Ecologically-based Invasive Aquatic Plant Management: Using Life History Analysis to Manage Aquatic Weeds

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ABSTRACT

Invasive plants are increasingly recognized as a major problem in conserving and managing natural resources. Invasive aquatic plants not only threaten the diversity and functioning of aquatic, wetland, and riparian areas, but also contribute to flooding and reduce irrigation water flow. Management of these species has often focused on an engineering approach, either with direct herbicide application or mechanical removal, with little thought to the biology and ecology of the target species. I will demonstrate how knowledge of the life history of the target plant can greatly enhance management effectiveness using five examples: waterchestnut (*Trapa natans* L.), curlyleaf pondweed (*Potamogeton crispus* L.), Eurasian watermilfoil (*Myriophyllum spicatum* L.), hydrilla (*Hydrilla verticillata* (L.f.) Michx.), and waterhyacinth (*Eichhornia crassipes* (Mart.) Solms). For these analyses, I utilize studies that have focused on seasonal biomass allocation, carbohydrate storage, and propagule production. Waterchestnut is an annual, reproducing from seed. Successful long-term management must focus on preventing seed production. Curlyleaf pondweed is an herbaceous perennial, which oversummers using a turion. In this instance, management timing was critical in preventing turion formation and depleting the turion bank. Eurasian watermilfoil is a widespread evergreen perennial; management techniques can utilize the lack of resistant dormant propagules, as well as examining the timing of carbohydrate storage low points in selecting the best timing and management technique. Hydrilla uses several diverse life history strategies and is found as at least two distinct biotypes in the United States with very different phenologies. Understanding the differential response of the biotypes to the environment is one component to a successful management strategy. Waterhyacinth, a tropical plant, has shifted its life history pattern in subtropical and temperature zones. For all invasive plants of natural habitats, an understanding of the plant life history is vital to successful management.

Keywords: Ecology, Invasive species, Wetlands

Introduction

Aquatic plants, whether submersed, floating, or emergent, are an important component to aquatic ecosystems (Carpenter and Lodge 1986). Aquatic plants stabilize lake sediments, reducing sediment and nutrient resuspension. Aquatic plants increase sedimentation rates, reducing turbidity and suspended solids. Aquatic plants provide habitat for macroinvertebrates and forage fish, are critical to the spawning of some fish species, and generally provide a nursery area for young-of-the-year fishes. Typically, nuisance problems develop in large water bodies through the introduction of invasive aquatic plants. Invasive aquatic plants are usually nonnative species that are well adapted to rapid growth, extensive spread, and competition with existing native vegetation (Madsen 2004). Invasive aquatic plant cause extensive disruption to economic uses of waterways, costing up to $100M per year in damages and control costs (Pimentel et al. 2000). Impacts to human uses of water resources include disruption of commercial navigation, hydropower generation, flood control, an recreational use; spread of insect-borne disease, reduction in property value, and direct impacts on human health (Madsen 1997). Ecological degradation caused by invasive plants includes degradation of water quality, reduction in species diversity, suppression of desirable native plant growth, localized extinction of rare, threatened, or endangered species, and alteration of predator/prey interactions (Mullin et al. 2000, Madsen 1997a).

Management of these species is typically approached from either an engineering (e.g., mechanical control) or biochemical perspective (e.g., chemical control), with limited consideration for the biology and ecology of the target plant species. The purpose of this paper is to demonstrate how the knowledge of the life history and ecology of the target plant can be utilized to identify weak points in the plant life cycle, and exploit them for long-term control (Madsen 1993a).

Plant Life History

Most aquatic plants initiate their growth in the early spring from low overwintering biomass, and increase their biomass exponentially until self-shading or self-limitation is reached. As the plant approaches its maximum point of biomass, typically the plant will flower, set fruit, and form its vegetative propagule. At this point, the plant will begin to senesce, and slough off excess biomass until the plant reaches its overwintering biomass point. For some plants, the overwintering or dormant mass is composed of green shoots, while other species have dormant stages composed of seeds or vegetative propagules (Westlake 1965, Wetzel 2001).

During the year, plants may utilize one or more strategies: sexual reproduction, vegetative reproduction, and clonal growth (Figure 1). Through sexual reproduction, plants form seeds (Figure 1A). Specific environmental cues regulate both the initiation of flowering, and the germination of seeds. Seeds are the most hardy and resistant propagule, but are often smaller than vegetative propagules (Madsen 1991). The second strategy, vegetative reproduction, involves the production of vegetative propagules such as tubers, turions, winter buds, and autofragments (Madsen 1991). Unlike

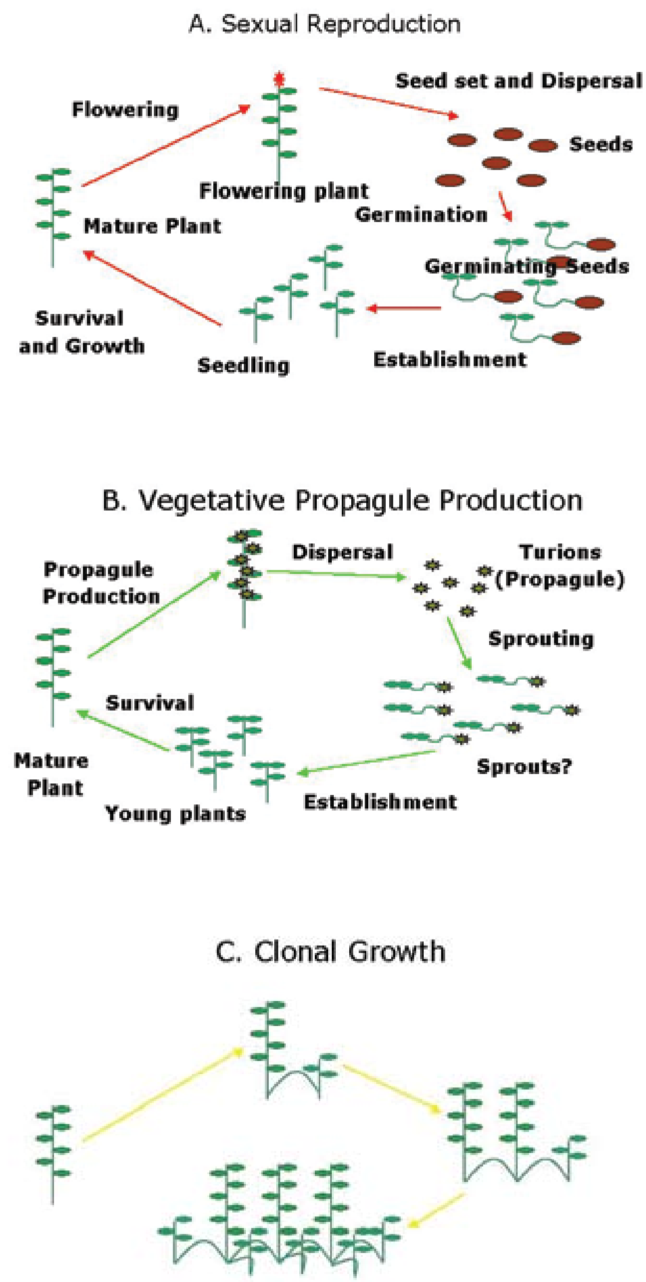

Figure 1. Life history strategys of plants during the year; A. sexual (seed-producing) strategy, B. vegetative propagule strategy, C. clonal growth strategy. An individual species may have any or all of these.

seed production, vegetative propagules are formed from the parent plant. As with seeds, specific environmental cues regulate both propagule production and propagule sprouting (Figure 1B). The third strategy is clonal growth, in which more individual plants, or ramets, are formed by stolons, rhizomes, or runners (Figure 1C).

Aquatic plants are predominantly herbaceous, or non-woody, plants; and have three potential life history types: annual, herbaceous perennial, or evergreen perennial. The life history types are based on the propagule type that predominates for the dormant period, when the plant is not actively growing. The annual life history is one in which the entire green portion of the plant dies back during the dormant season, and the only portion of the plant present is the seed. Therefore, sexual reproduction is critical to the annual regeneration of this plant. The herbaceous perennial life history is one in which the only life stage present during the dormant period is the vegetative propagule, and the entire green portion of the plant dies. Therefore, the vegetative reproduction cycle is critical to the annual regeneration of this plant. The last common life history of aquatic plants is the evergreen perennial life history, in which there are green shoots present throughout the calendar year. While these plants may have propagules or seeds, green shoots that are not actively growing dominate the dormant period.

Application to Management

To demonstrate how this is applied to management, I will use four examples: waterchestnut (an annual), curlyleaf pondweed (an herbaceous perennial), hydrilla (either an herbaceous perennial or evergreen perennial), and Eurasian watermilfoil (an evergreen perennial). For each, research will be presented to demonstrate how the timing of management, and not the selection of management technique, is critical to improving long-term control of the species.

Waterchestnut.

Waterchestnut (*Trapa natans* L.) is a floating rosette-forming plant that typically grows in water from 1 to 4 meters in depth. A true annual, a single floating rosette can form up to a two dozen nutlets that are up to 4 grams fresh weight (Madsen 1990, Madsen 1993b, Methe et al. 1993). A native of eastern Asia, it is currently found in the northeastern United States (Madsen 1994, 1997a). In New York, the annual growth cycle initiates by seed germination in late March

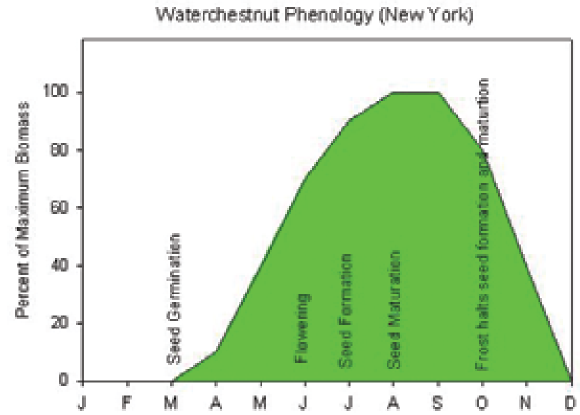

Figure 2. Annual growth cycle of the annual waterchestnut in New York State (from Madsen 1990).

to early May (Figure 2). By June, flowering begins, with seed formation and seed maturation following at four-week intervals afterwards. Seed production continues until the first heavy frost, typically in October. The key to long-term control of waterchestnut is to prevent new seed formation (Madsen 1993b).

The operators of Watervliet Reservoir, a drinking water supply overrun by waterchestnut, evaluated the effectiveness of long-term control by shallow-depth cutting. The City of Watervliet mounted a cutting bar on the front of an airboat that would cut rosettes only four inches below the surface of the water. Because of the rapid rate of cutting, they could cut waterchestnuts throughout the problem area as often as very two weeks, thus preventing the formation of mature seeds. Madsen (1993b) and Methe and others (1993) reported on seed production rates in untreated areas versus cut areas in 1989 and 1990, respectively. Seed production in untreated areas ranged from 140 to 210 new seeds per square meter per year, while areas that were cut lost 14 to 60 seeds per square meter per year from the seed bank. Therefore, cutting has potential for long-term control of waterchestnut.

Curlyleaf Pondweed.

Curlyleaf pondweed (*Potamogeton crispus* L.) is also a native of eastern Asia. It is a submersed plant that survives its dormant period in axillary turions, which are hardened axillary buds. Instead of overwintering, though, this plant

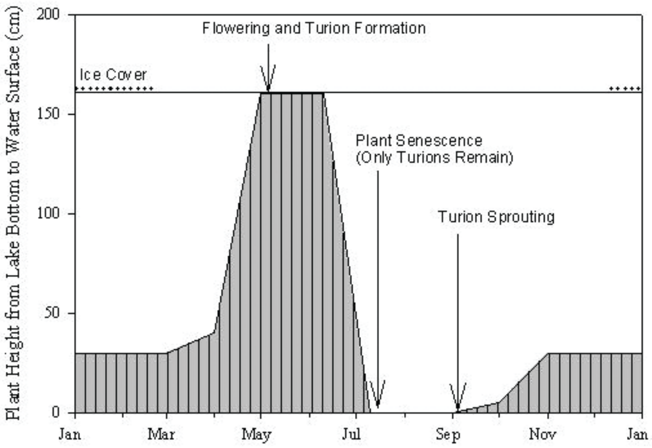

Figure 3. Life history of curlyleaf pondweed in Minnesota (from Woolf and Madsen 2003b).

oversummers (Woolf and Madsen 2003b, Figure 3). The plant survives its dormant period from July through September as the turion, which sprouts in September. Plant growth is slow over winter, but occurs rapidly beginning in March as water temperatures warm above 5°C. Maximum biomass occurs in May, with flowering and turion formation beginning in June. By early July, the entire shoot biomass has died away. The key to long-term control of curlyleaf pondweed is to prevent turion formation (Woolf and Madsen 2003a).

Traditionally, herbicide treatments with contact herbicides in May or June provided short-term control of nuisance growth, but were not successful in long-term control of this species because turions had formed prior to herbicide applications.. Herbicide applications would have to occur in March or April, in waters colder than indicated on the herbicide label. For long-term control, Netherland and others (2000) first had to demonstrate that the contact herbicides diquat and endothall could be effective at cold temperatures (10 to 15°C). Once the effectiveness of endothall was established at low temperatures, a pond study verified that early season treatments in cold water before turion formation was initiated would significantly reduce turion and seedhead formation (Netherland et al. 2000, Skogerboe and Getsinger 2006). The key to long-term curlyleaf pondweed control was to control the shoots before turion formation had begun.

Hydrilla.

Hydrilla (*Hydrilla verticillata* (L.f.) Royle) is a submersed aquatic plant that can form dense masses of plants in water depths of up to 5 meters. A widespread nuisance plant in the east, southeast and California, it is currently the fastest-spreading invasive aquatic plant. Two biotypes are found in the United States: a dioecious strain in the southeast, and a monoecious biotype in the mid-Atlantic, northeast, California, and Washington. Hydrilla can grow as an evergreen perennial or an herbaceous perennial, depending on seasonal temperatures and biotype. Both biotypes form large numbers of axillary turions, subterranean turions (hereafter called tubers), and can also spread by stem fragments. The tubers are formed deep in the sediment, and resist management activities. The key to long-term control of hydrilla is to control or reduce the production of tubers.

In north Florida, dioecious hydrilla forms tubers from October through May, and the tubers sprout from April through November (Haller et al. 1976). One technique to successfully control hydrilla in lakes that have water level control structures was to dewater the lake (drawdown) from September through November, to kill the hydrilla before tubers could

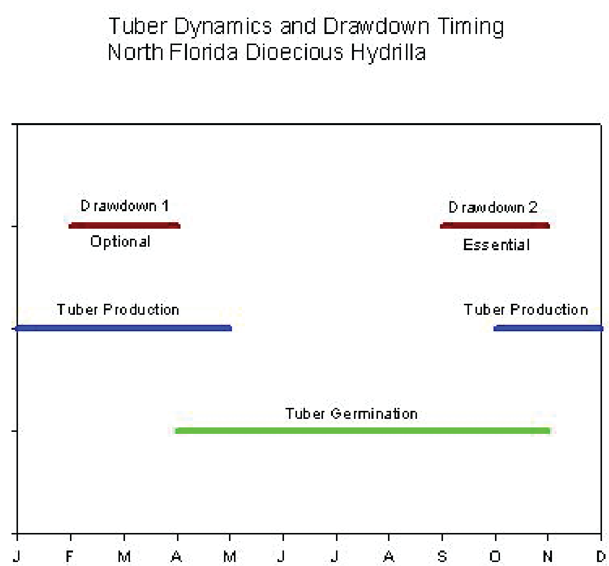

Figure 4. Timing of hydrilla tuber germination and production in North Florida, and optimal times for drawdown to control tubers. Redrawn from Haller et al. 1976.

be formed, with an additional drawdown in early spring (February to April) to stimulate additional tuber sprouting (Figure 4, Haller et al. 1976). Long-term hydrilla control is management of the tuber bank.

Eurasian watermilfoil.

Eurasian watermilfoil (*Myriophyllum spicatum* L.) is an evergreen perennial submersed aquatic plant, growing rooted to the bottom and forming a canopy in water from 1 to 5 m deep, although it can grow deeper in exceptionally clear water. Eurasian watermilfoil is possibly the most widespread invasive aquatic plant in the United States, with infestations from Maine to Florida to California to Washington and all states in between (Madsen 2005). The annual growth cycle varies tremendously across this range, from a winter dormant and late summer peak growth in cold northern lakes to a summer dormant plant with peaks in spring and fall (Figure 5).

Eurasian watermilfoil does not possess any specialized vegetative propagule, and seeds are not considered important to its propagation and spread; but this plant does form a unique propagule: stem fragments can be formed by abscission (Madsen et al. 1988, Smith et al. 2002). While a number of factors are important to the density of fragments formed, autofragmentation does tend to occur seasonally just after flowering. This time period also coincides with the lowest point in carbohydrate storage in the plant (Madsen 1997b). Evergreen perennial plants rely on stored carbohydrates to regrow from dormant periods or plant damage. Timing management to occur just before flowering can gain the two-fold benefit of preventing the spread of Eurasian watermilfoil through autofragmentation and of exploiting a low-point in carbohydrate storage to reduce potential regrowth. Owens and Madsen (1998) demonstrated that control of Eurasian watermilfoil could be improved by timing the application of a contact herbicide (endothall) to the low-point in carbohydrate storage.

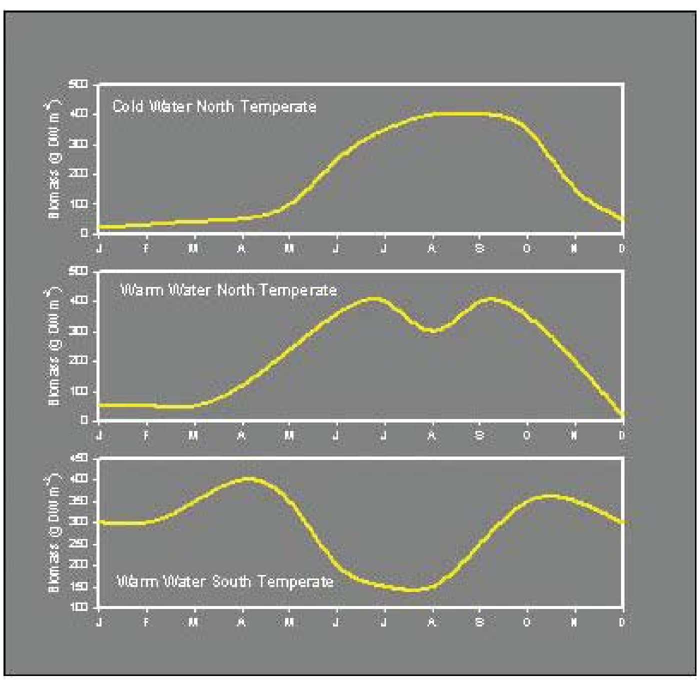

Figure 5. Growth cycles of Eurasian watermilfoil from cold northern lakes, to shallow mid-continental lakes, and southern ponds (from Madsen 2005).

Summary

Three important points should be gained from these examples. First, the life history and seasonal growth patterns are critical to long-term control of invasive aquatic plant species, and thus it is vital to know the growth pattern of the target invasive plant in your region. Second, the management technique itself is not of primary importance, so long as the technique can be utilized to further long-term control of the plant. Many different techniques (biological, chemical, mechanical, and physical) can be utilized to achieve long-term control, depending on the plant species, the location, and the constraints of the site. I have presented examples of long-term management that utilized completely different techniques, mechanical (cutting), chemical (endothall herbicide) and physical (drawdown). Third, research on the ecology and life history of target invasive aquatic plants linked with research on control techniques themselves will provide substantial benefits in terms of improved long-term control of invasive plants.

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