Hydrilla verticillata
"The Perfect Aquatic Weed"

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

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.

INTRODUCTION

Colonization of the land by ancestral marine autotrophs, which began long before the mid-

Paleozoic, gave rise to evolution of vascular plants (Sculthorpe 1967). Ecological adaptability has allowed this group to evolve species that have colonized diverse terrestrial habitats from desert to tundra. A small group of plants, 1 per cent by most liberal estimates, returned to life in aquatic and marine environments (Sculthorpe 1967). These fresh water and marine vascular plants, as a group, are particularly fascinating because of numerous adaptations they have evolved as they returned to the submersed environment. One of the most studied aquatic vascular plants is hydrilla (*Hydrilla verticillata* (L.F.) Royle (Hydrocharitaceae)). Hydrilla could easily be called the perfect aquatic plant because of the extensive adaptive attributes it possesses to survive in the aquatic habitat. These characteristics allow Hydrilla to be an aggressive and competitive colonizer of aquatic habitats. Hydrilla has become a serious pest in North American waters. This paper will discuss hydrilla as "the perfect aquatic weed" in North America.

IDENTIFICATION

Here are pictures of hydrilla...

Hydrilla is highly polymorphic, its appearance can vary considerably depending upon the conditions under which it is growing (Verkleij *et al*. 1983; Pieterse *et al*. 1985). It grows submersed in water and 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, then branching becomes profuse. Many horizontal above-ground stems (stolons) and underground stems (rhizomes) are also produced. Leaves are 2-4 mm wide, 6-20 mm long, and occur in whorls of 3-8. 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 also often red. Adventitious roots are usually glossy white unless growing in highly organic sediments in which case they take on the reddish brown color of the sediment, or they can have a green cast caused by the presence of chlorophyll when exposed to light.

Hydrilla can be either monoecious or dioecious with both male and female flowers singly froma spathe (Cook and L□”nd 1982, Pieterse 1981). Female flowers consist of three whitish sepals and three translucent petals, are 10-50 mm long, 4-8 mm wide, attached at leaf axils, 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 re-float. A submerged female flower has been described as an inverted bell filled with a large bubble. Male flowers have three whitish red or brown sepals that are up to 3 mm long and 2mm wide. They have three whitish or reddish linear petals that are about 2mm long and they have three stamens which are formed in leaf axils. Male flowers are released and float to the surface as they approach maturity. Thousands of these free floating male flowers are sometimes observed in windrows on ponds (Langeland and Schiller, 1983). Both male and female flowers are produced singly from the spathe.

Hydrilla produces hybernacula, turions in leaf axils and tubers (subterranean turions) terminally on rhizomes. Turions are very compact dormant buds that are produced in leaf axils and fall from the plant when they mature. These structures are 5-8 mm long, dark green, and appear to be spiny. Tubers are formed terminally on rhizomes or stolons and can be found 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.

DISTRIBUTION

Hydrilla is probably native to the warmer regions of Asia (Cook and L□”nd 1982). It is a cosmopolitan species that occurs in Europe, Asia, Australia, New Zealand, the Pacific Islands, Africa, Europe, South America, and North America. Although hydrilla occurs in temperate areas, it tends to be more widespread in tropical areas of the world.

Hydrilla was discovered in the United States in 1960 at two Florida locations, a canal near Miami and in Crystal River (Blackburn *et al.* 1969). It spread throughout the state very rapidly. By the early 1970s it was established in major water bodies of all drainage basins in the state. In 1988, the Florida Department of Natural Resources estimated over 20,000 ha of water in Florida contained hydrilla (Schardt and Nall 1988). Hydrilla continues to spread in Florida and in 1995 covers 40,000 ha of water in 43% of public lakes. Hydrilla is now found in all Gulf Coast states, Atlantic Coast States as far north as Maryland and Delaware, and in the western states, California, Washington, and Arizona.

It is evident that there have been at least two hydrilla introductions into the United States because at least two different forms occur. Florida populations are dioecious female, as are all wild populations thus far observed as far north as Lake Marion in South Carolina. Most populations north of Lake Marion are monoecious. The exceptions are a dioecious population in Wilmington, North Carolina and both dioecious and monoecious plants in Lake Gaston, which borders North Carolina and Virginia (Ryan *et al.* 1995).

A major question that remains is how far north in the United States hydrilla will spread and whether it will be a problem in the northern states as it is in the southern states. The northernmost monoecious hydrilla population occurs at approximately 40o north latitude in the United States. In Poland and the Soviet Union, hydrilla occurs near 50o north latitude. These latitudes are similar to US and Canadian border and suggest the northern limit for hydrilla colonization in the northern hemisphere. However, hydrilla does not seem to spread readily from existing populations in Northeastern Europe (Cook and L□”nd 1982). Still, how far north in the United States hydrilla will thrive and be a weed problem remains a question.

Research suggests that the monoecious strain is better adapted to the temperate climate because it can form tubers more quickly during short photoperiods (Spencer and Anderson 1986, Van 1989) and also during long photoperiod (Van 1989). This may explain the distribution of the monoecious and dioecious populations along the Atlantic coast, or the distribution could be coincidental.

BIOLOGY AND PHYSIOLOGY

Hydrilla can establish and then displace native aquatic plants such as pondweeds (*Potamogeton* sp.) and eelgrass (*Vallisneria americana* Michaux). While all aquatic plants have developed adaptations for life in the aquatic environment, hydrilla seems to be a couple of steps ahead of other submersed plants. Research has identified many of the characteristics that enable hydrilla to exist and compete so effectively. Some of these characteristics are very simple and effective while others are complex and of scientific interest.

The growth habit of hydrilla enables it to compete effectively for sunlight. It can elongate very rapidly, up to one inch per day, until it nears the water surface. Near the water surface it branches profusely and produces greater stem density than other submersed aquatic plants. One half of hydrilla standing crop occurs in the upper 0.5 m of water column (Haller and Sutton 1975). By producing this mat of vegetation on the water surface hydrilla is able to intercept sunlight to the exclusion of other submersed plants. Hydrilla makes efficient use of available nutrients. Hydrilla tissue is composed of approximately 90% water (Van *et al.* 1976). Therefore, the plants can produce a great deal of fresh plant material from a limited supply of the essential plant nutrients carbon, nitrogen and phosphorus.

Hydrilla is able to grow under a wide range of water chemistry conditions. It is commonly found in oligotrophic (low nutrients) to eutrophic (high nutrients) lakes (Cook and L□”nd 1982). It can grow in water up to about 7% the salinity of seawater (Haller *et al.* 1974) or higher (Steward and Van 1987); and it tolerates a wide range of pH, but tends to grow better at pH 7 (Steward 1991).

Hydrilla is adapted to use low light levels for photosynthesis (Van *et al.* 1976, Bowes *et al.* 1977). This means that hydrilla can begin to photosynthesize earlier in the morning and thus successfully compete with other aquatic plants for limited dissolved carbon in the water . The low light requirement (1% of full sunlight or less) also allows hydrilla to colonize in deeper water than other aquatic plants. Hydrilla has been found growing at a depth of 15 m in Crystal River and commonly occurs in water 3 m deep in Florida lakes.

Submersed plants are subjected to constraints on photosynthesis in comparison to terrestrial plants. Owing to the 104x slower diffusion rate of carbon dioxide in water than air, efficient use of bicarbonate ion as a dissolved inorganic carbon source is an important competative characteristic for existence in the aquatic environment. Hydrilla can use free carbon dioxide from surrounding water when it is available and can switch to bicarbonate utilization when conditions favors its use i.e., high pH and high carbonate concentration (Salvucci and Bowes 1983). These conditions occur in highly productive waters during warm water and high photosynthesis conditions. Under these conditions, hydrilla can also switch to C4-like carbon metabolism, characterized by low photorespiration, and inorganic carbon fixed into malate and aspartate (Holaday and Bowes 1980).

Hydrilla is very efficient at reproducing itself and maintaining itself during adverse conditions. It can reproduce itself in four different ways. These are: fragmentation, tubers, turions, and seed.

Almost 50% of hydrilla fragments that have a single whorl of leaves can sprout a new plant that a new population can grow from, and greater than 50% of fragments with only three whorls of leaves can sprout (Langeland and Sutton, 1980). This means that small amounts of hydrilla on boat trailers, bait buckets, draglines, and from aquariums can spread the plant from place to place.

Turions are formed terminally on rhizomes (commonly called tubers or subterranean turions) and in leaf axils (commonly called turions or axillary turions). One single subterranean turion has been shown to produce over 6000 new turions per m2 (Sutton *et al.* 1992), and 2,803 axillary turions can potentially be produced per m2 (Thullen 1990). Subterranean turions can remain viable for several days out of water (Basiouny *et al.*1978), and for over four years in undisturbed sediment (Van and Steward, 1990). They also survive ingestion and regurgitation by waterfowl (Joyce *et al*. 1980), and herbicide applications (Haller *et al.* 1990).

Seed production is probably of minor importance to hydrilla reproduction compared to its successful vegetative reproduction. Although seed production and viability is low compared to many other weeds (Langeland and Smith 1984), the importance of seed production has not been well researched and is not adequately understood. Seeds of many plants can be ingested by birds, carried for long distances, and passed through the gut in a viable condition. If this proves to be true for hydrilla seed, it may prove to be an important means of natural, long distance dispersal.

IMPORTANCE

Hydrilla causes major detrimental impacts on water use. In drainage canals it greatly reduces flow, which can result in flooding and damage to canal banks and structures. In irrigation canals it impedes flow and clogs intakes of pumps used for conveying irrigation water. In utility cooling reservoirs it disrupts flow patterns that are necessary for adequate cooling of water. Hydrilla can severely interfere with navigation of both recreational and commercial craft. In addition to interfering with boating by fisherman and waterskiers in recreational waters, hydrilla interferes with swimming, displaces native vegetation communities, and can adversely impact sportfish populations. The economic impacts of these water uses to real estate values, tourism, and user groups can be staggering. For example, an economic study on Orange Lake in North Central Florida indicated that the economic activity attributed to the lake was almost $11.0 million and during years that hydrilla completely covers the lake these benefits can be virtually lost (Milon *et al.* 1986). Cost of hydrilla management is also extremely high, especially when funding is insufficient for adequate management. An estimated $10.0 million is necessary to manage hydrilla in Florida public waters in 1994-95 and $14.5 million will be necessary in 1995-96, as hydrilla continues to expand (Jeff Schardt, Florida Department of Environmental Protection, personal communication). Some sport fishermen consider hydrilla to benefit largemouth bass habitat (Tucker 1987). While the opinion that hydrilla is beneficial for sportfish production is supported by certain research (Estes *et al.* 1990; Porak *et al.* 1990), other research suggests that largemouth bass are adversely affected when hydrilla coverage exceeds 30% (Colle and Shireman 1980). Canfield and Hoyer (1992) found no relation between standing crop of harvestable largemouth bass and percent area covered with aquatic macrophytes in 60 Florida lakes (many dominated by hydrilla). When fish biomass was adjusted for lake trophic state (chlorophyll a), maximum biomass tended to occur in lakes when 20% to 40% of the lake volume was occupied by aquatic macrophytes. Hydrilla is eaten by waterfowl, and maintaining hydrilla populations is sometimes advocated by waterfowl scientists because it increases the feeding habitat for ducks (Johnson and Montalbano 1984, Esler 1989).

Highly transparent water is often considered desirable by the public and large populations of submersed aquatic macrophytes, such as hydrilla, will tend to increase water clarity (Canfield *et al.* 1984). The exact reasons for this increase in water clarity are not completely understood but it probably results from a combination of factors which include lowering sediment re-suspension and reduction of phytoplankton populations by compartmentalizing nutrients. Regardless, large amounts of aquatic macrophytes are necessary to cause substantial increases in water clarity (Canfield *et al.* 1984; Canfield and Hoyer 1992).

The endeavor to benefit sportfish or waterfowl habitat or produce clear water has resulted in deliberate dispersal of hydrilla by individuals unwary of the severe detrimental impacts that can be caused by the plant. Detrimental impacts caused by hydrilla far outweigh beneficial impacts and it is usually more difficult to manage than native plant populations, which it displaces.

MANAGEMENT

Hydrilla is managed differently in different types of waters, which depends on water uses. Therefore different methods or combination of methods are used depending on the desired end result. In water conveyance systems, the end result may be no vegetation, whereas in recreational waters the goal is usually to improve the environment by selectively controlling hydrilla amongst native vegetation. Management methods include herbicides, grass carp (*Ctenopharyngodon idella* Val.), and mechanical removal. Insects have been released for classical biological control agents and others are under study.

The herbicide active ingredients, copper, diquat, endothall, and fluridone can be used to selectively control hydrilla to some extent, depending on the associated plant community. Copper, diquat and endothall are fast acting contact herbicides that have relatively broad spectrums on submersed aquatic plants. They are used to selectively control hydrilla by injection of liquid herbicides, from trailing hoses, under floating leafed vegetation such as spadderdock (*Nuphar* sp.) or around emergent vegetation such as bulrush (*Scirpus* sp.) (Langeland *et al.* 1991). Granular endothall can be used in the same manner. Fluridone is only effective for whole-pond applications or large scale (>2 ha.) applications in large water bodies and its selectivity is dependent on application rates, contact times, and timing of applications. For example, fluridone has been used to manage hydrilla in Lake Okeechobee with minimum to no long term impact on a native vegetation community consisting of southern naiad (*Najas guadalupensis* (Sprang.) Magnus), eelgrass, pondweed (*Potamogeton illinoensis* Morong), and American lotus (*Nelumbo lutea* Willd.) (Langeland *et al.* 1991).

Grass carp is a herbivorous fish that is effective for controlling hydrilla (Van Dyke *et al.* 1984). Possession of this fish is illegal in most states because of the potential environmental damage that could result if escaped fish establish a breeding population. Sterile, triploid grass carp (Malone 1984) are also effective (Cassani and Caton 1986) and are now available and legal by permit in some states in the U.S. In small ponds or lakes and canal systems, with adequate control structures, and where total removal of vegetation is acceptable, triploid grass carp stocking is highly recommended. They have been used to selectively manage hydrilla in water detention ponds where emergent vegetation was desirable but this use is unpredictable (personal communications with contractors). Because they are non-specific herbivores, an adequate method of recapturing the fish has not been developed, and because stocking rates for partial control have not been established, grass carp are rarely used in large multi-purpose lakes where aquatic vegetation is desirable for sportfish and waterfowl habitat.

Specialized machines are used for mechanically removing hydrilla. However, this is not a widespread practice because of the high cost involved, which is often over $1000 per acre and because of logistical constraints in large water bodies. Because of hydrilla's rapid growth rate, up to six harvests are required annually (McGehee 1979). Mechanical removal is mainly used for hydrilla management in proximity to domestic water supply intakes, in rapidly flowing water, and when immediate removal is necessary.

A commonly asked question is if there is a use for harvested plant material that would help defray the high cost of harvesting. Research has been conducted to determine the feasibility of using harvested hydrilla for practical purposes, such as cattle feed (Easley and Shirley 1974, Bagnall *et al.* 1978). Considering the high cost of harvesting hydrilla and its low nutritive value and fiber content compared to its wet bulk very little return can be derived from the product.

Some of the earliest research for classical biological control of hydrilla was with snails (Blackburn and Taylor 1968). Snails are very effective at consuming large amounts of hydrilla when they are present in high density in enclosed experimental areas. However under natural environmental conditions they are not effective. Likewise, plant pathogens have been isolated that are effective against hydrilla under experimental conditions (Charudattan and Lin, 1974; Charudattan and McKinney 1978), but not under natural conditions.

Insects offer promise as biological suppressants for hydrilla, but as yet none has been shown to effectively fit into management programs. Here are pictures and more information about biocontrol insects for hydrilla.

Extensive, worldwide surveys for natural hydrilla enemies were begun in 1981 in a cooperative study between the University of Florida-IFAS, United States Department of Agriculture, and U.S. Army Corps of Engineers. Over 40 species of insects have been found that feed on hydrilla. Several of these are presently being evaluated as potential hydrilla biosuppressants in the United States and other insects from Australia are under consideration (Center 1992). *Bagous affinis* Hustache is a weevil that was discovered in Pakistan and India. This is not a truly aquatic insect, but the adult lays its eggs on rotting wood and other organic matter and after hatching the larvae burrows through the sediment until it encounters a hydrilla tuber (Bennett and Buckingham 1991). The tuber is then destroyed as the insect feeds on it while it completes its life cycle. This insect will only be potentially useful in combination with lake drawdown or intermittently wet and dry shorelines. Another un-named *Bagous* sp. has been released in U. S. but has not become established. *Hydrellia pakistanae* Deonier is a leaf mining fly that is very promising as a hydrilla biosuppressant (Buckingham *et al.* 1989). *H. pakistanae* is established in Florida but it's impact on hydrilla is undetermined.

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 hydrilla, however extensive damage does not occur until late in the growing season after hydrilla is already at problem levels. Although the moth larvae sometimes defoliates large areas of hydrilla, the viable stems remain and the plant remains a problem. Predators, such as fish, also limit the density of *P. diminutalis* populations (Perkins 1978) and it does not appear to be an effective biosuppressant for hydrilla.

Even manatees or sea cows (*Trichechus manatus*) have been considered for biological control of hydrilla. A study conducted by the U.S. Fish and Wildlife Service reported that over 1000 manatees, 10 times the actual number of 116, would be needed to consume just the standing biomass of hydrilla in Kings Bay (Crystal River, Florida) (Etheridge *et al*. 1985). The manatee is not presently considered for use as a potential biological control for hydrilla because it's numbers are too few, it is not well suited for moving from place to place, and it is an endangered species.

The use of drawdown for aquatic plant management is limited to those lakes or ponds that have sufficient water control structures and hydrologic characteristics to adequately control water level, and where drawdown will not interfere with other primary water uses such as domestic or irrigation supplies, navigation, or hydrologic power. Following hydrilla life cycle research it was suggested that drawdown may be used successfully for hydrilla management by timing drawdowns to prevent tuber formation in the fall and vegetative regrowth and sprouting of tubers in the spring (Haller *et al*., 1976). Large scale tests of this drawdown schedule for hydrilla control in Florida have demonstrated that hydrilla can be temporarily controlled, but tubers remained dormant and viable in organic hydrosoils. Also, other areas were quickly colonized by fragments from unaffected areas (Haller and Shireman 1983). Similarly, drawdown for hydrilla control in North Carolina and Virginia, where lake bottoms had a high clay content, was unsuccessful (Hodson *et. al* 1984, Langeland and Pesacreta 1986).

The old saying "an ounce of prevention is worth a pound of cure" is very applicable to hydrilla control. In states such as Florida where hydrilla is widespread, it is difficult to totally prevent movement of the plant between public lakes. However, an aggressive educational program can prevent many heartaches for private pond owners and may prevent the spread of hydrilla into new areas of the country. State and federal agencies can help by developing and implementing programs to educate the public about the problems that can arise from the introduction of non-native aquatic plants, such as hydrilla, to lakes rivers and ponds. These programs should be directed toward water resource user groups, such as fishing clubs and aquaculturists and also to aquarium hobbyists. Programs should include information on ways to identify these plants and to prevent their introduction, by careful checking and then removal of plant fragments from boats and trailers.

SUMMARY

Hydrilla was introduced into the United States about 35 years ago (ca. 1960). Because of unique biological and physiological characteristics and an aggressive growth habit, hydrilla has established itself in a wide range of aquatic habitats. Once established in a system it can alter the environment detrimentally by replacing native aquatic vegetation and affecting fish populations. Monetary losses occur when waterfront property values are reduced as a result of these environmental impacts or when interference with boating access reduces recreational use of the water body. In urban and agricultural situations hydrilla interferes with the movement of water for drainage or irrigation purposes and again, monetary or property losses can result.

Through scientific research, innovative aquatic plant management programs, and educational programs we have dealt with many of the challenges presented by this weed. However, hydrilla management costs millions of dollars annually and many water resources are diminished because of hydrilla infestations that cannot be remedied. Many challenges remain and it is hoped that further advances in hydrilla management will be made in the years to come.

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