ELEMENT STEWARDSHIP ABSTRACT
for

Hydrilla verticillata (L.F.) Royle

Hydrilla

To the User:

Element Stewardship Abstracts (ESAs) are prepared to provide The Nature Conservancy's Stewardship staff and other land managers with current management related information on species and communities that are most important to protect or control. The abstracts organize and summarize data from many sources including literature and from researchers and managers actively working with the species or community.

We hope, by providing this abstract free of charge, to encourage users to contribute their information to the abstract. This sharing of information will benefit all land managers by ensuring the availability of an abstract that contains up-to-date information on management techniques and knowledgeable contacts. Contributors of information will be acknowledged within the abstract.

For ease of update and retrievability, the abstracts are stored on computer at The Nature Conservancy. Anyone with comments, questions, or information on current or past monitoring, research, or management programs for the species described in this abstract is encouraged to contact The Nature Conservancy's Wildland Invasive Species Program.

This abstract is a compilation of available information and is not an endorsement of particular practices or products.

Please do not remove this cover statement from the attached abstract.

Author of this Abstract: Michael S. Batcher, Consulting Ecologist and Environmental Planner, 1907 Buskirk-West Hoosick Road, Buskirk, NY 12028, e-mail: mbatcher@netheaven.com.

THE NATURE CONSERVANCY

4245 North Fairfax Drive, Arlington, Virginia 22203-1606 (703) 841-5300

SCIENTIFIC NAME

Hydrilla verticillata (L.F.) Royle

Synonyms: *Elodea verticillata* (L.f.) F. Muell, *Hydrilla lithuanica* (Andrz. ex Besser) Dandy, *Serpicula verticillata* L.f.

COMMON NAME

Hydrilla

DESCRIPTION AND DIAGNOSTIC CHARACTERISTICS

H. verticillata is a submerged aquatic perennial plant that is highly variable in appearance, depending upon the conditions under which it is growing (Verkleij et al. 1983; Pieterse et al. 1985). *H. verticillata* generally is rooted to the bottom, although sometimes fragments will break loose and survive in a free-floating state. Erect stems can be quite long when the plant grows in deep water. Branching is usually sparse until the plant grows to near the water surface, where branching becomes profuse. Many horizontal aboveground stems (stolons) and underground stems (rhizomes) are also produced. Leaves are lanceolate, usually toothed, and arranged in bottlebrush-like whorls. Reproduction can occur sexually (through the production of seeds) or vegetatively. Vegetative reproduction in *H. verticillata* occurs by fragmentation of the stem, or by the production of above-ground and below-ground (subterranean) turions. The above-ground turions are sometimes referred to as axillary turions, as they are formed in the leaf axils, and the subterranean turions are often incorrectly referred to as tubers.

H. verticillata occurs in both monoecious (both male and female flowers on the same plant) and dioecious (male and female flowers on different plants) forms. Dioecious forms occur primarily in the southeastern U.S., California, Texas, Poland, Malaysia, Indonesia and Panama, while monoecious *H. verticillata* has been found in the mid-Atlantic U.S. (on the Potomac River near Washington, D.C.), India, and Indonesia. Isoenzyme comparisons of the Potomac River and Florida types are genetically distinct (McFarland and Barko 1990). Evidence indicates, however, that spatially disjunct and genetically distinct populations should be partially fertile and sexually compatible, with respect to chromosome pairing (Langeland et al. 1992). There is little evidence of self-incompatibility (Cook and Luond 1982).

Female flowers consist of three whitish sepals and three translucent petals. Flowers are 10-50 mm long and 4-8 mm wide, and are borne from a green spathe attached at the leaf axils. Flowers are clustered toward the tips of the stems, and float on the water surface. The stem tips from which female flowers arise are often very compact and have very short leaves. Female flowers are resistant to wetting and when returned to the water surface after submergence, will immediately float. A submerged female flower has been described as an inverted bell filled with a large bubble (Cook and Luond 1982). Male flowers have three whitish red or brown sepals 3 mm long and 2 mm wide, three whitish or reddish linear petals approximately 2 mm long, and three stamens. The male flowers are borne on a short stalk (Reed 1977), and as they approach maturity, are released and float to the surface, where they release pollen. Female flowers are wind-pollinated. Pollen that lands on the water surface is lost for reproductive purposes (Cook and Luond 1982). Thousands of free-floating male flowers have been observed in windrows on ponds (Langeland and Schiller 1983). In monoecious plants, male and female flowers are produced singly from the spathe.

Leaves are 2-4 mm wide, 6-20 mm long, sessile, and arranged in whorls of 3-8 (generally five leaves per whorl) (Cook and Luond 1982). The leaves have 11-39 sharp teeth per cm along the margins and often have either spines or glands on the underside of the midrib. The midrib is often red. The teeth are deciduous and leave behind elevated projections (Reed 1977). Adventitious roots are usually glossy white, although when growing in highly organic sediments, may take on the reddish brown color of the sediment. When exposed to light, the roots may have a greenish cast caused by the presence of chlorophyll (Langeland 1996).

The axillary turions of *H. verticillata*, also called winter buds, are condensed shoots of 12-15 internodes surrounded by fleshy leaves arranged in alternating whorls. They are oval to oblong in shape, 3-12 mm long and 2-3.5 mm wide. Axillary turions are green in color and can be distinguished from vegetative buds by the absence of spines on the midrib of their leaves. They fall from the plant when they mature. Subterranean turions are formed terminally on rhizomes or stolons, and can be found up to 30 cm deep in the sediment. They are 5-10 mm long and are off-white to yellow, unless they take on darker colors from organic sediments (Langeland 1996). They are filled with reserve food material in the form of starch (Miller et al. 1992).

H. verticillata was originally confused with *Elodea* sp., a common native aquatic plant of the central and northern U.S. and parts of Canada. *H. verticillata* can be distinguished from *Elodea* by its sharply serrated leaf margins (usually visible to the naked eye), red veins, spinous midrib and scabrous texture, and its anthers that open explosively. However, leaf morphology, the variation in the number of leaves per node, and variation in hydrilla under different conditions, make misidentification common (Hench et al. 1994).

PEST WEED STATUS

H. verticillata is a federal noxious weed and an A-ranked noxious weed in California. It is considered a pest species throughout its introduced range.

STEWARDSHIP SUMMARY

H. verticillata is native to the warmer areas of Asia, and was first discovered in the United States in 1960. It possesses specialized growth habits, physiological characteristics, and reproductive strategies that allow for rapid growth and expansion in freshwater environments. *H. verticillata* has spread rapidly through portions of the United States and has become a serious weed in aquatic systems, causing substantial economic hardships, interference with water uses, displacement of native aquatic plant communities, and other adverse impacts to freshwater habitats. Management methods currently include mechanical removal and drawdowns, herbicides, and biological controls.

Mechanical removal is a primary method of *H. verticillata* removal, but because it is so costly, it is only used in proximity to domestic water supply intakes, in rapidly flowing water, or when immediate removal is necessary. Water drawdown can be effective if done while subterranean turions are developing in the fall and prior to regrowth in the spring, but drawdowns are restricted to water bodies with water control structures, and where they will not interfere with other primary water uses. Several herbicides have also been used to control hydrilla. Most effective have been the contact poisons copper sulfate (brand name Komeen and others) and endothal (brand name Aquathol and others), and the systemic herbicides fluridone and bensulfuron methyl. Contact poisons are especially toxic to other plants and/or animals. Several organisms have shown promise as biocontrol agents against hydrilla. Sterile, triploid Chinese grass carp are available and legal by permit in some states in the U.S. They are useful in small ponds or lakes and canal systems where the fish can be retained within the water body and where the removal of all vegetation is acceptable. Two weevils, two leaf-mining flies, and one aquatic moth, have also been purposely or accidentally introduced to control hydrilla.

RANGE

H. verticillata is native to the warmer regions of Asia (Cook and Luond 1982), and now occurs in Asia, Australia, New Zealand, the Pacific Islands, Africa, Europe, South America, and North America (Cook and Luond. 1982; Langeland 1996). In North America, states which have recorded occurrences of *H. verticillata* include: Alabama, Arizona, California, Delaware, District of Columbia, Florida, Georgia, Louisiana, Maryland, Mississippi, North Carolina, South Carolina, Tennessee, Texas, Virginia, and Washington. *H. verticillata* was recently reported in Connecticut (USDA, NRCS 1999).

IMPACTS AND THREATS POSED BY HYDRILLA

Because of unique biological and physiological characteristics, and an aggressive growth habit, *H. verticillata* has established itself in a wide range of aquatic habitats. Once established, hydrilla can replace native aquatic vegetation and affect fish populations. *H. verticillata* can have long-term impacts on native systems by reducing seed production of native species, resulting in a decline in the native species proportion of the seed bank (De Wintono 1996). *H. verticillata* can also displace native aquatic plants such as pondweeds (*Potamogeton* sp.) and eelgrass (*Vallisneria americana* Michaux). Hydrilla can elongate 2-3 cm per day as it approaches the water surface. Near the water surface, it branches profusely, with 50% of the standing crop occurring in the upper 0.5 m of the water column (Haller and Sutton 1975). By producing such a large mat of vegetation on the water surface, *H. verticillata* intercepts sunlight to the exclusion of other submersed plants. Both inorganic and organic sediment levels increase with increasing hydrilla abundance (Joyce et al. 1992). Such increases may themselves have effects on aquatic community composition. In natural systems, as well as in channels and rivers providing urban and agricultural water supplies, hydrilla slows the movement of water. Supply, drainage and irrigation uses are hampered. Recreational uses (e.g., boating) are also degraded. *H. verticillata* can, therefore, have a serious impact on the functioning of natural systems, cultural water uses, and economic uses of water supplies.

HABITAT

H. verticillata has a large ecological amplitude and is found in a variety of aquatic habitats, but rarely in swift-flowing water. Water quality is rarely limiting. It is able to grow under a wide range of water chemistry conditions, and is found in oligotrophic (low nutrients) to eutrophic (high nutrients) lakes (Langeland 1996). *H. verticillata* can grow in water up to about 7% the salinity of seawater (Haller et al. 1974) or higher (Steward and Van 1987), and tolerates a wide range of pH values, but prefers a pH of 7.0 (Steward 1991). *H. verticillata* grows very rapidly from rootstocks, stem fragments, and from turions. Only one node or whorl of leaves is necessary for growth. *H. verticillata* is normally associated with low amounts of sulfate, chloride, nitrate and iron, and in deep sediments (Cook and Luond 1982). It is adapted to low light levels (Van et al. 1976).

ECOLOGY AND BIOLOGY

Light, temperature and nutrients

Hydrilla has low rates of dark respiration and photorespiration, and a high rate of photosynthesis (Cook and Luond 1982). It can therefore, begin photosynthesis at lower light levels (early in AM, later in PM, and seasonal) than other aquatic plants. Its low light requirements (1% of full sunlight or less) also allow *H. verticillata* to colonize deeper waters than other aquatic plants (Langeland 1996). In clear waters, hydrilla can grow from more than 10 meters deep (Hall and Vandiver 1991). *H. verticillata* most commonly occurs in around three meters deep, but has been found growing from depths of 15 meters.

Submersed plants are often subjected to more constraints from photosynthesis, in comparison to terrestrial plants. Carbon dioxide has a low diffusion rate in water, so the efficient use of bicarbonate ion as a dissolved inorganic carbon source is an important competitive characteristic for existence in aquatic environments. *H. verticillata* can use free carbon dioxide from surrounding water when it is available, and can easily switch to bicarbonate utilization when conditions favors its use, such as when waters have a high pH or a high carbonate concentration (Salvucci and Bowes 1983). These conditions occur in highly productive waters during warm water and high photosynthesis conditions. Under these conditions, *H. verticillata* can also switch to C4-like carbon metabolism, characterized by low photorespiration and inorganic carbon fixed into malate and aspartate (Holaday and Bowes 1980).

Monoecious and Dioecious Biotypes

Comparisons of monoecious and dioecious biotypes indicate that the monoecious type can germinate at lower temperatures and produce the maximum number of subterranean tubers under short day lengths. This indicates that the monoecious type may be better adapted to cooler climates (Steward and Van 1987).

Allelopathy

H. verticillata does not produce allelopathic chemicals. It is also not affected by allelopathic exudations from native aquatic species such as *Ceratophyllum demersum, Potamogeton nodosus,* or *Vallisneria americana* (Jones 1995).

Reproduction

H. verticillata reproduces by both vegetative and sexual methods. Vegetatively, *H. verticillata* reproduces by stem fragmentation and by the production of turions (axillary and subterranean). In general, most hydrilla plant fragments (more than 50%) can resprout and grow into new plants (Langeland 1996).

Turions are vegetative propagules. Formation of turions begins in September and increases from October to November, decreases in December and January, and increases again in the late spring. Turion production is significantly higher in floating plants (75.6 turions/kg) than in rooted plants (28.6 turions/kg). Production of turions decreases with increasing plant density of *H. verticillata* (Miller et al. 1992).

Subterranean turions are considered the more important of the two methods of turion reproduction. One single subterranean turion has been shown to produce over 6000 new turions per m^2 (Sutton et al. 1992), per year, while only 2,803 axillary turions can be produced per m^2 (Thullen 1990). Subterranean turions can remain viable for several days out of water (Basiouny et al*.*1978), and for over four years in undisturbed sediments (Van and Steward 1990). They can also survive ingestion and regurgitation by waterfowl (Joyce et al*.* 1980), and herbicide applications (Haller et al. 1990).

Subterranean turion and biomass production are closely correlated with temperature. In laboratory experiments, both are inhibited at 12° to 16° C. Biomass production increased linearly with increasing temperature to 28° C and reached a maximum at 28° to 32° C. Subterranean tuber production was highest at 24° C. Both subterranean tuber and biomass production were higher on inorganic than organic sediments. Most subterranean tubers are formed during the short days of spring and autumn. Higher temperatures during simulated short day lengths increased the number of subterranean tubers; higher temperatures during simulated long day-lengths increased subterranean tuber mass. Amendments of N had no significant effect (McFarland and Barko 1990).

Seed production is probably of minor importance to *H. verticillata* reproduction, compared to its successful vegetative reproduction. Seed production and viability is low compared to many other weedy species. Survivability of seeds after ingestion is unknown. The importance of seed dispersal, therefore, after ingestion by birds or other species, is also unknown (Langeland 1996).

ECONOMIC AND OTHER USES

H. verticillata causes major negative impacts on water use. In drainage canals, it greatly reduces flow and can cause flooding and damage to canal banks and structures. In irrigation canals, it impedes flow and clogs the intakes of pumps used for conveying irrigation water. Hydrilla has interrupted water flow patterns in utility cooling reservoirs. It can severely interfere with the navigation of both recreational and commercial craft. Furthermore, *H. verticillata* interferes with boating by fisherman and water-skiers, and interferes with swimming. Limitations on water use can reduce real estate values and tourism.

Some sport fishermen consider *H. verticillata* to benefit largemouth bass habitat (Tucker 1987), although research results differ (Estes et al. 1990; Porak et al. 1990; Colle and Shireman 1980; Canfield and Hoyer

1992). Because *H. verticillata* displaces native plant communities, it may adversely impact sportfish populations.

H. verticillata may have some positive economic consequences. It is eaten by waterfowl, and maintaining hydrilla populations is sometimes advocated by waterfowl scientists because it increases feeding habitat for ducks (Johnson and Montalbano 1984; Esler 1989). Highly transparent water is often desired by the public, and submersed aquatic macrophytes such as *H. verticillata* tend to increase water clarity (Canfield et al. 1984) probably by lowering suspended sediment loads, and removing nutrients on which phytoplankton populations depend.

MANAGEMENT

Potential for Restoration of Invaded Sites

H. verticillata has an unusually high level of reproductive vigor, and is also highly adaptable to different habitats. There are currently no known important native insect pests of *H. verticillata.* In wildlands, the application of herbicides can kill other aquatic plants and animals. Unless and until biological controls become biologically and economically feasible, the potential for large-scale restoration of wildlands infested with *H. verticillata* is probably very low.

Management methods currently include mechanical removal and drawdowns (controlled water drainage), herbicides, and the use of some biological controls.

Specialized machines are used for mechanically removing *H. verticillata*. This is not a widespread practice because of the high cost involved (often over $1000 per acre) and because of logistical constraints. Up to six harvests may be required annually due to the rapid growth rate of *H. verticillata* (McGehee 1979). Mechanical removal is used for *H. verticillata* management only in areas that are in close proximity to domestic water supply intakes, in rapidly flowing water, or when immediate removal is necessary. The high cost of harvesting *H. verticillata,* and its low nutrient value, greatly restrict hydrilla's value as a forage plant (Easley & Shirley 1974; Bagnall 1978).

Drawdowns can be an effective mode of hydrilla control if the drawdown is performed while subterranean turions are developing in the fall, and prior to regrowth in the spring (Haller et al. 1976). Drawdowns for aquatic plant management are restricted to only those lakes or ponds that have water control structures, and have hydrologic characteristics that permit water levels to be controlled. Additionally, the drawdown must not negatively impact other primary water uses, such as domestic or irrigation supplies, navigation, or hydrologic power. Even in drained lakes and ponds, subterranean turions may remain dormant and viable in organic substrates (Haller and Shireman 1983).

Several herbicides have been used to control hydrilla. Most effective have been the contact poisons copper sulfate (brand name Komeen and others) and endothal (brand name Aquathol and others), and the systemic herbicides fluridone and bensulfuron methyl. For both contact and systemic herbicides, concentration in the water column and exposure time are key variables determining effectiveness. Copper sulfate and endothal are non-selective herbicides, and copper sulfate is highly toxic to fish. Fluridone has been used to control *H. verticillata* in Lake Okeechobee in Florida with minimal to no long-term impact on native aquatic plants (Langeland 1996). Application rates vary according to a number of factors, including water depth, water chemistry, whether the water is still or moving, and the size of the infestation. Getsinger & Netherland (1997) report that the following formulations have been effective: for endothal, 2.0 mg ae/L for 48 hours or 3.0-5.0 mg ae/L for 24 hours; for fluridone, 15-30 ug/L for 20-40 days (minimum of 4 ug/L); and for bensulfuron methyl, 25 ug/L and higher for in excess of 42 days. The use of plant growth regulators such as fluridone and bensulfuron methyl is relatively recent, and is intended to reduce, but not to necessarily eliminate, *H. verticillata*. Less vigorous remnant plants may perform useful functions such as providing oxygen, stabilizing sediment loads, and creating habitat (Lembi and Chand-Goyal 1994).

Acetic acid in concentrations of 9-26 mmol/L (which is less concentrated than commercial vinegar) for 24 hours reduced growth by 50% in laboratory studies (Spencer and Ksander 1995). The use of compounds from native aquatic plant species with allelopathic properties has not been shown to be an effective control for *H. verticillata* (Jones 1995).

Grass carp or white amur (*Ctenopharyngodon idella* Val.) is a biological control agent that effectively controls *H. verticillata* (Van Dyke et al.1984). Possession of this fish species, however, is illegal in many states because of the potential environmental damage that could result if escaped fish were to establish breeding populations. Sterile, triploid grass carp are available and legal by permit in some states in the U.S. Not all triploid grass carp are sterile, however, and every individual released needs to be genetically checked. Grass carp is recommended for small ponds or lakes and canal systems where the fish can be retained within the water body and where the removal of all vegetation is acceptable. There is no adequate method of recapture. Since Chinese grass carp prefer food other than *H. verticillata*, a reduction in the overall abundance of native aquatic plants, and the potential reduction in food and habitat for invertebrates, other fish, and waterfowl, are to be expected. Stocking rates for partial control have not been established.

Worldwide surveys for natural *H. verticillata* enemies were begun in 1981 in a cooperative study undertaken by the University of Florida-IFAS, United States Department of Agriculture, and U.S. Army Corps of Engineers. Snails consume large amounts of *H. verticillata* when they are present in high densities in enclosed experimental areas, but not in natural settings. Plant pathogens effective against *H. verticillata* under experimental conditions have been ineffective in the field (Charudattan and Lin 1974; Charudattan and McKinney 1978). Several pathogens have been identified from Asia, but their effectiveness has yet to be tested (Shearer 1997).

Over 40 species of insects have been found that feed on *H. verticillata*. Several are being evaluated as potential *H. verticillata* biocontrols in the United States. Other insects from Australia are also under consideration (Balciunas et al.1996). *Bagous affinis* Hustache is a weevil that was discovered in Pakistan and India. Adults lay eggs on rotting wood and other organic matter. After hatching, the larvae burrows through the sediment until it encounters a *H. verticillata* subterranean turion, which it then feeds on and destroys (Buckingham and Bennett 1994). This insect is useful only where there are periodic lake drawdowns or intermittently wet and dry shorelines. Another *Bagous* species has been released in the U.S. but has not become established. *Hydrellia pakistanae* Deonier is a leaf-mining fly that is very promising as a *H. verticillata* biosuppressant (Buckingham et al.1989). *H. pakistanae* is established in Florida, but its impact on *H. verticillata* has yet to be determined. *H. balciunasi*, released in 1989, has had limited establishment, apparently due to several factors including competition with other biological agents, parasitism by native wasps, genetic differences in *H. verticillata* types, and possible inbreeding depression (Grodowitz et al. 1997). An aquatic moth, *Parapoynx diminutalis* Snellen, was accidentally introduced into the United States (Del Fosse et al*.* 1976). The larvae of this moth can frequently be found feeding in large numbers on *H. verticillata*, though usually not until late in the growing season. Large areas may be defoliated but viable stems remain and the plant remains a problem.

MANAGEMENT PROGRAMS

Management programs are extensive where *H. verticillata* impacts recreational and economic resources. In the USA, California and Florida have spent millions of dollars on control efforts.

MONITORING

In general, the objectives of monitoring should track those of management. Abundance (cover) is often measured following control applications. Most areas subject to management for *H. verticillata* are of economic or recreational importance (e.g., recreational lakes, canals, and irrigation systems). In those areas, the goal is removal of *H. verticillata* to a degree sufficient to permit continued economic or recreational uses. Monitoring is generally designed to monitor changes in abundance of *H. verticillata* alone. In natural areas management, monitoring programs will likely combine changes in abundance of *H.*

verticillata with changes in abundance of species or changes in community attributes that are the targets of management. Such programs should have explicit objectives that can be measured and that are meaningful from both a biological and management standpoint. These objectives may vary depending on the abundance of *H. verticillata* and other invasive aquatic plants.

In terms of effort (number of plots established and monitored), transects, or long, linear plots are more effective in providing sufficient statistical power to determine change, than square or broadly rectangular or otherwise regularly shaped plots. Such techniques, however, are difficult to apply in aquatic situations. While generally a research technique, measuring change, or lack thereof, in control (unmanaged) areas can be an effective way of assuring that changes are actually resulting from management and not from other factors.

Extensive monitoring programs exist where management programs have been implemented, especially in California and in Florida. In Florida, monitoring the presence/absence and abundance of *H. verticillata* has been coupled with that of other species. Monitoring the abundance of subterranean turions has also been undertaken to determine long-term effects of management (Sutton 1996).

Contacts:

Lars W.J. Anderson, USDA-ARS Aquatic Weed Research Laboratory 208 Robbins Hall, University of California at Davis, Davis, CA 95616; (530) 752-7870; lwanderson@ucdavis.edu

Nate Dechoretz, CA Department of Food and Agriculture, Control and Eradication Branch: (916) 654-0768; Ndechoretz@cdfa.ca.gov

William A. Boyd, Dwilette G. McFarland, and/or John W. Barko, U.S. Army Engineers Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199; (601) 634-2100; http://wes.army.mil/

Center for Aquatic and Invasive Plants, University of Florida, Institute of Food an Agricultural Sciences, 7922 N.W. 71st St., Gainesville, FL. 32653-3071. (352) 392-1799; http://aquat1.ifas.ufl.edu/

RESEARCH

A great deal is known about the biology of this species. Further work is needed on the effectiveness of replanting native species to slow reinvasion by *H. verticillata* following control (Madsen 1997).

Extensive research on the biology and management of this species has been done and is ongoing. Several journals, such as the Journal of Aquatic Plant Management, regularly carry articles on management of this species. A computer model of growth and reproduction under various site conditions has been developed (Best and Boyd 1996). However, there is little research on management and restoration of natural areas where native species are targets of conservation. Further work is needed on the application of biocontrol agents and of the potential impacts of such agents on native species and natural ecosystems. Work is needed on the use of plant growth regulators, such as flurprimidol, which reduce plant growth but do not cause mortality (Lembi and Chand-Goyal 1994). In addition, work is needed on integrated management strategies that combine herbicide use with biological control and restoration techniques (Madsen 1997).

REFERENCES

Anderson, L.W.J. 1996. Eradicating California's Hydrilla. Aquatic Nuisance Species Digest. 1(3).

Balciunas. J.K., D.W. Burrows, and M.F. Purcell. 1996. Australian surveys (1985-1992) for insect biological control agents of *Hydrilla verticillata*. Technical Report A-96-5. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Best, E.P.H. and W.A. Boyd. 1996. A simulation model for the growth of the submersed aquatic macrophyte hydrilla (*Hydrilla verticillata* [L.f.] Royle). Technical Report A-96-8, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Buckingham, G.R. and C.A. Bennett. 1994. Biological and host range studies with *Bagous affinis*, an Indian weevil that destroys *Hydrilla* tubers. Technical Report A-94-8. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

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

de Winton, M.D. and J.S. Clayton 1996. The impact of invasive submerged weed species on seed banks in lake sediments. Aquatic Botany 53(1-2): 31-45.

Fox, A. M., W. T. Haller, and D.G. Shilling. 1996. Hydrilla control with split treatments of fluridone in Lake Harris, Florida. Hydrobiogia. 340: 235-239.

Getsinger, K.D. and M.D. Netherland. 1997. Herbicide concentration/exposure time requirements for controlling submersed aquatic plants: summary of research and accomplishments. Miscellaneous Paper A-97-2, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Grodowitz, M.J., A.F. Cofrancesco, J.E. Freedman, and T.D. Center. 1997. Release and establishment of *Hydrellia balciunasi* (Diptera: Ephydridae) for the biological control of the submersed aquatic plant *Hydrilla verticillata* (Hydrocharitaceae) in the United States. Miscellaneous Paper A-97-5. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Hall, D. W. and V. V. Vandiver 1991. Weeds in Florida. SP37, Florida Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Hench, J.E., R. Gibbs, and J.S. Hench. 1994. Some observations on Hydrilla and wintering waterfowl in Montgomery county, Maryland. The Maryland Naturalist. 38(1-2): 3-9.

Jones. H.L. 1995. Allelopathic ability of various aquatic plants to inhibit the growth of *Hydrilla verticillata* (L.f.) Royle and *Myriophyllum spicatum* L. Technical Report A-95-1. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Joyce, J.C., K.A. Langeland, T.K. Van, and V.V. Vandiver. 1992. Organic sedimentation associated with Hydrilla management. Journal of Aquatic Botany. 30: 20-23.

Langeland, K.A. 1996. *Hydrilla verticillata* (L.F.) Royle (Hydrocharitaceae), "The Perfect Aquatic Weed". Castanea 61:293-304.

Langeland, K.A., D.G. Shilling, J.L. Carter, F.B. Laroche, K.K. Steward, and P.T. Madiera. 1992. Chromosome morphology and number in various populations of H. verticillata (L.f.) Royle. Aquatic Botany. 42: 253-263.

Lembi, C.A. and T Chand-Goyal. 1994. Plant growth regulators as potential tools in aquatic plant management: efficacy and persistence in small-scale tests. Contract Report A-94-1. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Madsen, J.D. 1997. Methods of management of nonindigenous aquatic plants. In Luken, J.O. and J.W. Thieret (eds) Assessment and management of plant invasions. Springer, New York, NY.

McFarland, D.G. and J.W. Barko. 1996. Investigations of the production, transport, and survival of monoecious *Hydrilla* propagules in the tidal Potomac River. Technical Report A-96-7. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

McFarland, D.G. and J.W. Barko. 1990. Interactive influences of selected environmental variables on growth and tuber formation in Hydrilla. Aquatic Plant Control Research Program Technical Report A-90-6. Department of the Army, Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, MS.

Miller, J.D., W.T. Haller; and M.S. Glenn. 1992. Turion production in Hydrilla. In New and Improved Methods for the Control of Aquatic Weeds. Semi-annual report, USDA/ARS-IFAS/University of Florida, Gainesville, FL.

Reed, C. F. 1977. Economically Important Foreign Weeds. Agricultural Research Service. USDA.

Shearer. J.F. 1997. Classical pathogen biocontrol research in Asia 1994-1995: surveys for pathogen agents of *Hydrilla verticillata* (L.f.) Royle and *Myriophyllum spicatum* L. Technical Report A-97-1. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

South Caroline Hydrilla Home Page. http://entweb.clemson.edu/caps/state/survey/exotic/hyd/hyrilla.

Spencer, D.F. and G.G. Ksander. 1995. Influence of acetic acid on regrowth of dioecious Hydrilla from root crowns. Journal of Aquatic Plant Management 33:61-63.

Steward, K.K. and T.K. Van. 1987. Comparative studies of monoecious and dioecious Hydrilla (*Hydrilla verticillata*) biotypes. Weed Science. 35: 204-210.

Sutton, D.L. 1996. Depletion of turions and tubers of Hydrilla verticillata in the North New River Canal, Florida. Aquatic Botany 53: 121-130.

USDA, NRCS 1999. The PLANTS database (http://plants.usda.gov/plants). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.

AUTHORED BY: Michael S. Batcher, Consulting Ecologist and Environmental Planner, 1907 Buskirk-West Hoosick Road, Buskirk, NY 12028, e-mail: mbatcher@netheaven.com.

EDITED BY: Mandy Tu & Barry Meyers-Rice, The Nature Conservancy, Wildland Invasive Species Program, Department of Vegetable Crops and Weed Science, 124 Robbins Hall, University of California, Davis, CA 95616.