Monoecious Hydrilla Literature Review
Cited Articles and Abstracts

Benoit, L.K. "Cryptic Speciation, Genetic Diversity and Herbicide Resistance in the Invasive Aquatic Plant Hydrilla verticillata (L.f.) Royle (Hydrocharitaceae)" (January 1, 2011). *Dissertations Collection for University of Connecticut.* Paper AAI3492149.
http://digitalcommons.uconn.edu/dissertations/AAI3492149

Blackburn, R.D., L.W. Weldon, R.R. Yeo, and T.M. Taylor. 1969. Identification and distribution of certain similar-appearing submersed aquatic weeds in Florida. Hyacinth Control J. 8(1): 17-22.
http://apms.org/wp/wp-content/uploads/2012/10/v8p17.pdf

Bowmer, K.H., S.W.L. Jacobs, and G.R. Sainty. 1995. Identification, Biology, and Management of *Elodea canadensis*, Hydrocharitaceae. Journal of Aquatic Plant Management. 33: 13-19.
Abstract: *Elodea, Egeria, Hydrilla,* and *Lagarosiphon* have been much confused in the literature, mainly because of similarities in appearance and habitat. As well there has been confusion as to the number of species in *Elodea* and their correct names. We provide two keys, the first to help distinguish the genus *Elodea* from its near relatives, and the second to distinguish the species within *Elodea*. The distribution of the species of *Elodea* is described along with their physiology, survival and dispersal. The economic importance and management of the weed species of
Elodea are discussed and recommendations for control are made.
Key words: *Hydrilla, Egeria, Lagarosiphon*, taxonomy, herbicides.

Carter, V., N. B. Rybicki and C. L. Schulman. 1987. Effect of salinity and temperature on germination of monoecious hydrilla propagules. Journal of Aquatic Plant Management. 25: 54-57.
http://apms.org/wp/wp-content/uploads/2012/10/v25p54.pdf
Abstract: Salinity will be a major factor controlling the future distribution of hydrilla in the Chesapeake Bay system because salinity affects germination of monoecious hydrilla propagules (tubers and turions). Propagule germination and growth are reduced significantly as salinity increases. 92 to 97% of hydrilla propagules germinated at salinities of 0 ppt, four to 20 percent germinated at 5 to 9 ppt, and no germination occurred at salinities higher than 9 ppt. 92% of the propagules that were chilled continuously at 7 C for 42 days germinated when they were planted, whereas propagules that had not been chilled failed to germinate.
Key words: Tubers, turions, hydrilla, salinity, temperature, germination.

Chadwell, T. B. and K. A. Engelhardt. 2008. Effects of pre-existing submersed vegetation and propagule pressure on the invasion success of *Hydrilla verticillata*. Journal of Applied Ecology. 45(2): 515-523.
Abstract: With biological invasions causing widespread problems in ecosystems, methods to curb the colonization success of invasive species are needed. The effective management of invasive species will require an integrated approach that restores community structure and ecosystem processes while controlling propagule pressure of non-native species. 2. We tested the hypotheses that restoring native vegetation and minimizing propagule pressure of invasive species slows the establishment of an invader. In field and greenhouse experiments, we evaluated (i) the effects of a native submersed aquatic plant species, Vallisneria americana, on the colonization success of a non-native species, Hydrilla verticillata; and (ii) the effects of H. verticillata propagule density on its colonization success. 3. Results from the greenhouse experiment showed that V. americana decreased H. verticillata colonization through nutrient draw-down in the water column of closed mesocosms, although data from the field

experiment, located in a tidal freshwater region of Chesapeake Bay that is open to nutrient fluxes, suggested that V. americana did not negatively impact H. verticillata colonization. However, H. verticillata colonization was greater in a treatment of plastic V. americana look-alikes, suggesting that the canopy of V. americana can physically capture H. verticillata fragments. Thus pre-emption effects may be less clear in the field experiment because of complex interactions between competitive and facilitative effects in combination with continuous nutrient inputs from tides and rivers that do not allow nutrient draw-down to levels experienced in the greenhouse. 4. Greenhouse and field tests differed in the timing, duration and density of propagule inputs. However, irrespective of these differences, propagule pressure of the invader affected colonization success except in situations when the native species could draw-down nutrients in closed greenhouse mesocosms. In that case, no propagules were able to colonize. 5. Synthesis and applications. We have shown that reducing propagule pressure through targeted management should be considered to slow the spread of invasive species. This, in combination with restoration of native species, may be the best defence against non-native species invasion. Thus a combined strategy of targeted control and promotion of native plant growth is likely to be the most sustainable and cost-effective form of invasive species management.

Cook, C. D. K. and R. Lüönd. 1982. A revision of the genus *Hydrilla* (Hydrocharitaceae). Aquatic Bot. 13: 485-504.

Abstract: A taxonomic revision of the genus Hydrilla (Hydrocharitaceae) is presented with a full description, diagnosis, synonyms with typifications, distribution maps and illustrations, also including information on ecology, floral biology, anatomy, embryology, chromosomes, genetics, variation and applied aspects with a rather extensive bibliography. Hydrilla is considered to be monotypic; however, the single species (H. verticillata (L. fil.) Royle) is genetically variable and shows ill-definable morphological, caryological and physiological differentiation. The centre of differentiation is considered to lie in tropical Asia.

Coley, C. 1997. Hydrilla tubers recovered from waterfowl Lake Mattamuskeet, North Carolina. Aquatic Plant News. 54:2.

Conant, Jr., R.D., Van, T.K., and Steward, K.K., 1984. Monoecious hydrilla produces viable seeds in the United States. Aquatics, 6 (3):10. http://www.fapms.org/aquatics/issues/1984fall.pdf

Dibble, E.D. and K. Kovalenko. 2009. Ecological impact of grass carp: a review of the available data. J. Aquat. Plant Manage. 47:1-15. http://apms.org/wp/wp-content/uploads/2012/10/v47p001_2009.pdf

Abstract: The exotic grass carp (*Ctenopharyngodon idella*) has been used for almost a half a century in the United States as a biological agent to control and manage aquatic plants. This long-lived generalist herbivore consumes large amounts of vegetation and can considerably alter habitat and impact aquatic communities. We conducted a literature review to determine whether previous studies adequately addressed ecological impacts of grass carp and their underlying mechanisms. Our goal was to identify strengths and limitations of ecological assessment in the literature and suggest a trajectory of future research. The review yielded 1,924 citations on grass carp; however, data on ecological interactions were limited, and most research emphasized the biology of grass carp or eradication of aquatic plants rather than ecological mechanisms responsible for ecosystem-wide impacts. Very few studies addressed effects on habitat complexity or community-structuring processes. We provide a comprehensive tabulated overview of feeding preferences and environmental impacts of grass carp. We argue that ecology is paramount to evaluating grass carp impacts and thorough understanding of these impacts is

essential for the appropriate management of aquatic communities. Current knowledge is not sufficient to accurately predict long-term effects of grass carp on freshwater ecosystems. We advise a more cautious approach to developing guidelines for grass carp use.
Key words: aquatic plant management*, Ctenopharyngodon idella*, habitat alteration, literature review.

Doyle, R. D., M. J. Grodowitz, R. M. Smart, and C. S. Owens. 2002. Impact of herbivory *Hydrellia pakistanae* (Diptera: Ephydridae) on growth and photosynthetic potential of *Hydrilla verticillata*. Biol. Control 24: 221-229.

Abstract: The impacts of varying levels of herbivory by Hydrellia pakistanae on the dioecious ecotype of Hydrilla verticillata were evaluated by conducting a 10-week growth experiment within mesocosm tanks. The observed leaf damage to H. verticillata stems was highly correlated with the total number of immature H. pakistanae in H. verticillata tissue at the time of harvest ($P<0.001$, $R2>0.80$). Increasing levels of insect herbivory significantly impacted biomass and growth morphology of H. verticillata. Relative to control tanks, plants under intermediate or high levels of herbivory produced progressively less biomass. Insect herbivory also significantly impacted investment of energy in sexual and asexual reproduction. Plants under an intermediate or high level of herbivory produced fewer than 15% of the number of pistillate flowers produced by plants in control tanks. Furthermore, plants subject to high insect herbivory produced fewer and smaller tubers than control tanks. Finally, herbivory had a strong impact on the photosynthetic potential of stems. With 10–30% leaf damage, the maximum rate of light-saturated photosynthesis was reduced 30–40% relative to undamaged controls. Total daily photosynthetic production in these stems was estimated to balance, just barely, the daily respiratory needs of stems. Photosynthetic rate was reduced by about 60% in stems showing 70–90% leaf damage. This level of photosynthetic reduction would make continued survival of the plants unlikely since they would be unable to meet daily respiratory demands.
Keywords: Hydrilla verticillata; Hydrellia pakistanae; Insect herbivory; Biocontrol; Photosynthesis; Aquatic weed; Invasive species; Aquatic plant management

Doyle, R. D., M. J. Grodowitz, R. M. Smart, and C. S. Owens. 2007. Separate and interactive effects of competition and herbivory on the growth, expansion, and tuber formation of *Hydrilla verticillata*. Biol. Control 41:327-338

Abstract: This study examined the interaction and main-effect impacts of herbivory by the leaf-mining fly Hydrellia pakistanae and plant competition from Vallisneria americana on the growth, expansion and tuber formation of Hydrilla verticillata in a 2 × 2 factorial design experiment. The study was conducted in 14,000-L tanks, over two growing seasons. Each tank represented a single experimental unit and contained 32 1-L pots. At the beginning of the experiment half of these were planted with H. verticillata while the other half were either left empty or planted with V. americana (the competitor). H. pakistanae fly larvae (the herbivore) were added to tanks as appropriate. No significant interactions were identified between herbivory and competition on any parameter of H. verticillata growth analyzed (i.e., total tank biomass accumulation, total number of rooting stems, total tuber number, total tuber mass, and tuber size), indicating that the factors were operating independently and neither antagonism nor synergism was occurring. Both competition and herbivory impacted the growth of H. verticillata. H. verticillata plants grown in the presence of V. americana developed less total biomass, had fewer total basal stems, had fewer tubers and less tuber mass per tank, and produced significantly smaller tubers relative to control plants. Herbivory also suppressed H. verticillata biomass accumulation and tended to suppress the number and total mass of tubers produced in each tank. Both factors showed 30–40% reduction of total H. verticillata biomass, although the mechanism of impact was different. Competition suppressed expansion of H. verticillata into adjoining pots but had little impact on its growth in pots where it was originally planted. Herbivory resulted in a general suppression of growth of H. verticillata in all pots.

Although herbivory significantly impacted H. verticillata biomass, it did not result in competitive release for V. americana under the current experimental conditions. We conclude that management activities that promote competition or herbivory will impact the growth and expansion of H. verticillata. Furthermore, since these factors operated independently, the combined use of both factors should be beneficial for suppression of H. verticillata dominance.
Keywords: Competitive release; Invasive species; Hydrellia pakistanae; Vallisneria americana

Dray, F. A., Jr., and T. D. Center. 1996. Reproduction and development of the biocontrol agent *Hydrellia pakistanae* (Diptera: Ephydridae) on monoecious hydrilla. Biol. Cont. 7:275-280.
Abstract: Previous investigations of the laboratory biology and host range of*Hydrelliapakistanae,*a biological control of*Hydrilla verticillata*(hydrilla), used the dioecious hydrilla biotype common to Florida, Texas, and California. A monoecious biotype that is now spreading throughout the mid-Atlantic states, California, and Washington was not investigated during these original studies. We therefore compared the dioecious and monoecioushydrilla biotypes as hosts for*H. pakistanae.*Female*H. pakistanae*accepted the two biotypes equally as ovipositional substrates. Overall developmental success differed little: 42% of eggs oviposited on monoecioushydrilla produced adults compared to 39% of eggs oviposited on dioecious hydrilla. Fly development required about 33 days on both biotypes (at 22 ± 2°C), but larvae that completed development mined 1.6 times as many leaves on monoecioushydrilla as on dioecious plants. These data suggest that*H. pakistanae*would be a useful biocontrolagent of monoecioushydrilla, should this plant invade areas where it can grow as a perennial.
Keywords: *Hydrilla verticillata, Hydrelliapakistanae,* classical biological control, biotypes, herbivory, monoecious, dioecious, submerged macrophyte.

Estes, L.D., C. Fleming, A.D. Fowler, and N. Parker. 2011. The distribution, abundance, and habitat colonization of the invasive submersed macrophyte, *Hydrilla verticillata*, in a high-gradient riverine system. Proc. 72nd Annual Association of Southern Biologists (ABS) Meeting, 13-16 April, Huntsville, AL; Oral presentation.

Grodowitz, M., J. Nachtrieb, N. Harms, and J. Freedman. 2010. Suitability of using introduced *Hydrellia* spp. for management of monoecious *Hydrilla verticillata* (L.f.) Royle. APCRP Technical Notes Collection, ERDC/TN APCRP-BC-17. Vicksburg, MS: U.S. Army Engineer Research and Development Center.
Abstract : The main objective of this study was to determine the suitability of using introduced hydrilla leaf-mining flies (Hydrellia pakistanae Deonier and H. balciunasi Bock) for the management of monoecious hydrilla (Hydrilla verticillata (L.f.) Royle). This was accomplished using a variety of procedures and experimental designs, including small container bioassays, development of a greenhouse-based fly colony reared exclusively on monoecious hydrilla, a larger tank study designed to evaluate short-term impact on both monoecious and dioecious hydrilla, use of small ponds to evaluate establishment in a more natural situation, evaluation of overwintering biology of the agents, and field releases to determine establishment success. Introduction of biological control agents is a critical component of aquatic plant management. Using host-specific agents complements the goal of targeting nuisance vegetation while minimally affecting native vegetation. Two species of introduced ephydrid leaf-mining flies, Hydrellia pakistanae Deonier and H. balciunasi Bock, have been shown to suppress dioecious hydrilla by reducing photosynthesis, thereby impacting biomass production, tuber formation, fragment viability, and hydrilla's ability to compete effectively with beneficial native vegetation (Doyle et al. 2002, 2005; Grodowitz et al. 2003; Owens et al. 2006, 2008). However, only limited research has been conducted evaluating their effectiveness on monoecious hydrilla found in the more northern portions of the United States. Dray and Center (1996) indicated that the flies would be highly suitable,

but this research was confined mainly to short-term laboratory and greenhouse-based studies with no actual field releases; hence, more research is warranted.
Key words: Aquatic plants, bioassay, biological agents, biology, release, biomass conversion, laboratories, vegetation, ponds, impact, management, United States, containers

Haller, W. T. 1982. Hydrilla goes to Washington. Aquatics 4(4):6-7.
http://www.fapms.org/aquatics/issues/1982winter.pdf

Haller, W.T., J.V. Shiremana, and D.F. Duranta. 1980. Fish harvest resulting from mechanical control of hydrilla. Transactions of the American Fisheries Society. 109(5): 517-520.
Abstract: Mechanical harvesting of the submersed weed hydrilla, Hydrilla verticillata (L.F.) Royle, in Orange Lake, Florida entangled fish in the cut vegetation resulting in their disposal with the weeds on shore. Three block-net samples in dense hydrilla indicated fish standing crops (mean ± SD) of 205,000 ± 35,000 fish/hectare and 460 ± 30 kg/hectare. The estimated loss of fish to mechanical harvesting represented 32% of fish numbers and 18% of fish biomass. Fish most susceptible to mechanical removal with hydrilla were juvenile sportfish and smaller species. The monetary replacement value of the fish lost was estimated at over $6,000/hectare.

Haller, W.T., D. L. Sutton and W. C. Barlowe. 1974. Effects of salinity on growth of several aquatic macrophytes. Ecology. 55(4): 891-894.
Abstract: Growth rates of 10 aquatic macrophytes in various salinities under greenhouse conditions varied widely. Salt concentrations of 1.66'S and 2.50%, were toxic to Pistia stratiotes L. and Eichlornia crassipes (Mart.) Solms, respectively. Salinities of 16.65Sc, or higher were toxic to Lemna minor L., but growth of Lemna was increased by salt concentrations of 0.83?, 1.66S(, 2.506/c, and 3.33%, as compared to other Lemna plants grown in fertilized pondwater. Other species studied, Hydrilla v'erticillata Royle, Myriophlyllumn spicatum L., Najas quadalupensis (Spreng.) Magnus, Vallisneria amnericana Michx., Azolla caroliniana Willd., and Salvinia rotundifolia Willd., gradually declined in growth as salinity increased. Transpiration of the emersed growth form of Myriophyllumn brasiliense Camb. decreased with increasing levels of salinity, but root growth was stimulated by salt concentrations of 0.83(,-3.33%,, presumably a response of the plant to overcome an internal water deficit resulting from the saline solutions.
Key words: Aquatic plants; drought; estuary; niche; nutrients; salinity; salt tolerance; salt water intrusion; sodium chloride; transpiration

Harlan, S. M., G. J. Davis, and G. J. Pesacreta. 1985. Hydrilla in three North Carolina lakes. J. Aquat. Plant Manage. 23:68-71.
http://apms.org/wp/wp-content/uploads/2012/10/v23p68.pdf
Abstract: Hydrilla did not overwinter in lakes in Wake County, North Carolina in 1982 to 1983. Most biomass was produced at water depths between 0 and 2 m with little growth at depths greater than 3 m. Tuber formation began in late June, while regrowth from tubers and turions began from late March to mid April. Laboratory experiments indicated no seasonality in tuber germination, but this was not true for turion germination. Both male and female flowers were produced, but reproduction was solely vegetative.
Key words: biomass, tubers, turions, flowers, phenology

Harms, N.E. and M.J. Grodowitz. 2011. Overwintering biology of *Hydrellia pakistanae*, a biological

control agent of hydrilla. J. Aquat. Plant Manage. 49:114-117. http://apms.org/wp/wp-content/uploads/2012/10/v49p114.pdf

Hodson, R.G. G.J. Davis, and K.A. Langeland. 1984. Hydrilla management in North Carolina. Water Resources Research Inst. Of Univ. of N.C. Rep. No. 217.

Hofstra, D.E., P.D. Champion, and J.S. Clayton. 2010. Predicting invasive success of *Hydrilla verticillata* (L.f) Royle in flowing water. Hydrobiologia. 656:213-219.
Abstract: Alien aquatic plant species have had spectacular success in invading New Zealand's freshwaters. Their continued introduction has resulted in few water bodies retaining their natural or original indigenous aquatic vegetation, and associated adverse changes, such as reduced biodiversity and amenity values are well known. This highlights the need to accurately assess aquatic plant species that are already in the country and those outside for their potential to have a negative impact on New Zealand's lakes and waterways. The study presented in this paper describes an approach to evaluating the invasive weed potential of *Hydrilla verticillata* (L.f.) Royle compared with *Elodea canadensis* Michx. under flowing water conditions. The two species were planted in combination and alone, and in a sheltered or exposed position relative to the direction of the water flow. Over the 2-year study, two different waterflow rates were used (0.1 and 0.2 m/s) which represented the gauged flows from a stream of interest that contains *E. canadensis* and flows from a *H. verticillata* infested lake. *H. verticillata* was competitive compared with *E. canadensis* and able to persist and thrive in the presence of *E. canadensis* in both exposed and sheltered habitats. These results corroborate observations from other countries of *H. verticillata* growing in flowing waters and highlight the significant threat posed by *H. verticillata* to streams and waterways in New Zealand.
Key Words: Alien aquatic weeds, risk assessment, competitive interaction.

Hofstra, D.E., J. Clayton, J.D. Green, and M. Auger. 1999. Competitive performance of Hydrilla verticillata in New Zealand. Aquatic Botany. 63(3):305-324.
Abstract: *Hydrilla verticillata* is an invasive submerged weed, which has been introduced and become established in a variety of freshwater habitats around the world. It was first recorded in NewZealand in 1963, and today occurs in four lakes in the Hawke's Bay region. Isozymeanalyses (six enzyme systems; MDH, PGM, PGD, GPI, AAT and IDH) were carried out on these populations to determine the level and pattern of genetic diversity in NewZealand*H. verticillata*. Australian and USA monoecious and dioecious *H. verticillata* samples were also analysed for the same six enzyme systems. Four isozymes (MDH, PGM, GPI and AAT) were polymorphic between country-samples. Isozyme banding patterns of NewZealand*H. verticillata* populations were compared with those of *H. verticillata* from other countries, both by examining published data as well as by direct analysis, to determine the likely source of *H. verticillata* in NewZealand. Random amplified polymorphic DNA (RAPD) reaction carried out on the same sample set using 14 random primers indicated that there was a single dominant genotype present in all four NewZealand*H. verticillata* populations. USA and Australian *H. verticillata* samples contained more than one genotype. Both analyses indicated that the NewZealand*H. verticillata* plants were more similar to those from Australia than to either of the USA samples. The study also indicated that NewZealand*H. verticillata* was probably the result of a single introduction, the most likely source being Australia, and that reproduction is solely by vegetative means.
Key words: Genetic variation, monoecious, dioecious, RAPD.

Joyce, J.C., W.T. Haller, and D. Colle. 1980. Investigation of the presence and survivability of of hydrilla propagules in waterfowl. Aquatics 2(3):10-11. http://www.fapms.org/aquatics/issues/1980fall.pdf

Kracko, K.L. and R.M. Noble. 1993. Herbicide inhibition of grass carp feeding on hydrilla. J. Aquat. Plant Manage. 31:273-275.
http://apms.org/wp/wp-content/uploads/2012/10/v31p273.pdf

Langeland, K.A. and G.J. Pesacreta. 1986. Management program for hydrilla (a monoecious strain) in North Carolina. Water Resources Research Inst. Of Univ. of N.C. Rep. No. 225.

Langeland, K.A. 1996. *Hydrilla verticillata* (L.F.) Royle (Hydrocharitaceae), "The Perfect Aquatic Weed". Castanea. 61(3): 293-304.
Abstract: The submersed macrophyte hydrilla [Hydrilla verticillata (L.F.) Royle], which is native to the warmer areas of Asia, was first discovered in the United States in 1960. A highly specialized growth habit, physiological characteristics, and reproduction make this plant well adapted to life in submersed freshwater environments. Consequently, hydrilla has spread rapidly through portions of the United States and become a serious weed. Where the plant occurs, it causes substantial economic hardships, interferes with various water uses, displaces native aquatic plant communities, and adversely impacts freshwater habitats. Management techniques have been developed, but sufficient funding is not available to stop the spread of the plant or implement optimum management programs. Educational efforts to increase public and political awareness of problems associated with this weed and the need for adequate funding to manage it are necessary.

Langeland, K.A. and C.B. Smith. 1984. Hydrilla produces viable seed in North Carolina Lakes. Aquatics. 6(4):20-21.
http://www.fapms.org/aquatics/issues/1984winter.pdf

Lal, C. and B. Gopal. 1993. Production and germination of seeds in *Hydrilla verticillata*. Aquat. Bot., 45: 257-261.
Abstract: A monoecious population of Hydrilla verticillata (L.f.) Royle, occurring in the Wazirabad reservoir on the river Yamuna at New Delhi, produces seeds profusely during late winter. The seeds are light sensitive and germinate within a week at laboratory temperature (23–28°C). Seeds stored dry or in water in darkness for up to 1 year germinate readily in light. Thus, seeds offer a long-term strategy for survival of Hydrilla after prolonged dry periods in regions with a monsson climate.

Les, D.H., L.J. Mehrhoff, M.A. Cleland, and J.D. Gable. 1997. Hydrilla verticillata (Hydrocharitaceae) in Connecticut. J. Aquat. Plant Manage. 35:10-14.
http://apms.org/wp/wp-content/uploads/2012/10/v35p10.pdf
Abstract: A specimen of hydrilla (Hydrilla verticillata (L.f.) Royle) collected at Mystic, Connecticut in 1989 was recently discovered in the University of Connecticut herbarium. Unnoticed previously because of its misidentification as egeria (Egeria densa Planch.), this specimen is the first authenticated record of hydrilla in New England, and represents the most northern locality of the species currently known in eastern North America. A 1996 field survey verified that hydrilla continues to thrive at the Connecticut site. Connecticut plants were positively identified as hydrilla by morphological features, and by comparing the rbcL gene sequence of Connecticut specimens with a hydrilla plant from India. Internode lengths of Connecticut hydrilla exceeded those reported for both dioecious and monoecious strains grown in greenhouse conditions. However, leaf lengths of Connecticut hydrilla were comparable to those of the dioecious strain designated as 'USA hydrilla I'. A RAPD profile of Connecticut hydrilla produced the molecular marker that reportedly distinguishes the dioecious strain. Cytological analysis

indicated that the Connecticut hydrilla plants are triploid (2n = 3x = 24). Hydrilla in Connecticut presumably represents an introduction of dioecious plants. Hydrilla grew well on both sandy and mucky substrates and apparently overwinters in Connecticut by production of numerous, subterranean stem tubers.
Key words: chromosome number, distribution, identification, North America, rbcL sequence, RAPD, triploid, weed.

Madeira, P.T., T.K. Van, K.K. Steward, and R.J. Schnell. 1997. Random amplified polymorphic DNA analysis of the phonetic relationships among world-wide accessions of *Hydrilla verticillata*. Aquatic Biology. 59:217-236.
Abstract: The phenetic relationships among forty-four accessions of Hydrilla verticillata from various regions of the world were determined using random amplified polymorphic DNA (RAPD) analysis of bulked genomic samples. Five primers were used, producing a total of 85 resolvable, polymorphic bands. The accessions were compared using Gower and Dice metrics, clustered using unweighted pair-group arithmetic average clustering (UPGMA) and consensus algorithms, and factored using principal coordinate analysis. Four major clusters (Asian, Australian, Indonesian, monoecious USA) and one minor outlier cluster (Japan/Poland) were identified. The USA dioecious accessions formed a group closest to an accession from Bangalore, India, possibly lending credence to historical reports that it was imported from Sri Lanka. The USA monoecious plants cluster with an accession from Seoul, Korea Republic. Accessions from Taiwan, Burundi and Panama join the Asian cluster late. The New Zealand accessions cluster loosely with those from Australia. The use of band intensity in combination with the Gower similarity coefficient generated a cophenetic correlation coefficient (similarity matrix versus UPGMA matrix) of r = 0.92, superior to that for the corresponding Dice metric (r = 0.85).

Madeira, P.T., C.C. Jacono, and T.K. Van. 2000. Monitoring hydrilla using two RAPD procedures and the nonindigenous aquatic species database. J. Aquat. Plant Manage. 38:33-40. http://apms.org/wp/wp-content/uploads/2000/12/v38p33.pdf
Abstract: Hydrilla (Hydrilla verticillata (L.f.) Royle), an invasive aquatic weed, continues to spread to new regions in the United States. Two biotypes, one a female dioecious and the other monoecious have been identified. Management of the spread of hydrilla requires understanding the mechanisms of introduction and transport, an ability to map and make available information on distribution, and tools to distinguish the known U.S. biotypes as well as potential new introductions. Review of the literature and discussions with aquatic scientists and resource managers point to the aquarium and water garden plant trades as the primary past mechanism for the regional dispersal of hydrilla while local dispersal is primarily carried out by other mechanisms such as boat traffic, intentional introductions, and waterfowl. The Nonindigenous Aquatic Species (NAS) database is presented as a tool for assembling, geo-referencing, and making available information on the distribution of hydrilla. A map of the current range of dioecious and monoecious hydrilla by drainage is presented. Four hydrilla samples, taken from three discrete, non-contiguous regions (Pennsylvania, Connecticut, and Washington State) were examined using two RAPD assays. The first, generated using primer Operon G17, and capable of distinguishing the dioecious and monoecious U.S. biotypes, indicated all four samples were of the monoecious biotype. Results of the second assay using the Stoffel fragment and 5 primers, produced 111 markers, indicated that these samples do not represent new foreign introductions. The differences in the monoecious and dioecious growth habits and management are discussed.

Madeira, P.T., T.K. Van, and T.D. Center. 2004. An improved molecular tool for distinguishing monoecious and dioecious hydrilla. J. Aquat. Plant Manage. 42:28-32

http://apms.org/wp/wp-content/uploads/2012/10/v42p28.pdf
Abstract: Two biotypes of hydrilla [*Hydrilla verticillata* (L.f.) Royle] occur in the United States, a dioecious type centered in the southeast and a monoecious type in the central Atlantic and northeastern states. Ecosystem managers need tools to distinguish the types as the ranges of each type expand and begin to overlap. A molecular tool using the randomly amplified polymorphic DNA (RAPD) procedure is available but its use is limited by a need for reference samples. We describe an alternative molecular tool which uses "universal primers" to sequence the trnL intron and trnL-F intergenic spacer of the chloroplast genome. This sequence yields three differences between the biotypes (two gaps and one single nucleotide polymorphism). A primer has been designed which ends in a gap that shows up only in the dioecious plant. A polymerase chain reaction (PCR) using this primer produces a product for the monoecious but not the dioecious plant.
Key words: *Hydrilla verticillata*, trnL intron, trnL-F intergenic spacer, sequencing.

Maki, K.C. and S.M. Galatowitsch. 2008. Cold tolerance of two biotypes of hydrilla and northern watermilfoil. J. Aquat. Plant Manage. 46:42-50.
http://apms.org/wp/wp-content/uploads/2012/10/v46p042_2008.pdf
Abstract: A two-step assay was developed to test the cold tolerance ranges of axillary turions of dioecious and monoecious *Hydrilla* (*Hydrilla verticillata* [L.F] Royle) and *Myriophyllum sibiricum* (Kamarov). In phase one, cold treatments of 0, 28, 63, and 105 d duration were used to test overwintering effects on mortality rates. Phase two consisted of a test of survivorship over 10 weeks in treatments simulating early growing season. These early growing season treatments included rapid and slow temperature increases and long and short daylengths. Survivorship, shoot dry weight, branch number, and root development were measured to determine responses to different temperature increases and daylengths. As overwintering period (phase I) increased from 0 to 105 d, mortality increased from 8% to 98% for dioecious *Hydrilla* and 0% to 48% for monoecious *Hydrilla*. *M. sibiricum* had low percent mortality across all overwintering treatments (0 to 105 d) and no deaths at 0 and 105 d. Survivorship decreased during the early growing season (phase II) for both *Hydrilla* biotypes and was affected by overwintering period. No dioecious *Hydrilla* turions survived the early growing season after overwintering periods of 63 and 105 d. Monoecious *Hydrilla* turions survival ranged from 67% (63 d) to 42% (105 d). *M. sibiricum* had variable rates of survival in the early growing season after all overwintering treatments, ranging from a minimum of 8% at 0, 28, and 105 d, to a maximum of 67% at 63 d. Shoot dry weight and branching increased with more rapid changes in early growing season temperatures. Using a two-step assay to determine cold tolerance suggests that monoecious *Hydrilla* will likely overwinter in northern latitudes more successfully than dioecious *Hydrilla.*
Key words: cold stress, invasive potential, invasive species, submersed aquatic vegetation, vegetative propagules, *Myriophyllum sibiricum*.

McFarland, D.G. and Barko, J.W. 1987. Effects of temperature and sediment type on growth and morphology of monoecious and dioecious hydrilla. J. Freshwater Ecol. 4(2):245-252.
Abstract: In a five-week greenhouse investigation, variations in growth and morphology of monoecious and dioecious Hydrilla [Hydrilla verticillata (L. f.) Royle] were compared over a range of temperatures, 12 to 32 C, on an inorganic sediment and on an organic sediment. For these bio-types, total biomass production was severely restricted at 16 C and below, with thermal optima for growth occurring between 28 and 32 C. Total biomass, shoot number, and shoot length for each biotype were greater on the inorganic sediment than on the organic sediment. At higher temperatures, dioecious Hydrilla lengthened more extensively than monoecious Hydrilla; however, the latter produced higher shoot densities and tuber numbers under most experimental conditions. Monoecious Hydrilla appears to be

better adapted to moderate temperatures than dioecious Hydrilla, and its potential distribution may include sediments less favorable for growth of the dioecious biotype.

McFarland, D.G. and Barko, J.W. 1999. High-temperature effects on growth and propagule formation in hydrilla biotypes. J. Aquat. Plant Manage. 37:17-25.
http://apms.org/wp/wp-content/uploads/2012/10/v37p17.pdf
Abstract: In consecutive greenhouse studies, growth and propagule formation were examined first in monoecious hydrilla [*Hydrilla Verticillata* (L.f.) Royle], then in dioecious hydrilla, at three temperature levels (25, 30, and 35 C) and contrasted over three periods of growth (8, 12 and 16 wks). Each biotype was grown under natural photoperiods, decreasing from 14 hrs (in Aug) over 8, 12, and 16 wks respectively to 12, 11, and 10 hrs (in Oct, Nov, and Dec). For both biotypes, total biomass and root-to-shoot ratios were significantly reduced at 35 C; greater biomass was produced both at 25 and 30 C. Increases in growth period generally enhanced total biomass and shoot production; however, shoot length was unresponsive to growth periods beyond 8 wks. The 35 C treatment strongly impeded tuber formation and eliminated the production of axillary turions; the number and biomass of these propagules peaked at lower temperatures under short photoperiods after 12 to 16 wks. Shoot elongation was stimulated with increases in temperature and was especially pronounced in the dioecious biotype. Notably, in the monoecious biotype, the number of shoots as a potential source of fragments, and tuber production (although reduced) occurred at relatively high levels under unfavorably high-temperature (35 C) conditions. These results suggest that monoecious hydrilla may be better adapted to high temperatures than previously shown, and that the distribution of both biotypes in the U.S. could overlap further in southern states.
Key words: *Hydrilla verticillata*, biomass, morphology,tubers, turions, reproduction, thermal conditions, photoperiod.

Michel, A., B. E. Scheffler, R. S. Arias, S. O. Duke, M. D. Netherland and F.E. Dayan. 2004. Somatic mutation-mediated evaluation of herbicide resistance in the invasive plant hydrilla. Mol. Ecol. 13:3229-3237.
Abstract: Hydrilla (Hydrilla verticillata L.f. Royle) was introduced to the surface water of Florida in the 1950s and is today one of the most serious aquatic weed problems in the USA. As a result of concerns associated with the applications of pesticides to aquatic systems, fluridone is the only USEPA-approved chemical that provides systemic control of hydrilla. After a decrease in fluridone's efficacy at controlling hydrilla, 200 Florida water bodies were sampled to determine the extent of the problem and the biological basis for the reduced efficacy. Our studies revealed that hydrilla phenotypes with two- to six-fold higher fluridone resistance were present in 20 water bodies. Since fluridone is an inhibitor of the enzyme phytoene desaturase (PDS), the gene for PDS (pds) was cloned from herbicide-susceptible and -resistant hydrilla plants. We report for the first time in higher plants three independent herbicide-resistant hydrilla biotypes arising from the selection of somatic mutations at the arginine 304 codon of pds. The three PDS variants had specific activities similar to the wild-type enzyme but were two to five times less sensitive to fluridone. In vitro activity levels of the enzymes correlated with in vivo resistance of the corresponding biotypes. As hydrilla spread rapidly to lakes across the southern United States in the past, the expansion of resistant biotypes is likely to pose significant environmental challenges in the future.

Miller, R.W. 1998. The First State's experiences controlling the northern monoecious form of hydrilla. Aquatics 10(2):16-23.
http://www.fapms.org/aquatics/issues/1988summer.pdf

Meadows, S.T. and R.J. Richardson. 2012. Competition of monoecious hydrilla with other submersed macrophytes. Proc. 52nd Annual Meeting Aquatic Plant Management Society (APMS), July 22-25, Salt Lake City, UT. Abstract pp.

Abstract: In order to assess the potential of monoecious hydrilla to invade existing aquatic plant communities, monoecious hydrilla was grown in competition with four submersed plant species: Eurasian watermilfoil (Myriophyllum spicatum L.; invasive), curly leaf pondweed (Potamogeton crispus L.; invasive), Elodea canadensis Michx. (native), and Vallisneria americana Michx. (native). Initial plant establishment occurred in fall 2010 in a glasshouse; plants were then moved to outdoor mesocosms, and the trial was initiated in March 2011. Competition treatments included all tested plant species alone, at two different densities, and in combination with sprouted monoecious hydrilla tubers, at two different introduction timings. Treatments were replicated three times and completely randomized. Stem lengths of the longest shoot of each plant were measured initially, and biweekly for 20 weeks. At the termination of the experiment, all plant biomass was separated by species and harvested, separating root mass from shoot mass for dry weight determination. Vegetative reproductive structures were counted when present, and fresh weight was taken. While the introduction of monoecious hydrilla at both timings lowered the shoot biomass dry weight for all plant species, the decrease was only significant for the early introduction of hydrilla with Elodea, curly leaf pondweed, and Vallisneria; not for Eurasian watermilfoil and not the late introduction of hydrilla. Hydrilla introduction had no effect on root biomass dry weight at either timing. Plant density had no effect on biomass dry weight for all naturalized species, with or without monoecious hydrilla. Elodea, at both densities, significantly hindered monoecious hydrilla shoot biomass for the late introduction only. No other plant tested, at either density, had an effect on hydrilla biomass at either introduction timing. This research illustrates what effects previous establishment of these four species may have on hindering monoecious hydrilla colonization.

Nawrocki, J.J. 2011. Environmental and Physiological Factors Affecting Submersed Aquatic Weed Management (Masters Thesis). http://repository.lib.ncsu.edu/ir/handle/1840.16/7126

Abstract: Invasive aquatic weeds such as Hydrilla verticillata L.f Royle and Myriophyllum spicatum L. are spreading across the continental United States. This has resulted in the invasion of large, complex flowing water systems. Management is difficult due to bulk water exchange, wind mixing, and thermal density gradients. Assessing these factors on a site to site basis can allow managers to properly select the correct herbicide, formulation, treatment timing, and application technique to be most effective at controlling target weeds. Rhodamine water tracing (WT) dye can be applied in a similar fashion as an aqueous herbicide, and tracked in real time to calculate the bulk water exchange rate in the treatment area. Rhodamine water tracing (WT) dye was used on Lake Gaston, NC to assess bulk water exchange on 2 sites, which were 20 and 24 ha in size. The presence of a well pronounced thermocline trapped the majority of the dye near the surface where it was subjected to wind, waves, and natural currents moving it off target. Dye became evenly distributed vertically in the water column after 16 to 20 hours after application. Granular herbicides can be used in sites with a moderate degree of water flow and still provide excellent control of target weeds. A slow release fluridone granule was commercially applied to two sites on Lake Gaston, NC for hydrilla management. Subsequent sampling to determine residues was conducted for a length of 69 days. An average concentration of 1.35 ± 0.15 µg/L fluridone was observed in the benthic region of the water column for the length of the study, which resulted in 18 of 19 survey points being devoid of hydrilla. Another water exchange trail was conducted on Lake Pend Oreille, ID, which has historically been infested with Eurasian watermilfoil (EWM). Successful management has reduced EWM infestations to areas with high water flow. Bulk water exchange was evaluated on 4 sites ranging in size from 3 to 16.6 ha with the use of Rhodamine (WT). A deep water injection application

system was used and resulted in up to 90% of the dye measured being located in the lower half of the water column. A final area of research was conducted on hydrilla subterranean turions, which are a source for reinfestation in areas where successful management has occurred. Tuber densities were measured on 4 hydrilla infested water-bodies in NC that received various management practices. Tuber densities on the Tar River Reservoir, which was treated yearly with fluridone, declined 96% after 4 years. Lake Tillery which has also been treated yearly had a 65% decline in tuber densities. On Lake Gaston, sites treated two consecutive years resulted in a 75% reduction whereas sites only treated the first year had only a 26% decrease after two years. On the unmanaged Shearon Harris Reservoir, tuber densities ranged from 939 to 1,700 tubers per m2.

Nawrocki, J.J., S.T. Hoyle, J. Scott, and R.J. Richardson. 2011. Proc. 51st Annual Meeting Aquatic Plant Management Society (APMS), 24-27 July, Baltimore, MD. Abstract pp. 37-38.

Abstract: Since the discovery of Hydrilla verticillata in the United States, much research has been conducted to find weaknesses in its life cycle. Most of this work has been done on the dioecious form, which has historically been the most prevalent and problematic. However, the monoecious form is rapidly expanding in range and significant differences may exist in the biology of the two biotypes. Recent research at North Carolina State University into the dynamics of monoecious hydrilla tuber sprouting has revealed interesting, and sometimes surprising results. Growth chamber trials have indicated similarities in sprouting of both biotypes under temperature and light manipulation. Research has also been conducted to determine the effect on tuber sprouting under exposure to a range of pH, salinity, or herbicides. Tubers sprouted in solutions with pH between 4.0 and 10.0 with few differences in initial growth. Tubers exposed to a salinity level of 24 part per thousand for 2 weeks sprouted when placed into a solution of deionized water, but did not sprout under constant salinity exposure. It was also observed that monoecious hydrilla tubers have multiple axillary buds preformed within dormant tubers that are capable of producing secondary shoots even when the terminal shoot is removed. These findings can help refine management plans to best exploit weaknesses in the biology of monoecious hydrilla.

Netherland, M. D. 1997. Turion Ecology of Hydrilla. J. Aquat. Plant Manage. 35: 1-10. http://apms.org/wp/wp-content/uploads/2012/10/v35p1.pdf

Abstract: A literature survey was conducted to compile the numerous papers on the ecology of subterranean and axillary turions produced by the exotic macrophyte hydrilla (Hydrilla verticillata (L.f.) Royle). The monoecious and dioecious biotypes of hydrilla exhibit distinct differences in seasonal turion production, turion production in response to photoperiod, quantity and size of turions produced, and geographic distribution. Although a high level of variabilityexists within and between aquatic systems, several million subterranean turions per hectare have been reported. These propagules have been noted to remain quiescent in undisturbed sediment for up to 4 years and they represent the key target in breaking the life-cycle of hydrilla. The detached turions allow hydrilla to survive abiotic, biotic, and anthropogenic induced stress. Although turions sprout optimally at temperatures between 15 and 35 C, factors such as light, CO2, oxygen, and various plant hormones and herbicideshave been shown to either promote or inhibit sprouting. Improving control strategies for hydrilla requires a betterunderstanding of factors that influence turion quiescence,sprouting, and longevity.

Key words: Hydrilla verticillata, subterranean turion, tuber,axillary turion, vegetative propagule.

Owens, C. S., M. J. Grodowitz, R. M. Smart, N. E. Harms, and J. M. Nachtrieb. 2006. Viability of hydrilla fragments exposed to different levels of insect herbivory. J. Aquat. Plant Manage. 44:145. http://apms.org/wp/wp-content/uploads/2012/10/v44p144.pdf

Owens, C. S., M. J. Grodowitz, and R. M. Smart. 2008. Impact of insect herbivory on the establishment of Hydrilla verticillata (L.f.) Royle fragments. J. Aquat. Plant Manage. 46: 199-202. http://apms.org/wp/wp-content/uploads/2012/10/v46p199_2008.pdf

Owens, C. S. & J. D. Madsen, 1998. Phenological studies of carbohydrate allocation in Hydrilla. Journal of Aquatic Plant Management 36: 40–44. http://apms.org/wp/wp-content/uploads/2012/10/v36p40.pdf
Abstract: Hydrilla (Hydrilla verticillata (L.f.) Royle), a nonindigenous submersed aquatic plant, was first introduced into the United States in the 1960's. Hydrilla exhibits aggressive growth, forming dense canopies of biomass at the surface of the invaded aquatic systems, affecting fisheries, water quality, transportation and recreational usage. Studies of the phenological seasonal cycles of invasive plants indicate optimal timing to apply management techniques. Biomass and total nonstructural carbohydrate (TNC) allocation of dioecious hydrilla were studied in outdoor ponds in Texas between January 1994 through July 1995. Biomass increased from May through September, growing from overwintering shoots and root crowns, not tubers. Tuber germination occurred in August. Tuber and turion production occurred from October through April. A carbohydrate storage minimum was observed in late July for 1994 and June for 1995, with storage generally split between stolon (7% TNC), root crown (10% TNC) and lower stem (16% TNC). Tubers and turions ranged from 58 to 68% TNC. These studies provide more insight into the timing of major allocation shifts in the hydrilla seasonal growth cycle.
Key words: Hydrilla verticillata, total nonstructural carbohydrates, Hydrocharitaceae, dioecious hydrilla.

Owens, C.S. and R.M. Smart. 2007. Sexual preference and alternative life cycles in hydrilla: monecious and dioecious. Proc. 47th Annual Meeting Aquatic Plant Management Society (APMS), July 15-18, Nashville, TN. Abstract p. 47.
Abstract: Two biotypes of hydrilla exist in Lake Gaston, NC/VA: dioecious (plants are either male or female) and monoecious (plants have both male and female flowers on the same plant). Both biotypes are problematic, forming dense surface canopies which can impede navigation, degrade habitat and water quality, and interfere with recreational activities. While the dioecious biotype has been intensively studied, much less is known about monoecious hydrilla. Anecdotal information and personal observations in Lake Gaston (Snow and Owens) suggested that the two biotypes differ in their overwintering strategies. In order to effectively manage the growth of monoecious hydrilla and its tuberbank, we need to understand the life cycle of the plant. An outdoor mesocosm study of the of the two hydrilla biotypes was initiated at the LAERF in July 2006, to compare the phenology of the biotypes in a controlled, outdoor setting. Primary interest was focused on aboveground biomass dynamics and tuber/turion production and sprouting in relation to natural changes in temperature and photoperiod over a 15-month study period. Harvests were conducted every 6 weeks starting in October 2006. While the study is ongoing, initial results (through December 2006) indicate that monoecious hydrilla behaves as an herbaceous perennial, completely dying back to tuber or turion by December. In contrast, the dioecious biotype acts as an evergreen perennial – overwintering as an intact plant or semidormant rootcrown. Results to date found no significant differences in aboveground biomass between the biotypes until December, 2006, when the monoecious biotype senesced, resulting in an almost 10-fold difference in shoot biomass between the two biotypes. Over the three harvest dates monoecious hydrilla produced nearly twice as many tubers as did the dioecious biotype. By the November harvest monoecious had produced 60 times more turions than the dioecious. The implications of an herbaceous perennial life cycle on management of monoecious hydrilla will be discussed.

Pesacreta, George J. 1990. "Pilot Study: Carbohydrate Allocation in Hydrilla Biotypes."

Miscellaneous Paper A-90-2. US Army Engineer Waterways Experiment Station. Vicksburg. MS.

Poovey, A.G. and K.D. Getsinger. 2010. Comparitive response of monoecious and dioecious hydrilla to endothall. J. Aquat. Plant Manage. 48:15-20.
http://apms.org/wp/wp-content/uploads/2012/10/vol48p15.pdf
Abstract: Hydrilla (*Hydrilla verticillata* [L.f.] Royle) is an aggressive submersed weed that has invaded many United States waterbodies. While both the monoecious and dioecious biotypes are present in the United States, monoecious populations have continued to spread along the eastern seaboard and in the Great Lakes Region. There is limited documentation of this biotype's response to herbicides; therefore, we conducted two laboratory studies to compare the efficacy of endothall against monoecious and dioecious hydrilla under various concentrations and exposure times. In the first experiment, plants were propagated from shoot fragments. In the second experiment, plants were propagated from subterranean turions (tubers). Results showed that endothall is efficacious against both monoecious and dioecious hydrilla, reducing biomass by >85% with concentrations of 2 mg ai L -1 coupled with exposure times of 48 h for dioecious and 72 h for monoecious plants grown from shoot fragments. Higher concentrations (4 mg ai L-1) or extended exposure times (96 h) were required to control hydrilla grown from tubers. Treatment of newly sprouted monoecious tubers may be an effective application strategy because most monoecious tubers sprout during spring and summer. Endothall efficacy against monoecious and dioecious hydrilla grown from tubers requires further study.
Key words: aquatic herbicide, chemical control, shoot fragment, submersed aquatic plant, subterranean turion, tuber.

Poovey, A.G. and S.H. Kay. 1998. The potential of a summer drawdown to manage monoecious hydrilla. J. Aquat. Plant Manage. 36:127-130.
http://apms.org/wp/wp-content/uploads/2012/10/v36p127.pdf
Abstract: A summer drawdown to manage monoecious Hydrilla (*Hydrilla verticillata* (L.f.) Royle) was investigated using a mesocosm system. The objectives were: to determine the length of drawdown required to kill vegetative biomass; to evaluate plant recovery in terms of regrowth and production of propagules following the drawdown; and to examine the influence of hydrosoil characteristics on plant response to drawdown. Hydrilla tubers were collected from the field, sprouted in the laboratory, planted in sand or silt loam soil, and placed in concrete tanks. A drawdown was simulated by taking plants out of the tanks, exposing them to ambient conditions for one to four weeks, and returning them to the mesocosms until the end of the growing season. A one-week drawdown was sufficient for killing hydrilla on sand; no regrowth or tuber production occurred. A one-week drawdown on silt loam was not effective in desiccating the root system and preventing regrowth; these plants produced the same amount of biomass and twice as many tubers as the reference plants. A drawdown of two weeks or longer, however, suppressed hydrilla regrowth and greatly reduced tuber numbers. Few turions were found on reference plants at the end of the season. Plants subjected to drawdown did not produce turions. These results suggest that a short-term summer drawdown on might be useful in monoecious hydrilla management; however, hydrosoil type may determine length of drawdown required for complete soil desiccation and plant kill.
Key words: aquatic weed, *Hydrilla verticillata* (L.f.) Royle, cultural control.

Pieterse, A. H. 1981. Hydrilla verticillata - a review. Tropical Agriculture. 7: 9-34.
Abstract: H. verticillata is one of the most troublesome spp. of submerged weeds that block waterways throughout the world. This review focuses on its distribution; general biology and physiology; formation

and germination of turions; mechanical, manual, chemical and biological control; and chemical composition and practical use.

Ryan, F.J., C.R. Coley, and S.H. Kay. 1995. Coexistence of monoecious and dioecious hydrilla in Lake Gaston, North Carolina and Virginia. J. Aquat. Plant Manage. 33:8-12. http://apms.org/wp/wp-content/uploads/2012/10/v33p8.pdf
Abstract: Biotypes of hydrilla (Hydrilla verticillata (L.f.) Royle) at twosites in North Carolina were characterized by growth habitand flower type under controlled conditions, patterns oftuber proteins after electrophoresis, and reaction of DNAswith a single primer in the random amplified polymorphic DNA (RAPD) reaction. Plants from Burnt Mill Creek in Wilmington, in the southeastern part of the state, were dioecious by all criteria. Plants of both the monoecious and dioecious biotype were found in Lake Gaston, at the Virginia-North Carolina border. This is the first report of the presence of plants of both biotypes in a single body of water.
Key words: biotype, electrophoresis, growth habit, RAPD,tuber proteins.

Ryan, F. J., J. S. Thullen, and D. L. Holmberg. 1991. Non-genetic origin of isoenzymic variability in subterranean turions of monoecious and dioecious hydrilla.J. Aquat. Plant Manage. 29: 3-6. http://apms.org/wp/wp-content/uploads/2012/10/v29p3.pdf
Abstract: Isoenzymic variability was investigated in subterranean turions of monoecious hydrilla collected in North Carolina and dioecious hydrilla collected in Texas and California. Two variants of each biotype were found in the field samples. One, termed Type A, had patterns of alcohol dehydrogenase and aspartate aminotransferase after gel electrophoresis that were identical to those previously reporte for turions grown in the laboratory. Dioecious plants in laboratory culture were originally from Imperial Irrigation District in California, while monoecious plants were from the Washington, D.C., area. The second variant, termed Type B, had more rapidly moving electromorphs of both enzymes. The ration of the two variants was different at each site in the field collections. Plants from monoecious turions know to be Type B produced only turions of Type A under laboratory conditions. Plants grown from dioecious plants or turions from sites in Texas that had high populations of Type B produced turions only of Type A. The presence of Type B for either biotype was not due to genetic variants within the populations, but might be due to environmental factors or ageing of the turions.
Key words: alcohol dehydrogenase, aspartate aminotransferase, biotypes, gel electrophoresis, Hydrilla verticillata, isoenzymes, turions

Rybicki, N.B., J.D. Kirshtein, and M.A. Voytek. 2013. Improved insight about the distribution of Hydrilla, Egeria, and Elodea (Hydrocharitacea): application of molecular techniques for identification. J. Aquat. Plant Manage. *In Press*. http://apms.org/journals/

Serafy, J.E., R.M. Harrell, and L.M. Hurley. 1994. Mechanical removal of hydrilla in the Potomac River, Maryland: Local impacts on vegetation and associated fishes. Journal of Freshwater Ecology. 9(2): 135-143.
Abstract: Tidal freshwater fish assemblages were sampled quantitatively from beds of Hydrilla verticillata in the Potomac River, Maryland, to assess local impacts of mechanical plant harvesting. Seasonal and diel estimates of fish density, biomass and species richness were compared at an undisturbed site and an adjacent mechanically harvested site. Harvesting had a “pruning” effect on Hydrilla: plant biomass levels at the harvested site exceeded those at the undisturbed site after periods > 23 d. Fish species composition at the two sites was very similar and species richness differences were minor. Significantly lower ($P<0.05$) mean fish density and biomass values were found at the harvested

versus the undisturbed site < 23 d after plant removal. However, 43 d after plant removal, fish density was significantly higher (P<0.05) at the harvested site, while biomass differences were minor. Species-specific differences suggested that harvesting improved habitat for pelagic species (e.g., *Menidia beryllina*) but negatively affected cover-oriented species (e.g., *Fundulus diaphanus*). Results suggest impacts of mechanical harvesting on the fish assemblages investigated were short-term and minor at the local, community level. However, ten species were killed in the mechanical harvesting process. We estimated that this immediate loss represented 11–22% of fish numbers and 4–23% of biomass. Mechanical harvesting, when macrophyte beds are in short supply, may not be prudent.

Shields, E.C., K.A. Moore, and D.B. Parrish. 2012. Influences of salinity and light availability on abundance and distribution of tidal freshwater and oligohaline submersed aquatic vegetation. Estuaries and Coasts. 35:515-526.

Abstract: Submersed aquatic vegetation (SAV) communities have undergone declines worldwide, exposing them to invasions from non-native species. Over the past decade, the invasive species Hydrilla verticillata has been documented in several tributaries of the lower Chesapeake Bay, Virginia. We used annual aerial mapping surveys from 1998 to 2007, integrated with spatial analyses of water quality data, to analyze the patterns and rates of change of a H. verticillata-dominated SAV community and relate them to varying salinity and light conditions. Periods of declining SAV coverage corresponded to periods where salinities exceeded 7 and early growing season (April to May) Secchi depths were <0.4 m. Increases were driven by the expansion of H. verticillata along with several other species into the upper estuary, where some areas experienced an 80% increase in cover. Field investigations revealed H. verticillata dominance to be limited to the upper estuary where total suspended solid concentrations during the early growing season were <15 mg l−1 and salinity remained <3. The effect of poor early growing season water clarity on annual SAV growth highlights the importance of water quality during this critical life stage. Periods of low clarity combined with periodic salinity intrusions may limit the dominance of H. verticillata in these types of estuarine systems. This study shows the importance of the use of these types of biologically relevant episodic events to supplement seasonal habitat requirements and also provides evidence for the potential important role of invasive species in SAV community recovery.

Keywords Chesapeake Bay Hydrilla verticillata Salinity Submersed aquatic vegetation

Spencer, D.F. and L.W.J. Anderson. 1986. Photoperiod responses in monoecious and dioecious hydrilla verticillata. Weed Sci. 34(4):551-557.

Abstract: Thirty-eight % of monoecious hydrilla (H. verticillata) grown from tubers produced new tubers after 28 days exposure to a 10-h photoperiod. One hundred percent of the plants grown at a 10-h photoperiod produced tubers by 56 days while only thirty-eight percent of those grown at a 12-h photoperiod did so. Plants grown at 14- or 16-h photoperiods did not produce tubers. Tubers appeared to be produced at the expense of new root and shoot tissue. Dioecious hydrilla (female) grown under similar conditions did not produce tubers by 56 days at any photoperiod examined. Relative growth rates (total dry weight) for both types did not differ with photoperiod and ranged between 81 plus or minus 63 and 284 plus or minus 52 mg multiplied by g super(-1) multiplied by wk super(-1). In general, total chlorophyll (a+b) was greater for dioecious than for monoecious plants.

Keywords: tuber production, aquatic weed, weed ecology, dry matter allocation, HYLL1.

Spencer, D.F., L.W.J. Anderson, M.D. Ames, and F.J. Ryan. 1987. Variation in *Hydrilla verticillata* (L.f.) Royle propagule weight. J. Aquat. Plant Manage. 25:11-14. http://apms.org/wp/wp-content/uploads/2012/10/v25p11.pdf

Abstract: Weight distributions for hydrilla (Hydrilla verticillata (L.f) Royle) vegetative propagules (axillary or subterranean turions) were skewed in eleven of thirteen sample populations. Subterranean turions from dioecious plants weighed more than those from monoecious plants when grown under similar conditions. Axillary turions weighed less than subterranean turions. The data support the notion that, although they are anatomically similar, axillary and subterranean turions represent alternate reproductive mechanisms.
Keywords: hydrilla, turions, reproductive strategy, weight distribution.

Spencer, D., L. Anderson, G. Ksander, S. Klaine, and F. Bailey. 1994. Vegetative propagule production and allocation of carbon and nitrogen by monoecious hydrilla verticillata (L.f.) Royle grown at two photoperiods. Aquat. Bot. 48(2):121-132.

Abstract: Plants of *Hydrilla verticillata* (L.f.) Royle were grown under two photoperiods (11 or 15 h) in a greenhouse. Under the 11 h photoperiod, *Hydrilla* produced geotropic shoots after 34 days, tubers were first observed at 48 days, and turions after 76 days. During this study, *Hydrilla* plants grown under the 11 h photoperiod produced 317 tubers, and those grown under the 15 h photoperiod produced two tubers. C and N were directed from other plant structures, especially shoots and roots, into newly formed tubers and turions. C was allocated to new tubers at a rate that was about 43 times that for N. After 12 weeks, about 15 times more C and N were allocated to tuber production than to turion production. Nutrient use efficiency for N increased significantly in both photoperiods. N use efficiency was not a good indicator of the onset of tuber or turion production.

Spencer, D.F. and G.G. Ksander. 1999. Influence of dilute acetic acid treatments on survival of monoecious hydrilla tubers in the Oregon House Canal, California J. Aquat. Plant Manage. 37:67-71.
http://apms.org/wp/wp-content/uploads/2012/10/v37p67.pdf

Abstract: Hydrilla (Hydrilla verticillata (L.f.)Royle), a serious aquatic weed, reproduces through formation of underground tubers. To date, attacking this life-cycle stage has been problematic. The purpose of this study was to measure the impact of exposure to dilute acetic acid on monoecious hydrilla tubers under field conditions. In this field experiment, treatments were acetic acid concentration (0, 2.5, or 5%) and sediment condition (perforated or not perforated). Each of 60, 1x1 m plots (in the Oregon House Canal) were randomly assigned to one treatment. Two weeks after treatment, we collected three samples from each plot. One was washed over 2 mm wire mesh screens to separate tubers from sediment. Relative electrolyte leakage was measured for one tuber from each plot. Five additional tubers from each plot were placed in a growth chamber and sprouting monitored for four weeks. A second sample from each plot was placed in a plastic tub and placed in an outdoor tank, filled with water. These samples were monitored for tuber sprouting. Relative electrolyte leakage increased significantly for tubers exposed to 2.5% or 5% acetic acid. Effects on tubers in perforated sediment were reduced. Exposure to acetic acid inhibited tuber sprouting by 80 to 100%, in both chamber and outdoor tests. These results confirm findings from earlier laboratory/greenhouse experiments, and suggest that this approach may be useful in the management of hydrilla tuber banks in habitats where the water level can be lowered to expose the sediments.
Key words: aquatic plant management, tuber bank, vinegar, *Hydrilla verticillata* (L.f.) Royle, monoecious.

Spencer, D.F. and G.G. Ksander. 2000. Interactions between American pondweed and monoecious hydrilla grown in mixtures. J. Aquat. Plant Manage. 38:5-13.
http://apms.org/wp/wp-content/uploads/2000/12/v38p5.pdf

Abstract: To assess the potential for monoecious hydrilla (*Hydrilla verticillata* (L.f.) Royle) to invade existing aquatic plant communities, monoecious hydrilla was grown in mixtures with American

pondweed (*Potamogeton nodosus* Poiret). When grown with Hydrilla from axillary turions, American pondweed was a stronger competitor. When grown with Hydrilla from tubers, American pondweed was equally as strong a competitor as hydrilla. In these eight-week long greenhouse and outdoor experiments, American pondweed grew taller than hydrilla, produced floating leaves, and produced more vegetative propagules. Results of an additional outdoor experiment indicated that hydrilla plants from axillary turions grew and successfully produced new tubers in an existing American pondweed bed. Hydrilla produced twice as many tubers as American pondweed produced winter buds in this experiment. These results are based on Hydrilla plants grown from smaller or larger than average size tubers and turions, and American pondweed grown from smaller than average or average size winter buds. The results indicate the strong competitive ability of hydrilla since hydrilla from small propagules coexisted with American pondweed from larger propagules.
Key words: invasive aquatic weed, competition, underwater irradiance*, Potamogeton nodosus, Hydrilla verticillata*.

Spencer, D.F., G.G. Ksander, and S.R. Bissell. 1992. Growth of monoecious hydrilla on different soils amended with peat or barley straw. J. Aquat. Plant Manage. 30:9-15. http://apms.org/wp/wp-content/uploads/2000/12/v38p5.pdf
Abstract: Hydrilla is an introduced plant that has caused serious problems in many aquatic systems in the United States. Growth requirements and capabilities of the monoecious strain of hydrilla appear to differ in important ways (i.e., responses to photoperiod and perhaps temperature, and allocation of dry matter to tubers and turions) from those of the dioecious strain. Monoecious hydrilla (Hydrilla verticillata (L. f.) Royle) was grown in six soil types amended with two levels of barley straw or peat to test the hypothesis that substrate organic matter would cause reduced growth. Soil type significantly influenced hydrilla dry weight and weight of tubers produced during 8 weeks of growth under outdoor conditions. Also, increased organic matter content (measured as loss on ignition) of the substrate over the range of 1.5 to 27.2 % was associated with increased growth of hydrilla. Of 14 substrate properties, multiple regression revealed that the square root of Kjeldahl N and the square root of soil conductivity were the best predictors of hydrilla weight. These results suggest that variability in the responses of rooted aquatic plants to substrate organic matter content reported previously may be partially explained by considering properties of the organic matter, especially nutrient content.

Spencer, D.F. and G.G. Ksander. 2001. Field evaluation of degree-day based equations for predicting sprouting of hydrilla (Hydrilla verticillata) turions and tubers. Journal of Freshwater Ecology. 16:479-486.
Abstract: The ability to predict sprouting of aquatic macrophyte vegetative propagules is an important step in understanding their temporal distribution and abundance and in developing long-range management strategies. We examined the ability of degree-day based equations to predict monoecious hydrilla (Hydrilla verticillata L. f. Royle) tuber and turion sprouting in Clear Lake, California using sediment and water temperatures measured in the lake. Sediment temperature data were used to calculate accumulated degree-days. Sprouting of turions and tubers was estimated using previously developed equations relating sprouting to accumulated degree-days. There was good agreement between sprouting predictions and field data on the presence of hydrilla in weed rake samples. Small differences among water temperatures at the five sites and strong relationships between water and sediment temperatures indicate that sprouting should be similar in hydrilla beds found along the western and southern shores of upper Clear Lake. These results can be used to estimate optimal timing for surveys of hydrilla abundance and the application of hydrilla management techniques.

Steward, K.K. 1991a. Light requirements for growth of monoecious hydrilla from the Potomac River.

Florida Sci. 54(3/4):204-214.
Abstract: Estimates from laboratory and aquarium studies were obtained of light compensation levels for the race of monoecious hydrilla [Hydrilla verticillata (L.f.) Royle] established in the Potomac River and of the effects of reduced light levels on plant growth and development. Results of this investigation indicate that hydrilla growth is retarded at Photosynthetically Active Radiation (PAR) levels below 100 mu e/m super(2)/sec. This is approximately equivalent to Secchi disc transparency, which is 5% of incident solar PAR. Results suggest that depth and areal distribution of hydrilla in the Potomac River will be restricted to the limnetic zone. Growth should not occur below 1% of incident solar PAR, and probably will not occur below the 5% level.

Steward, K.K. 1991b. Competitive interaction between monoecious hydrilla and American eelgrass on sediments of varying fertility. Florida Sci. 54(3/4):135-147.
Abstract: Monoecious hydrilla [Hydrilla verticillata (L.f.) Royle] from the Potomac River and American eelgrass (Vallisneria americana Michx.) were grown in monoculture and in mixed culture on aquatic sediments of decreasing fertility to assess their ability to compete for nutrients. Biomass yield in hydrilla decreased with decreasing fertility and increased an average of 45% when grown intermixed with eelgrass. This was interpreted as evidence of within species competition. Biomass yield only decreased in eelgrass when grown on sand, evidence of lower nutrient requirements than hydrilla. Sediment fertility had little effect on nutrient concentrations in tissues, except that concentrations were depressed when plants were grown on sand alone. Reduced growth of hydrilla was not related to tissue concentrations of measured nutrients. Nutrient accumulation in plant tissues was most closely related to dry weight and was greatest in hydrilla. Potassium accumulation in plant tissues exceeded supplies in sediments indicating potassium uptake occurred from ambient water. Sediment potassium concentrations were increased by plant growth in some sediment treatments.
Keywords: aquatic plants, biomass, competition, interspecific relationships, nutrient availability, nutrients (mineral), sediment chemistry

Steward, K.K. 1993. Seed production in monoecious and dioecious populations of hydrilla. Aquatic Botany. 46:169-183.
Abstract: The potential for sexual reproduction was evaluated in the various races of an international Hydrilla germplasm collection. Crosses between dioecious and monoecious races of Hydrilla verticullata (L.f.) Royle resulted in seed production in 40 of the 56 crosses (71%). Seeds from 90% of these crosses were viable and most seedlings survived. The dioecious female plant, established in the US since the 1950s, has never been reported to produce seed, but this female was discovered to be one of the greatest seed producers. This race has been reported to be triploid, but seed from four of its five crosses were viable. Triploids are generally sterile, so these findings raise questions about the reported ploidy level of this race. Another observation, not previously reported for Hydrilla, was the occurrence of monoecious offspring from dioecious parents. The reported lack of seed production in the US for female plants of the dioecious race has been due to the absence of a viable pollen donor.

Steward, K.K. and T.K. Van. 1987. Comparative studies of monoecious and dioecious hydrilla (*Hydrilla verticillata*) biotypes. Weed Science. 35: 204-210.
Abstract: Selected biological and physiological parameters of hydrilla (Hydrilla verticillata (L.f.) Royle No. 3 HYLLI) biotypes were compared in growth chambers, glasshouse, or outside aquaria. Salinity tolerance was similar for both biotypes with an injury threshold of approximately 23 parts per thousand (ppt). Tuber production in monoecious plants was greatest under short days and was significantly higher than in dioecious plants under the same conditions. Growth response to temperature was similar among all plants and was retarded at 15 C. Tuber germination occurred at lower temperatures in the monoecious

plants, which was indicate of a lower temperature tolerance. Vegetative propagules were the only perennating structures observed in the monoecious biotype, and regrowth was entirely from tubers and turions. The annual growth habit, in conjunction with rapid and abundant propagule production, adapts the monoecious biotype to northern area with short growing seasons.
Key words: salinity, copper, diquat, endothall, photoperiod, temperatures, tubers, HYLL1.

Steward, K.K., T.K. Van, V. Carter, and A.H. Pieterse. 1984. Hydrilla invades Washington, DC and the Potomac. American Journal of Botany. 71(1):162-163
Abstract: Hydrilla verticillata was found growing in the Potomac river S. of Alexandria, Virginia, in Washington, DC and in the Chesapeake and Ohio Canal in Maryland. Cultures of the Washington clone in Florida were monoecious and this is the 1st report of the monoecious form in the USA. The occurrence of this monoecious form and the consequent possibility of increased diversity through sexual reproduction may have serious consequences on the management of this weed.

Sutton, D.L., T.K. Van, and K.M. Portier. 1992. Growth of dioecious and monoecious hydrilla from single tubers. J. Aquat. Plant Manage. 30:15-20.
http://apms.org/wp/wp-content/uploads/2012/10/v30p15.pdf
Abstract: Dioecious and monoecious biotypes of hydrilla (*Hydrilla verticillata* Royle) were cultured outdoors in 1.0 m2 boxes filled with sand amended with fertilizer. The boxes were placed in cement tanks filled with pond water to a depth of 0.8 m. A single sprouted tuber was planted in the center of each box and allowed to grow for 16 weeks. Total plant dry weight was generally higher in the summer (May to September) than in the winter (November to late February or early March). Maximum observed biomass was 4.043 g and 4.559 g per box for dioecious and monoecious biotypes respectively. Monoecious hydrilla produced tubers year-round, up to 6,046 per box during the summer, while tubers of the dioecious biotype were produced only in the winter. Although monoecious hydrilla produced an average of 56% more tubers than dioecious hydrilla, the average individual weight of monoecious tubers was 32% less than for dioecious tubers. Tubers produced by both hydrilla biotypes were uniformly distributed horizontally in low numbers in the middle of the box and increased in number towards the sides and corners. These data demonstrate tremendous growth potential of a single hydrilla tuber under favorable conditions such as those found in Florida.
Key words: Aquatic plants, *Hydrilla verticillata*, propagules, biotypes.

Twilley, R.R. and J.W. Barko. 1990. The growth of submersed macrophytes under experimental salinity and light conditions. Estuaries. 13(3):311-321.
Abstract: The growth, morphology, and chemical composition *ofHydrilla verticillata, Myriophyllum spicatum, Potamogeton perfoliatus,* and *Vallisneria americana* were compared among different salinity and light conditions. Plants were grown in microcosms (1.2 m s) under ambient photoperiod adjusted to 50% and 8% of solar radiation. The culture solution in five pairs of tanks was gradually adjusted to salinities of 0, 2, 4, 6, and 12%. With the exception of *H. verticillata,* the aquatic macrophytes examined may be considered eurysaline species that are able to adapt to salinities one-third the strength of sea water. With increasing salinity, the inflorescence production decreased in *M. spicatum and P. perfoliatus,* yet asexual reproduction in the latter species by underground buds remained constant. Stem elongation increased in response to shading in *M. spicatum,* while shaded *P. pcrfoliatus* had higher concentrations of chlorophyll a. In association with high epiphytic mass, chlorophyll a concentrations in all species were greatest at 12%~ The concentration of sodium increased in all four species of aquatic macrophytes examined here, indicating that these macrophytes did not possess mechanisms to exclude this ion. The nitrogen content (Y) of the aquatic macrophytes tested increased significantly with higher sodium concentration (X), suggesting that nitrogen may be utilized in osmoregulation (Y = X x 0.288 +

6.10, r 2 = 0.71). The tolerance of V. *americana* and *P. petfoliatus* to salinity was greater in our study compared to other investigations. This may be associated with experimental methodology, whereby macrophytes were subjected to more gradual rather than abrupt changes in salinity. The two macrophytes best adapted to estuarine conditions in this study by exhibiting growth up to 12%0, including *M. spicatum* and *V. americana,* also exhibited a greater degree of response in morphology, tissue chemistry (including chlorophyll content and total nitrogen), and reproductive output in response to varying salinity and light conditions.

Van, T.K. 1989. Differential responses to photoperiods in monoecious and dioecious *Hydrilla verticillata*. Weed Science. 37:552-556.

Abstract: Growth and morphology of two U.S. hydrilla biotypes grown under 10- and 16-h photoperiods in outdoor aquaria were investigated. The dioecious hydrilla biotype elongated extensively under both photoperiods and reached the water surface within 2 to 3 weeks after planting. In contrast, the monoecious biotype grew more densely near the sediment, primarily by producing a high number of horizontal stems, root crowns, and higher shoot densities. Monoecious hydrilla grown from tubers produced new tubers after 4 weeks of exposure to the 10-h photoperiod, and the number of tubers produced was five- to sevenfold higher in the monoecious than in the dioecious biotype. Furthermore, monoecious hydrilla produced tubers under both 10- and 16-h photoperiods, with tuber production much higher under the shorter photoperiod. Dioecious hydrilla grown from tubers under similar conditions produced new tubers after 8 weeks only under the 10-h photoperiod. No tubers were produced by the dioecious biotype throughout a 10-week exposure to the 16-h photoperiod.

Van, T.K. and K.K. Steward. 1990. Longevity of monoecious hydrilla propagules. J. Aquat. Plant Manage. 28:74-76.
http://apms.org/1990/12/journal-of-aquatic-plant-management-volume-28-1990/

Abstract: In 1984, a long-term study of tuber longevity in monoecious hydrilla (Hydrilla verticillata) was initiated in Fort Lauderdale, Florida. Plants were grown and allowed to produce tubers and turions from September 1984 to June 1985. Manipulation was done to prevent plants from making new propagules after June 1985. The plants were harvested quarterly thereafter to determine the persistence in soil of the propagule populations. Tubers survived in undisturbed sediment for a period of over 4 years after being produced, whereas turions germinated readily and expired after 1 year. Persistence of monoecious hydrilla tubers appeared to be regulated by an environmentally-imposed enforced dormancy which prevented a rapid depletion of the tuber population through excessive germination in situ. The life span differences between tubers and turions support the notion that these two types of hydrilla propagules represent different reproductive strategies.

Key words: tubers, turions, reproduction, viability, dormancy, survival.

Van, T.K., Steward, K.K., and Conant, R.D., Jr. 1987. Responses of monoecious and dioecious hydrilla (*Hydrilla verticillata)* to various concentrations and exposures of diquat. Weed Science. 35(2):247-52.

Abstract: Control of monoecious and dioecious hydrilla [*Hydrilla verticillata* (L.f.) Royles #3 HYLL1] biotypes required a minimum of 2 days exposure to diquat (6,7-dihydrodipyrido [1,2-α2',1'-*c*] pyrazinediium ion) at a concentration of .25 mg/L under laboratory conditions. When treatment concentration was increased to 2.0 mg/L diquat, the minimum required contact time was reduced to 6 or 12 h depending on plant growth stage. Early growth emerging from sprouting tubers appeared to be more susceptible to diquat treatments. Herbicide uptake was linear during the 4-day exposure to 14C-diquat up to 1.0 mg/L, and the amounts of radio-activity in plant tissue varied proportionally with ambient levels of 14C-diquat in the water. The lethal concentration of diquat in

hydrilla tissue was estimated to be 81µg/g plant dry weight when hydrilla was exposed to diquat at 0.25 mg/L for 2 days.
Keywords: Herbicide uptake, bioconcentration factor, lethal concentration contact time, aquatic weed, HYLL1.

Van, T.K. and V.V. Vandiver Jr. 1992. Response of monoecious and dioecious hydrilla to bensulfuron methyl . Journal of Aquatic Plant Management. 30:41-44. http://apms.org/wp/wp-content/uploads/2012/10/v30p41.pdf
Abstract: The relationship between herbicide concn and exposure time was determined for bensulfuron-methyl used for the control of monoecious and dioecious hydrilla (Hydrilla verticillata) grown in large outdoor tanks at Fort Lauderdale during 1990-91. Twenty combinations of bensulfuron-methyl concn and exposure time were tested: concn included 0.05, 0.10 and 0.20 mg/litre; exposure times ranged from 3 to 42 d. Plant responses to bensulfuron-methyl were monitored over a period of 6 months after herbicide application. Severe plant damage was observed in all treatments after 1 month. However, regrowth occurred rapidly where herbicide exposure was limited to ≤14 d. Greatest reductions in plant growth and tuber production were obtained following 42 d of exposure. Application of 0.05 mg bensulfuron-methyl for 42 d reduced tuber production after 6 months by 81 and 93% in monoecious and dioecious hydrilla, resp. It was suggested that caution should be exercised in the application of bensulfuron-methyl for the control of hydrilla in high water exchange environments due to the herbicide's long exposure time requirements.

Verkleij, J.A.C, A.H. Pieterse, G.J.T. Horneman, and M. Torenbeek. 1983. A comparative study of the morphology and isoenzyme patterns of Hydrilla verticillata (L.f.) Royle. Aquat. Bot. 17:43-59.
Abstract: The genetic variability of Hydrilla verticillata (L.f.) Royle, a submerged aquatic weed which is becoming increasingly troublesome in tropical and sub-tropical areas, was estimated by comparing the morphology and isoenzyme patterns of various plants, collected from different parts of the world, after cultivation under similar conditions. It appeared that large genetic differences occur within the species which could be explained by the fact that its geographical range is extremely wide and disjointed. According to the isoenzyme patterns it may be presumed that the plants which were collected in the United States, with the exception of one from Washington, DC, are probably ramets of the same clone. A prolonged geographical isolation of Eastern European plants seems likely as a plant from Poland showed strongly deviating isoenzyme patterns. The individuals from a population of monoecious plants in Lake Curug in Indonesia showed differences in their isoenzyme patterns, but were morphologically very similar. The general appearance of certain plants, especially those from New Zealand and Kashmir, was relatively slender and delicate, whereas other plants, like those from Indonesia and Malaysia, were relatively robust. The chromosome numbers were either 16 or 24. There were no correlations between morphological data, isoenzyme patterns and chromosome numbers. The large genetic variations might imply differences in survival strategy which could have consequences for the control of this weed.

Weakley, A. S. 2012. Flora of the Southern and Mid-Atlantic States. The University of North Carolina Herbarium. Available online: http://www.herbarium.unc.edu/flora.htm.

Wilde, S.B., T.M. Murphy, C.P. Hope, S.K. Habrun, J. Kempton, A. Birrenkott, F. Wiley, W.W. Bowerman, and A.J. Lewitus. 2005. Avian vacuolar myelinopathy linked to exotic aquatic plants and a novel cyanobacterial species. Environ. Toxicol. 20:348–353.
Abstract: Invasions of exotic species have created environmental havoc through competition and displacement of native plants and animals. The introduction of hydrilla (Hydrilla verticillata) into the United States in the 1960s has been detrimental to navigation, power generation, water intake, and

water quality (McCann et al., 1996). Our field surveys and feeding studies have now implicated exotic hydrilla and associated epiphytic cyanobacterial species as a link to avian vacuolar myelinopathy (AVM), an emerging avian disease affecting herbivorous waterbirds and their avian predators. AVM, first reported in 1994, has caused the death of at least 100 bald eagles (Haliaeetus leucocephalus) and thousands of American coots (Fulica americana) at 11 sites from Texas to North Carolina (Thomas et al., 1998; Rocke et al., 2002). Our working hypothesis is that the agent of this disease is an uncharacterized neurotoxin produced by a novel cyanobacterial epiphyte of the order Stigonematales. This undescribed species covers up to 95% of the surface area of leaves in reservoirs where bird deaths have occurred from the disease. In addition, this species is rare or not found on hydrilla collected at sites where AVM disease has not been diagnosed. Laboratory feeding trials and a sentinel bird study using naturally occurring blooms of cyanobacteria on hydrilla leaves and farm-raised mallard ducks (Anas platyrhynchos) induced the disease experimentally. Since 1994 AVM has been diagnosed in additional sites from Texas to North Carolina. Specific site characteristics that produce the disjunct distribution of AVM are unknown, but it is probable that the incidence of this disease will increase with the introduction of hydrilla and associated cyanobacterial species into additional ponds, lakes, and reservoirs.

Williams, S.K., J. Kempton, S.B. Wilde, and A. Lewitus. 2007. A novel epiphytic cyanobacterium associated with reservoirs affected by avian vacuolar myelinopathy. Harmful Algae. 6:343–353.
Abstract: Avian vacuolar myelinopathy (AVM) is a newly discovered bird disease, which is killing bald eagles (Haliaeetus leucocephalus) and waterfowl in the southeastern United States. Surveys were conducted to investigate exotic macrophytes (e.g. Hydrilla verticillata) as a substrate for attachment by toxic cyanobacteria that may be associated with the incidence of AVM. While the specific cause of the disease has not been confirmed, one hypothesis is that birds ingest a neurotoxin produced by cyanobacteria epiphytic on macrophytes. A strong relationship was found between the field abundance of a specific undescribed epiphytic cyanobacterium and the incidence of AVM. The undescribed species is a filamentous, heterocystous, true branching cyanobacterium. Morphological characteristics place the cyanobacterium in section V, order Stigonematales. The 16S rRNA sequence identity was determined from environmental isolates of this unknown Stigonematalan species using DGGE (denaturing gradient gel electrophoresis). The 16S rRNA sequence data were aligned with additional cyanobacteria sequences to determine designations for probe development, to lay groundwork for its formal description and to advance understanding of the species' phylogeny. Real-time PCR assays were developed for rapid, specific detection of the Stigonematales species from environmental samples. The genetic probe produced by this study will help test the hypothesized link between these cyanobacteria and AVM, and therefore help guide decisions on managing hydrilla and other invasive macrophytes in AVM-affected waters.
Keywords: Avian vacuolar myelinopathy (AVM); Cyanobacteria; Fulica americana; Haliaeetus leucocephalus; Hydrilla; Real-time PCR; Stigonematales; 16S

Yeo, R. R., R. H. Falk and J. R. Thurston. 1984. The morphology of Hydrilla (Hydrilla verticillata (L.f.) Royle). Journal of Aquatic Plant Management 22: 1–17. http://apms.org/wp/wp-content/uploads/2012/10/v22p1.pdf
Abstract: Light and scanning electron microscopic examination of H. verticillata revealed the presence of small dormant axillary buds that form at the base of larger dominant axillary buds, turions forming on apices of branches, asexual reproductive structures (lateral stem buds) that develop near the base of vertical stems, and abscission layers at the base of axillary turions and lateral stem buds.