical ornamental species for the aquaculture market in the US. Dioecious hydrilla was found in several commercial warm-water aquaculture facilities in the Snake River basin, where it was possibly introduced via transport of live fish from Florida. It was also found in the warm springs of the Bruneau River along with waterlettuce (Section 2.12) plants that were obviously introduced in the spring by an unknown person who admired their ornamental qualities. In addition, dioecious hydrilla was discovered in a small spring-fed urban canal in Boise, where it was likely introduced via a dumped aquarium. All of these sites are under eradication orders by the Idaho Department of Agriculture with cooperation from landowners and no hydrilla has been found in the Snake River to date. The Idaho situation is unique and the question remains: will dioecious hydrilla grow in the cold waters of the northeastern states or upper Midwest? Time will tell!

Dioecious hydrilla in the Southeast spreads only via fragmentation or other vegetative means because only the dioecious "female" biotype has been found in the southern US; no pollen in available, so it is unable to produce seeds. This biotype produces underground tubers under short-day conditions from late September through April, but only when water temperatures are greater than 40 °F. Similarly, turions are formed primarily under short-day conditions. These structures are likely an adaptation to allow survival under adverse conditions such as alternating wet and dry periods in a monsoon climate. Turion production is greatly increased if the plants are floating fragments, but tubers are only formed on underground rhizomes of rooted plants. Dioecious hydrilla behaves like a perennial and grows throughout the entire year in the warm waters of southern Florida, Louisiana and Texas. In more northern areas (or following very cold winters), growth is greatly reduced; untreated mats of hydrilla sink to the bottom of the water body, where they remain until warm temperatures return and trigger new growth from the axillary buds of the previous year's sunken vegetation. The role of tubers and turions in initiating or contributing to early spring growth under these conditions is not well-understood, but these structures probably do not have a significant effect on early growth. However, tubers and turions are very important to the re-establishment and growth of hydrilla following successful herbicide treatments, drawdowns or other control techniques that destroy the stems of hydrilla. The longevity or dormancy of turions is thought to be relatively short (2 to 3 years), whereas tubers remain viable for considerably longer periods of time (perhaps 8 to 10 years or more). Resource managers have reported that some Florida ponds stocked with grass carp for hydrilla control 10 or 15 years ago have experienced a resurgence in hydrilla populations after the carp were removed or died off. The question remains as to whether the regrowth of hydrilla following many hydrilla-free years is the result of long-term dormant tuber sprouting or from re-introduction of hydrilla from an outside source.

Monoecious hydrilla

Monoecious hydrilla was reported almost concurrently near Washington DC and Raleigh NC in 1980, although both sites were likely infested for several years before plants were properly identified. This biotype may now be found as far south as Georgia and Alabama and as far north as Maine. It extends as far west as Nebraska, but has also been introduced into California. In 2019, a different biotype of monoecious hydrilla was reported from the Connecticut River, but this biotype has not yet been fully described in the literature and will not be further discussed here. Genetic analyses of the first monoecious introductions have shown that they are closely related and linked to hydrilla found growing near Seoul, South Korea. It has been speculated that this monoecious type could be a hybrid between the US dioecious biotype and another dioecious biotype, but data to support or refute this hypothesis are lacking. Monoecious hydrilla is typically smaller and finer than dioecious hydrilla and generally resembles elodea in size (dioecious hydrilla is more similar to the larger, coarser *Egeria densa*). This difference can be helpful for distinguishing between the two biotypes in the field, but are not completely reliable as many factors can influence the appearance of these plants.

There are significant differences in the life histories of the original US monoecious hydrilla (which typically behaves as a herbaceous perennial) and dioecious hydrilla (in which shoots typically overwinter in the southern portions of its range). Monoecious hydrilla tubers and turions sprout in spring, with most sprouting occurring within a one-month period, although a small percentage of tuber sprouting may occur through the summer months. It has been reported that half of monoecious hydrilla turions sprout by mid-June and half of tubers sprout by mid-July. Initial growth is lateral along the lake bottom, which may be due to having minimal competition from other submersed plants at the start of the growing season, then after plants are established, shoots begin to grow toward the surface of the water. Growth increases as water temperature increases; exponential growth occurs during the warmest portion of the growing season and dense monoecious stands may produce topped-out growth in late summer into fall. Tuber formation is stimulated by long summer days and continues into fall. Axillary turions form late in the growing season as shoots begin to senesce. Floral initiation occurs during midsummer, but flowering and potential seed production seem to be very minor concerns compared to the large amounts of tubers and turions produced.

The main challenge in long-term management of monoecious hydrilla is the presence of tubers. Axillary turions are also produced, but these are generally smaller and shorter-lived and are likely meant to remain viable for a single winter and sprout the following spring. Tubers have more stored carbohydrates, which allows for longer dormancy periods, and remain viable for seven or more years. Seed production can occur but is not often seen in the field and is likely an irregular or rare event. Also, the ability of different biotypes to hybridize is not well-understood. Colder temperatures seem to increase tuber sprouting, thus larger sprouting percentages have been observed in New York than in North Carolina, Georgia or Alabama. From a management perspective, this means that tuber banks in southern climates will require more time for depletion than will tuber banks in northern regions.

One of the first locations of monoecious hydrilla establishment in the US was in the Potomac River. However, monoecious hydrilla rapidly spread through reservoirs and lakes in many states and was generally considered a problem of lakes and impoundments. In the last few years, monoecious hydrilla has been reported in numerous flowing water systems, including the Erie Canal, the Ohio, Croton, Eno, Cape Fear and Chowan Rivers and others. Although the Potomac infestation is generally considered non-problematic, many of the other infestations (for example, Erie Canal, Croton and Eno Rivers) have been significant enough to warrant management even though it is much more difficult to implement management practices in flowing water. A major concern is that monoecious hydrilla will outcompete and displace native organisms. In the Eno River, for instance, hydrilla is overtopping and outcompeting native riffleweed (*Podostemum ceratophyllum*), which provides critical habitat to the rare Panhandle Pebble Snail, and was the impetus for hydrilla management in this ecosystem.

Summary

Prior to 1950 there was no scientific information suggesting that hydrilla would cause such serious problems throughout the world. Hydrilla has become one of the worst submersed weeds globally as water resources have been developed and now causes problems in all tropical and subtropical continents with the exception of Africa, where it is believed that native herbivorous fish (cichlids) apparently keep its growth in check. Dioecious hydrilla has spread from Florida north to Virginia and Kentucky and northwest to California and Idaho in the span of only 50 years. The annual cost to control hydrilla in public waters in Florida alone totals approximately $15 million. Florida is particularly impacted by hydrilla due to its moderate climate and shallow, naturally nutrient-rich lakes, but research on the distribution of hydrilla in Asia predicts that hydrilla could colonize virtually any area in North America and could survive as far north as Hudson Bay.

Both biotypes of hydrilla are best managed through the use of herbicides. Managers usually treat monoecious hydrilla in spring or early summer when this biotype is in its lateral growth stage and requires somewhat lower application rates to achieve control. However, some applicators have noted that monoecious hydrilla requires higher doses of diquat and copper compared to the amounts required for control of dioecious hydrilla. Eurasian watermilfoil (Section 2.3) was historically the major submersed weed problem in the Tennessee River Valley (TVA) reservoirs, but dioecious hydrilla became widely established in the 1990s and has taken over much of the area previously covered by Eurasian watermilfoil. Also, TVA biologists have noted that monoecious hydrilla is now replacing much of the dioecious biotype in their systems.

The search for biocontrol insects and other agents continues, but some believe that monoecious hydrilla might be less susceptible to insect biocontrol agents that the dioecious biotype because monoecious populations are topped out for only a few weeks during the year. Sterile grass carp do not seem to have a preference for either biotype.

The discovery of monoecious hydrilla in the 1970s and its subsequent survival and spread from the Mid-Atlantic States throughout New England may well prove the predictions of survival into northern Canada to be true. The similarity in appearance of the hydrilla biotypes makes positive identification impossible without confirmation by genetic analysis. Also, the similarity of hydrilla to other submersed plants makes early detection efforts very difficult. Hydrilla has now become the most widespread and costly submersed non-native weed in North America. The monoecious biotype is currently spreading rapidly into new areas, while the dioecious biotype has likely already colonized most areas suitable for its growth in the southern US. Monoecious hydrilla has replaced much of the dioecious hydrilla in the TVA system, but only time will tell whether this biotype will fail to colonize, co-exist with dioecious hydrilla, or outcompete dioecious hydrilla in the southern states.

Photo and illustration credits:

Page 29: Hydrilla infestation; Vic Ramey, University of Florida
Page 30 upper: Line drawing; University of Florida Center for Aquatic and Invasive Plants
Page 30 lower: Hydrilla bouquet; William Haller, University of Florida
Page 32: US Geological Survey, Nonindigenous Species Database, Gainesville FL. https://nas.er.usgs.gov/taxgroup/plants