Hydrilla *(Hydrilla verticillata)*

Hydrilla is probably the most well-known aquatic invader. Some even call it the perfect aquatic plant because of its ability to adapt and aggressively compete in its environment (Langeland, 1996). As a submersed macrophyte, it has multiple reproductive strategies and two distinct biotypes. Hydrilla is most notable for the economic and environmental devastation it has caused in Florida (i.e. displaces native plants, clogs water intakes, impedes boat traffic) (Schmitz, 2007). Since 2011 and 2012, it has been found as far north as Cayuga Inlet and the Erie Canal of New York, respectively (Cornell Cooperative Extension[CCE], 2012; NYSDEC; 2012). With hydrilla's close proximity to the Adirondacks and its aggressive characteristics, it is extremely important to be aware of this aquatic plant and the consequences of its invasion.

Hydrilla, a member of the Hydrocharitaceae family, is a submersed, vascular hydrophyte. Depending upon the conditions it grows under, it has highly polymorphic characteristics (reviewed in Langeland, 1996). Two different biotypes of hydrilla exist (Steward & Van, 1987). The female dioecious biotype populations only produce female flowers, while the monoecious biotype populations have both male and female flowers upon the same plant (Cook & Luond, 1982). It is generally rooted in sediments, but fragments can break free, survive, and re-establish in a new location (Langeland & Sutton, 1980). Branching of hydrilla is sparse until it reaches the water's surface, and then bifurcation becomes extremely profuse, forming thick, dense mats in the upper parts of the water column (Langeland, 1996). Hydrilla forms above and below ground stems called stolons and rhizomes, respectively, which gives rises to new vegetative growth (Langeland, 1996). The leaves of hydrilla are typically 2-4mm wide by 6-20mm long and occur in whorls of 3-8 (Langeland, 1996). There are serrations on the margins of the leaves, and the dioecious biotype may have sharp spines along the underside of the leaves' midrib (Langeland, 1996). Hydrilla produces hibernacula in the form of turions (overwintering/dormant buds) (Langeland, 1996). The dormant buds are formed either on the leaf axil or terminally on rhizomes and are known as axillary turions/turions and tubers/subterranean turions, respectively (Langeland, 1996).

The distribution of hydrilla is worldwide, occurring and dominating in aquatic communities in all continents except Antarctica but is most likely to be native to the warmer regions of Asia (Cook & Luond, 1982). There are two different and distinct introductions that have occurred in the United States (Langeland, 1996). Since the 1950s hydrilla's dioecious biotype has been found in canals near Miami and the Crystal River of Florida. This first introduction into the wild is thought to be a result of releases from aquarium trade (reviewed in Langeland, 1996). This dioecious biotype is typically found as far north as South Carolina, and there are even some population further north. A monoecious biotype discovered in the Potomac River, near Washington, D.C., in 1982, marks the second introduction in the United States (Steward, Van, Carter, & Pieterse, 1984). This second invasion is conspicuously different from the first because it is a different biotype, and therefore its source is from outside of the United States. The monoecious biotype is thought to be hardier to temperate climates, and its distribution usually expands north of South Carolina (Langeland, 1996; Spencer & Anderson, 1986; Steward & Van, 1987; Van, 1989). Since its two separate introductions, hydrilla has rapidly spread throughout the southern United States' lakes, rivers, reservoirs, ponds, and canals through anthropogenic activities (Langeland, 1996). More recently hydrilla has been expanding its distribution northward, is currently established in Cayuga Inlet, NY, and has been found in the Erie Canal at North Tonawanda, NY (near Buffalo, NY) (NYSDEC, 2012; CCE, 2012).

The biology of hydrilla makes it a perfect aquatic plant with the ability to outcompete and displace other hydrophytes (Langeland, 1996). The growth habit of hydrilla encourages competitiveness by growing up to one in per day, and then branching copiously near surface of the water. This enables the plant to effectively capture sunlight and shade preexisting aquatic macrophytes (Langeland, 1996). Hydrilla also displaces native aquatic plants by its ability to utilize available nutrients for growth. It is made up of 90% water, and thus more plant material can be produced from fewer available nutrients (Langeland, 1996).

Hydrilla also tolerates a wide range of aquatic environments, light requirements, and carbon availability. It has been found in oligotrophic to eutrophic waterways with wide ranges acidity/alkalinity but favors a pH of 7 (Steward, 1991). Additionally hydrilla is adapted to use low light levels for photosynthesis (Van, Haller, & Bowes, 1976). It begins to photosynthesize first thing in the morning and successfully competes with other aquatic plants for the limited dissolved carbon in the water (Van et al., 1976). Also these low light requirements enable hydrilla to colonize at deeper depths. In the Crystal River, FL, it has been found in 15m of water but most commonly occurs in 3m (Van et al., 1976). Hydrilla uses free carbon dioxide when available, but when dissolved carbon dioxide is limited, it can switch to bicarbonate utilization, usually under high pH conditions. This allows different forms of carbon to be exploited for photosynthesis depending on environmental conditions (Salvucci & Bowes, 1983).

Other than hydrilla's growth habit and biochemistry, its reproduction methods further its competitive advantage in aquatic ecosystems. Hydrilla has a few means of reproductions: seeds, fragmentation, and turions (axillary turions and tubers) (Langeland, 1996). Seed production accounts for the smallest portion of reproduction, especially in the female dioecious populations where seeds cannot be produced (reviewed in Langeland, 1996). Fragmentation is an important means of reproduction and spread once hydrilla has been established in a waterway. One studied shows that 68% of fragments with 3-5 nodes (whorls of leaves) display regrowth, and adventitious root formation happens every time regrowth occurred in the field (Langeland & Sutton, 1980).

Axillary turions and tubers account for the majority of hydrilla's reproductive strategies and persistence. One single subterranean turion from a monoecious biotype can grow into a plant that can then produce in one summer over 6000 new subterranean turions/m^3 (Sutton, Van, & Portier, 1992). During the winter months in southern Florida, monoecious plants have produced a minimum of 1784 tubers per m^2 (Sutton et al., 1992). Additionally, 1.0g of dry plant can produce over 46 turions which is equivalent to 2803 turions/m^3 (Thullen, 1990).

Turions are extremely resilient, especially subterranean. They can remain viable for several days out of the water and can successfully geminate after four years of dormancy in undisturbed sediments (Basiouny, Haller, & Garrard, 1978; Van & Steward, 1990). Turions have also been known to survive ingestion and regurgitation by water fowl, and even some herbicidal applications have failed to kill the tubers (reviewed in Langeland, 1996).

Tuber (subterranean turion) production as a means of reproduction seems to be more important in monoecious plant populations (Steward & Van, 1987). Their tuber production is greatest durring short days, and overall they form more tubers than dioecious populations (Steward & Van, 1987). Also germination in monoecious hydrilla occurrs at lower temperatures that are more associated with temperate regions (Steward & Van, 1987). This supports hydrilla's distribution with the monoecious biotype's prevalancy in the northern regions of the United States (Spencer & Anderson, 1986; Van, 1989).

Since hydrilla is so successful in establishment, dominance, and reproduction, it is important to understand its economic and environmental impacts. Hydrilla is associated with a reduction in flow of drainage canals which can lead to flooding and damage to shorelines and structures (Langeland, 1996). In irrigation canals it also impedes flow and cogs intake pumps. In one case clogged intake pipes due to hydrilla has cost a hydroelectric facility over $4 million in lost electrical production and $525,000 in losses of game fish due to reduced water flow and dissolved oxygen (reviewed in Richardson, 2008). It is also known to disrupt utility cooling reserviours by interupting flow patterns for adequate cooling

(Langeland, 1996). When hydrilla forms dense mats, which is often, it interferes with navigation of both commercial and recreational vessels (Langeland, 1996).

There are debates on hydrilla's impacts on the ecosystem. It is well documented that aquatic invasive plants can cause shifts in lake productivity, species composition, and food web dynamics (Kelly & Hawes, 2005). However one study has found that hydrilla had no statistical significant effect on all community measures tested (biomass, richness, diversity) (Hoyer, Jackson, Allen, & Canfield, 2008). Hoyer et al. (2008) suggest that hydrilla occupies a mostly vacant niche in some Florida lakes and has no effects on the occurrence or relative composition of native species of aquatic plants, birds, and fish. Additionally there is a growing consensus that moderate hydrilla coverage, 20-40%, provides excellent habitats for most fish and wildlife (Bonvechio & Bonvechio, 2006)

However invasive aquatic plants, like hydrilla, often exceed that vegetation cover and create monocultures (Richardson, 2008). Similarly largemouth bass populations are negatively impacted when hydrilla coverage exceeds 30% (reviewed in Langeland, 1996). Another study has compared a native aquatic plant to hydrilla while examining regrowth and establishment after floods have uprooted and scoured the two plants from the sediments. Sousa, Thomaz & Murphy (2012) have found that both plants start regenation at the same time, but hydrilla has a much higher rate of biomass increase. They suggest that hydrilla can outcompete native, aquatic plants after a major environmental event such as a flood (Sousa et al., 2012).

Due to hydrilla's negative impacts on the environment and specifically the economy, there has been millions of dollars spent in research, prevention, and control (Richardson, 2008; Schmitz, 2007). Since 1980 Florida alone has spent more than $250 million for the control of non-native plants with hydrilla contributing to a large percentage of that sum (Schmitz, 2007). Three main management techniques have been researched extensively, developed, and used to curtail hydrilla's negative impacts:

- Mechanical
- Stocking of triploid grass carp
- Systemic and contact herbicides

Mechanical techniques are limited by efficiency and logistical issues. It cost Florida approximately $2400/ha for mechanical harvesting and long term effectiveness is low, probably due to hydrilla's persistent tubers (reviewed in Evans & Wilkie, 2010; Richardson, 2008). Evans & Wilkie (2010) have looked into the logistical, economic, and productive uses of harvested hydrilla biomass. They have suggested that the use of harvested hydrilla for biogas or compost could have beneficial outcomes by avoiding fugitive methane emissions associated with aquatic plant over growth, limiting anoxic conditions that develop in the aftermath of an herbicide treatment, and/or eliminating the disposal of harvest plant biomass into landfills. However, the economic and energy outputs created by mechanical harvesting are decoupled by the financial expenses and environmental degradation associated with the practice. Additionally, mechanical harvesting could contribute to the spread of hydrilla in the already infected water body as a result of its fragments' viability (Langeland, 1996).

Biological tools have been used as management practices for control of hydrilla. The most widely implemented method is stocking triploid grass carp (*Ctenopharyngodon idella*, white amur) (Richardson, 2008). A southern lake in the United States with stocked triploid grass carp has experienced a mass reduction of hydrilla from 17,000ha to less than 500ha in two years. Plus, there have been no significantly negative effects on littoral fish populations because other forms of submersed cover have remained. When properly stocked the use of grass carp can be an extremely effective and inexpensive biological tool for invasive aquatic plant management (Hamel, *n.d.*; Richardson, 2008).

Another effective management method for regulating this invader is the use of herbicides. The most commonly used chemical for hydrilla is fluridone, especially for large scale management. Fluridone is a systemic herbicide that is translocated within the plant’s tissues. Unlike contact herbicides, fluridone is effective in controlling regrowth from subterranean turions for up to 1.5 to 2 years after a single application (reviewed in Schmitz, 2007). Additionally hydrilla is especially sensitive to fluridone, and small concentrations of 5-150ppb have proven effective (Netherland, Honnell, Staddon, & Getsinger, 2002). As a result of its sensitivity, fluridone can be selective which helps prevent a mass die off of all native and non-native aquatic macrophytes (Netherland et al., 2002). Additionally, the application of fluridone for hydrilla control is economically feasible and costs managers $125-880/ha (Netherland et al., 2002; reviewed in Richardson, 2008).

As a result of fluridone's wide use, fairly inexpensive application cost, relative selectivity, and effectiveness, some hydrilla populations in Florida have now become desensitized or resistant to fluridone treatments (Arias, Netherland, Scheffler, Puri, & Dayan, 2005; Richardson, 2008). For this reasons other herbicides have been considered and studied for use. Some contact herbicides that have been used are copper products, diquat, and endothal, but these products are inferior to fluridone (Richardson, 2008). These contact herbicides are not translocated throughout the plant and result in incomplete killing of the roots, tubers, and other parts that are not directly exposed to the chemical. However, there are other systemic herbicides under review and include bispyribac-sodium, imazamox, quinclorac, penoxsulam (Richardson, 2008).

There are a few new management practices studied to reduce hydrilla’s negative impacts. Insects, including leaf mining flies (*Hydrellia pakistanae* Deonier and *Hydrellia balciunasi* Bock) and weevils (*Bagous affinis* Hustache and *Bagous hydrillae* O’Brien) have been examined as additional biological controls. Under controlled and field conditions the flies have been shown to cause significant injury to hydrilla and suppress tuber formation (reviewed in Richardson, 2008). Another innovative management practice under review is the restoration of native aquatic species to defend against hydrilla establishment in a new site (Chadwell & Engelhardt, 2008). The restoration of native aquatic species in combination with targeted management could be the best defense against the spread of aquatic invasive species like hydrilla (Chadwell & Engelhardt, 2008).

Native to Asia, hydrilla is one of the most well documented invasive aquatic plants. As a submerged hydrophyte, hydrilla has two separate biotypes (monoecious and dioecious) that seem to be suited for different climatic regions. It effectively acquires nutrients, grows throughout the water column, and has multiple propagation strategies which lead to its invasive success. Commonly forming thick, vegetative mats, hydrilla can leave conditions undesirable for commercial/recreational use and alter the native aquatic community (CCE, 2012; Langeland, 1996). It is has been wreaking havoc on aquatic systems and related industry in the United States since the 1960s, and as a result state and private agencies have spent millions of dollars on research, management, and repairs (Langeland, 1996; Richardson, 2008; Schmitz, 2007). Once established hydrilla is extremely costly to manage and nearly impossible to eradicate because of its adaptability and resilient tubers (CCE, 2012; Langeland, 1996; Langeland & Sutton, 1980). For all these reasons and hydrilla's recent northern expansion, it is extremely vital to be aware of this invader and to keep it out of the Adirondacks Park.

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