Techniques for Managing Invasive Aquatic Plants in Mississippi Water Resources

John D. Madsen

Invasive aquatic plants are an ever-growing nuisance to water resources in Mississippi and the rest of the United States. These plants are generally introduced from other parts of the world, some for beneficial or horticultural uses. Once introduced, they can interfere with navigation, impede water flow, increase flood risk, reduce hydropower generation, and increase evapotranspirational losses from surface waters. Invasive species also pose direct threats to ecosystems processes and biodiversity. A variety of techniques have been used to manage these invasive plants in waterways around the United States. These techniques can be classified as Biological, Chemical, Mechanical and Physical techniques. Biological techniques utilize an herbivore or pathogen to control the plant, or reduce the equilibrium level of the population to an acceptable level. Chemical techniques utilize US EPA-approved herbicides to control plants, from small plots to large areas. Mechanical techniques utilize machines or tools to harvest, cut, pulverize or otherwise damage the plant. Physical techniques involve altering the environment to prevent or reduce the growth of invasive plant species. I will describe specific techniques and their potential niches for managing invasive aquatic plant species in Mississippi. I will also present some resources available for assisting in selecting the best technique, including the APIS system from USAERDC, available Best Management Practices plans, and information resources available from Mississippi State University.

Keywords: Invasive Species, Management & Planning, Recreation, Wetlands

Introduction

Invasive aquatic plants, mostly nonnative species introduced for ornamental and aquarium applications, have become a widespread nuisance problem in the United States (Madsen 1997). Many of the species common throughout the southeastern United States also create nuisance problems in Mississippi water resources; including waterhyacinth (*Eichhornia crassipes* (Mart.) Solms), hydrilla (*Hydrilla verticillata* (L.f.) Royle), and Eurasian watermilfoil (*Myriophyllum spicatum* L.) as typical examples (Madsen 2004). More recently, giant salvinia (*Salvinia molesta* Mitchell) has been found in southern Mississippi, despite repeated management efforts. Invasive aquatic plants interfere with human uses of water resources, including increasing flood magnitude and frequency, interfering with commercial and recreational navigation, impeding fishing, boating, and swimming, and increasing the survival of some disease vector insects (Pimentel et al. 2000). Invasive species can also have deleterious ecosystem impacts, including reducing species diversity, suppressing the growth of desirable native species, reducing habitat value for fish and wildlife, increasing internal loading of nutrients, reducing water quality, and increasing the extinction rate of rare, threatened, and endangered species (Madsen 1997, Mullin et al. 2000). The total cost of managing invasive aquatic plants in the United States has been estimated at $100M (Pimentel et al. 2000, Rockwell 2003).

For the Mississippi Water Resources Conference in 2004, I reviewed the species that either currently impact Mississippi water resources or may pose a future threat (Madsen 2004). During the 2005 Mississippi Water Resources Conference, I explained the process by which aquatic plant management plans could be developed (Madsen 2005). In this paper, I will detail the currently used techniques for managing invasive aquatic plants.

Management Plans

Before invasive plant management begins, some effort should be made to make an effective management plan (Madsen 2000). An aquatic plant management plan should have eight components: prevention, problem assessment, project management, monitoring, education, management goals, site-specific management, and evaluation (Madsen 2005). If management goals are not made before implementation, the resource manager increases the likelihood of either selecting techniques that are contrary to long-term but unstated goals. In addition, a lack of education and outreach may result in public reaction to management, often based on incorrect information or misperception.

Management Techniques

Management techniques described below can be classified as biological, chemical, mechanical, or physical control techniques. I will review the major techniques available, and indicate their applicability to the five most likely invasive aquatic plants for larger water resource systems (Table 1).

Each technique should not be viewed as an exclusive choice; but rather the techniques should be selected based on the nuisance problem at a given site and the economic and environmental constraints of the resource.

Table 1. The five most likely invasive aquatic plant species in Mississippi.

Common name	Scientific name	Growth form
Alligatorweed	*Alternanthera philoxeroides*	Emergent
Eurasian watermilfoil	*Myriophyllum spicatum*	Submersed
Giant salvinia	*Salvinia molesta*	Floating
Hydrilla	*Hydrilla verticillata*	Submersed
Waterhyacinth	*Eichhornia crassipes*	Floating/ Emergent

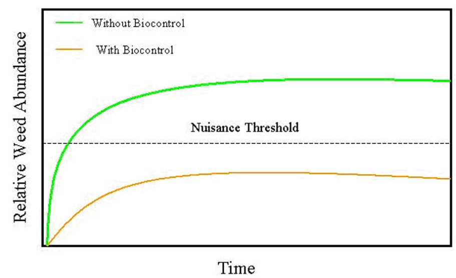

Figure 1. Relative weed abundance exceeds the nuisance-causing level without the biocontrol agent, and is reduced to below the nuisance threshold with an adequate population of the biocontrol agent.

Biological Control

Biological control is often misunderstood in terms of reasonable expectations and outcomes (Grodowitz 1998). This is in part because the first examples of successful biological control for terrestrial and aquatic weeds (pricklypear cactus and alligatorweed, respectively) were resounding successes in eliminating the nuisance problem (Grodowitz 1998). Rather, the typical expectation is that the established populations of the biological control agent will reduce the abundance of the target plant below nuisance-causing levels (Figure 1). Biological control insects may increase the competitive ability of native plants over the invasive species (Van et al. 1998).

The available biological control techniques include vertebrate generalist herbivores (specifically grass carp), insects, and pathogens (Table 2).

Grass carp can be effective at controlling hydrilla, but do little to control emergent or floating species (Van Dyke et al. 1994, Pine and Anderson 1991). Grass carp are not effective for control of Eurasian watermilfoil (Fowler and Robinson 1978). Grass carp can be economical and effective, particularly in small ponds with no outflow, but they tend to remove all submersed vegetation, travel at will, and migrate from large open aquatic systems (Haller 1994, Bonar et al. 1993). For these reasons, use of grass carp is not recommended for large waterbodies.

Introducing overseas insects that feed on invasive aquatic plants have been widely studied and utilized, with varying success (Grodowitz 1998). The first such project was to introduce the alligatorweed flea beetle for control of alligatorweed, which was a resounding success (Grodowitz 1998, Cofrancesco 1988). Several insects have been introduced to feed on both waterhyacinth and hydrilla, but neither has been nearly as successful under field conditions as releases for alligatorweed. Recently, releases of *Cyrtobagous salviniae* have been made in the U.S. to control giant salvinia, but it is too early to judge the results of those efforts. *Cyrtobagous salviniae* has been fairly successful in controlling giant salvinia in other countries (Oliver 1993, Thomas and Room 1986, Julien and Griffiths 1998)

In some instances, native or naturalized insects have been utilized in an attempt to control invasive weeds (Cofrancesco 2000). Several attempts have been made with various native insects to feed on Eurasian watermilfoil (Johnson et al. 2000), with the most common insect used being *Euhrychiopsis lecontei* (Creed 1998). To date, these attempts have had individual successes, but no long-term control or strategy for their implementation.

Pathogens have also been investigated for use in controlling invasive aquatic plants (Cofrancesco 2000). Thus far, the only current research and development is with *Mycoleptodiscus terrestris*, which acts like a contact bioherbicide (Shearer 1998, 2002). Much of the research has been focused on integrating the use of the pathogen with herbicides (Nelson and Shearer 2005, Nelson et al. 1998, Netherland and Shearer 1996). This pathogen is currently being formulated for demonstration use.

Revegetating with native plants after control is not a control technique in and of itself, but it may reduce the reinvasion rate and will definitely provide habitat and other valuable ecosystem services provided by plants in the littoral zone (Smart et al. 1996). The main problem is that this is very labor intensive and expensive, with some question as to whether this does more than reduce the time for recolonization (Madsen 2000).

Chemical Control

Chemical control of invasive plants has remained the mainstay of management techniques, with some good reason: chemicals are more effective, more predictable, and costs are competitive with most techniques. With the cost of most aquatic herbicides and application techniques, the costs typically range from $150 to $500 per acre, which is significantly more than terrestrial weed management. Herbicides formulated for aquatic use do not have

Table 2. Biological control techniques for managing invasive aquatic plants.

Type	Specifics	Activity	Applicability to MS Water Resources
Generalist vertebrate herbivore	Grass carp (*Ctenopharyngodon idella*)	Generalist feeder, preference for hydrilla	Small ponds with hydrilla
Insects	Alligatorweed flea beetle *Agasicles hygrophila* And others	Alligatorweed	Excellent, some herbicides may be needed
	Euhrychiopsis lecontei	Eurasian watermilfoil	Poor
	Cyrtobagous salviniae	Giant salvinia	Successful overseas
	Hydrellia spp. and *Bagous* spp.	Hydrilla	Some success
	Neocehtina spp. and others	Waterhyacinth	Some reduction in flowering and biomass
Pathogens	*Mycoleptodiscus terrestris*	Shows activity on submersed plants	Under development; Eurasian watermilfoil and hydrilla
Native Plant Restoration	Planting of desirable native plants	Possible restoration after control	Labor intensive and expensive, but possible

surfactants; so the applicator will have to add a surfactant appropriate for aquatic use when applying to the aerial portions of floating-leaved and emergent plants. For submersed plant applications, no surfactants are required. Lastly, it is imperative that applicators read the label before use, and only use herbicides that specify on the label that it is approved for aquatic use.

Nine active ingredients are currently approved for use in the aquatic environment for control of vascular aquatic plants (e.g., not algae), with several more being reviewed by the U.S. EPA. I have listed these nine active ingredients with the most common formulated products (Table 3). Four of these products (carfentrazone-ethyl, copper, diquat, and endothall) are contact herbicides, and work at the site of absorption. The remaining five products are slower-acting system herbicides that are translocated more readily throughout the plant. Some of these products are only for use on emergent plants, others only on submersed plants, and some are selective for certain groups of plants. Understanding the nature of each chemical and their use is critical for proper product selection and expectation of results.

To select an appropriate herbicide, the first step is to select an herbicide that is effective on the target species (Table 4). Proper identification of the target plant is critical to selecting an effective herbicide. In addition, different products or formulations of the same herbicide may vary in their efficacy on the target plant. Once the appropriate possibilities are identified, the use restrictions of the herbicides must be considered (Table 5). These use restrictions are generally limited based on the uses of the water, and are set based on toxicological data when the label is approved. Use restrictions are made to protect the health and safety of humans, animals, and crops using the treated water, so they should not be violated. For emergent and floating-leaved plants, this is typically the final consideration in selecting the right herbicide. For submersed plants, the herbicide is added to the water, and the plants take up the herbicide from the water.

For the herbicide to be effective, the plants must be in contact with an adequate amount of herbicide for a long enough period of time to be effective. For contact herbicides, contact times of 6 to 12 hours is often sufficient; whereas some of the systemic herbicides will require contact times ranging from 12 hours to 60 days (Table 6). Knowledge of the water exchange characteristics of the treatment site is critical for a proper herbicide treatment (Madsen 2000).

Herbicides may be used selectively to control emergent, floating-leaved, and submersed target plants while minimizing impacts on desirable native plants (Getsinger et al. 1997, Madsen et al. 2002). Selective use may be based on the timing of application, inherent selectivity of the molecule, or subtle differences in the metabolism of an herbicide in an otherwise "broad-spectrum" herbicide (Getsinger et al. 1997, Madsen et al. 2002, Netherland et al. 1997, 2000, Poovey et al. 2002, Skogerboe and Getsinger 2001).

Table 3. U.S. EPA-Approved aquatic herbicides for control of invasive aquatic plants.

Chemical	Product	Formulation	Company	Emergent, Floating or Submersed
2,4-D	Aqua-Kleen DMA IV Navigate	granular liquid granular	Cerexagri Dow AgroSciences Applied Biochemists	Submersed All Submersed
Carfentrazone-ethyl	Stingray	liquid	FMC	All
Copper	Captain Cutrine Plus Komeen	liquid liquid or granular liquid	SePRO Applied Biochemists SePRO	Submersed Submersed Submersed
Diquat	Reward Weedtrine	liquid liquid	Syngenta Applied Biochemists	All All
Endothall	Aquathol K Aquathol Super K Hydrothol 191	liquid granular liquid	Cerexagri Cerexagri Cerexagri	Submersed Submersed Submersed
Glyphosate	AquaPro Rodeo	liquid liquid	SePRO Dow AgroSciences	Emergent and floating Emergent and floating
Imazapyr	Habitat	liquid	BASF	Emergent and floating
Fluridone	Sonar	liquid and granular	SePRO	Submersed
Triclopyr	Renovate 3	liquid	SePRO	All

Table 4. Efficacy of U.S. EPA-Approved herbicides on Mississippi invasive aquatic weeds. E, excellent; G, good; F, fair; P, poor; NA, not applicable.

Chemical	Alligatorweed	Eurasian watermilfoil	Giant salvinia	Hydrilla	Waterhyacinth
2,4-D	E	E	P	P	E
Carfentrazone-ethyl	E	G	P	P	E
Copper	P	P	P	E	P
Diquat	G	G	G	G	G
Endothall	NA	G	NA	G	NA
Glyphosate	E	NA	G	NA	E
Imazapyr	E	NA	P	NA	E
Fluridone	NA	E	NA	E	NA
Triclopyr	E	E	P	P	E

Table 5. Water use restrictions, in days, for waters treated with U.S. EPA-approved herbicides. See the Mississippi Weed Management Guide or herbicide label for specific provisions or exemptions. An asterisk indicates examine the approved label.

	Treated Water Use Restriction (days)						
	Human			Animal	Irrigation		
Chemical	**Drinking**	**Swimming**	**Fish Consumption**	**Drinking**	**Turf**	**Forage**	**Food Crops**
2,4-D	21	0	0	0	21	21	21
Carfentrazone-ethyl	1	0	0	1	14	14	14
Copper	0	0	0	0	0	0	0
Diquat	1-3	0	0	1	1-3	5	5
Endothall	7-25	1	3	7-25	0	7-25	7-25
Glyphosate	0	0	0	0	0	0	0
Imazapyr	2	0	0	0	120	120	120
Fluridone	0	0	0	0	30	30	30
Triclopyr	*	0	0	0	0	120	120

Table 6. Herbicide exposure time for submersed applications, plant response, and application rate.

Chemical	Exposure Time (Submersed)	Plant Response	Maximum Application Rate
2,4-D	Intermediate (18-72 hours)	7-10 days	0.5 gal/acre (emergent) 2.84 gal/acre-ft (submersed)
Carfentrazone-ethyl	Unknown	7-14 days	0.2 lb ai/acre (emergent) 0.296 gal/acre-ft (submersed)
Copper	Intermediate (18–72 hours)	7-10 days	1.5 gal/acre-ft (submersed)
Diquat	Short (12-26 hours)	7 days	2 gal/acre (both)
Endothall	Short (12-36 hours)	7-14 days	3.2 gal/acre-ft (submersed)
Glyphosate	NA	Up to 4 weeks	2 gal/acre (emergent only)
Imazapyr	NA	Up to 8 weeks	.75 gal/acre (emergent only)
Fluridone	Very long (60 to 90 days)	Up to 90 days	5 oz/acre-ft (submersed application only, generally use much less)
Triclopyr	Intermediate (12-60 hours)	Up to 2 weeks	6 lb ae/acre (emergent) 2.3 gal/acre-ft (submersed)

Mechanical Control
Mechanical control techniques are often a useful tool for either small infestations, or in locations that cannot be treated with chemicals (Table 7). By far the most common mechanical technique used worldwide is manual removal, either with a bare hand or with a hand tool. In North America, this technique is most useful when only individual plants are found, particularly during noxious weed surveys. Cutting has been used in the past, where a sickle blade cutter or other device cuts the stem. While faster than other techniques, the fragments are often viable, so this technique mostly succeeds in spreading nuisance plant infestations.

Harvesting with aquatic harvesters has been widely used for all the species listed in Table 1 except alligatorweed. While immediate relief from the nuisance growth is achieved, the plants regrow rapidly and disposal of plant material may be problematic. Destructive machines like the cookie cutter or flail chopper have been used for herbaceous and woody mat-forming plants. While these machines may provide nuisance relief, the dead plant material may pose an environmental hazard and spread viable fragments. Diver operated suction harvesting has been widely used to remove small colonies of submersed plants like Eurasian watermilfoil and hydrilla, but is not practical for infestations larger than an acre (Eichler et al. 1993). Lastly, rotovating has been used in the Pacific Northwest and western Canada for control of Eurasian watermilfoil. Similar machines based on rototilling could be used for other invasive plants. These machines, however, will result in the spread of viable fragments.

Physical Control
Physical control techniques reduce or eliminate plant growth through altering the environment, rather than directly controlling plants. Types of physical control techniques include benthic barriers, drawdown, dredging, light attenuation or shading, and nutrient inactivation (Table 8).

Benthic barrier involves using a bottom covering of synthetic material to cover over a small colony of aquatic plants. This technique would be ineffective for free-floating plants, though it may be useful for rooted emergent plants. It has been most widely used for submersed plant control, particularly Eurasian watermilfoil, with excellent results (Engel 1984, Eichler et al. 1995).

In lakes or reservoirs that have a water level control structure, drawdown can be used to control plants by draining or dewatering the waterbody to below the level in which plants are rooted. Drawdown is most effective over the winter, especially if freezing temperatures occur. While inexpensive and effective for many species,

Table 7. Mechanical control technique advantages, disadvantages, and effectiveness. E, excellent; G, good; F, fair; P, poor; NA, not applicable.

			Efficacy on Target Species				
Technique	Advantages	Disadvantages	Alligatorweed	Eurasian watermilfoil	Giant salvinia	Hydrilla	Waterhyacinth
Hand cutting or pulling	Low technology and affordable	Labor-intensive, for individual plants	E	G	E	F	E
Cutting	More rapid than harvesting	Mats of cut plants my be environmental hazard and spread infestation	F	F	P	F	P
Harvesting	Removes plant biomass and nuisance	Slow and expensive, plants regrow	G	G	G	G	G
Cookie cutter	Rapid destruction of mat materials	Large amount of debris, may spread plants	G	NA	F	NA	G
Flail chopper	Rapid destruction of floating and emergent material	Fragments may spread plants	G	NA	P	NA	G
Diver-operated suction harvester	Direct removal of plants, no floating fragments	Slow and labor-intensive	NA	E	NA	G	NA
Rotovating	Disrupts root crown of submersed plants	Spreads fragments	G	G	NA	F	NA

Table 8. Physical control techniques for invasive aquatic plants: advantages, disadvantages, and effectiveness. E, excellent; G, good; F, fair; P, poor; NA, not applicable.

			Efficacy on Target Species				
Technique	**Advantages**	**Disadvantages**	Alligatorweed	Eurasian watermilfoil	Giant salvinia	Hydrilla	Waterhyacinth
Benthic Barrier	Direct and effective, may last several seasons	Expensive, small-scale, not selective	?	E	NA	E	NA
Drawdown	Inexpensive and effective	Requires water control structure, can have severe environmental effects and impacts on riparian users	P	E	G	P	E
Dredging	Creates deeper water, long term and effective	Too expensive if only goal is plant control, must deal with sediment disposal	G	E	P	E	P
Light Attenuation	Inexpensive and Effective	Nonselective, may not be aesthetically pleasing	G	G	G	G	G
Nutrient inactivation	Possible for floating plants, but not operations	Under research for rooted plants	NA	NA	F	NA	F, P

it may have significant environmental impacts and cause significant impairment to other water resource uses. Some plant species can be completely controlled (e.g., Eurasian watermilfoil and waterhyacinth), while others are resistant to water level drawdown through propagules tolerant to drying (e.g., hydrilla).

In some lake restoration projects, dredges are used to deepen the water by removing sediment. This will create water too deep for rooted plants to grow, resulting in a reduction of nuisance growth (Nichols 1984, Tobiessen et al. 1992). While effective, this method is too expensive for most situations.

Shading or light attenuation can control plant growth effectively, but the method may interfere with other water uses or otherwise be impractical. Light reduction can be created using shade trees plantings, covers, or fabric above the water surface (Dawson 1986, Madsen and Adams 1989). This may work either for emergent, floating-leaved, or submersed plants. The use of water-soluble dyes has also been used for submersed plant control, but this is best used for only small ornamental ponds (Madsen et al. 1999). Pond management in the southeast has long recommended the addition of fertilizer to create an algal bloom, which in turn reduces light availability to rooted plants. While this may be effective, it has other consequences, and should not be attempted in larger multipurpose water resources.

Nutrient inactivation has been widely used for control of phytoplankton blooms through the addition of alum to bind phosphorus in the water column (Welch and Cooke 1995). Unfortunately, most invasive aquatic plants are limited by nitrogen availability in the sediment rather than phosphorus availability in the water column. To date, attempts to manipulate the nutrient concentrations of sediment have been unsuccessful, though water column manipulation of nutrients could control free-floating plants.

Information Resources

A number of Internet websites provide good authoritative information on aquatic plant management techniques (Table 9). The Aquatic Ecosystem Restoration Foundation site has up-to-date links to most aquatic herbicide manufacturers, and a regularly updated Best Management Practices manual. The Aquatic Plant Control Research Program of the US Army Corps of Engineers has a complete bibliography of their research articles and reports, as well as an online information system for aquatic plant management techniques that is periodically updated. This information system is also available as a CD-ROM.

The Center for Invasive and Aquatic Plants at the University of Florida has the premier collection of color photos and line drawings of invasive plants, as well as an online bibliographic service that includes both peer-reviewed articles and government reports

Table 9. Internet web page sources for information on invasive aquatic plants and their management.

Title	Purpose	Location
Aquatic Ecosystem Restoration Foundation	*Source for herbicide manufacturer information*	www.aquatics.org
AERF Best Management Practices	Report on best management approaches for invasive aquatic plants	www.aquatics.org/aquatic_bmp.pdf.
Aquatic Plant Control Research Program	Federal research program for invasive aquatic plants	el.erdc.usace.army.mil/aqua/
Aquatic Plant Information System	Information on aquatic plant management techniques	el.erdc.usace.army.mil/aqua/apis/
Center for Invasive and Aquatic Plants	Information, photos, and bibliography	aquat1.ifas.ufl.edu/
Florida Aquatic Plant Management Program	Full description of techniques and application procedures	www.dep.state.fl.us/lands/invaspec/2ndlevpgs/Aquaticplnts.htm
GeoResources Institute Invasive Species Program	Information and research on invasive species at Mississippi State University	www.gri.msstate.edu/lwa/invspec.php
Mississippi Weed Control Guidelines	Aquatic Weed Control Recommendations	msucares.com/pubs/publications/p1532aquatic.pdf
Mississippi State University Extension Service	Information from all of Extension Service	msucares.com

on invasive plant research. The Florida Department of Environmental Protection has developed an excellent web page of operational aquatic plant management techniques. The GeoResources Institute has information on invasive species research in Mississippi. The Mississippi Weed Control Guidelines are produced by the Mississippi Weed Science Consortium, and are updated annually. The link provided is specifically for aquatic weeds, but additional weed management information is available in this report. Lastly, the Mississippi State University Extension Service web page, msucares.com, has an extensive listing of fact sheets and reports on water resource management.

Conclusion

Aquatic plant management techniques are constantly updated and revised. While deciding on aquatic plant management techniques, look for the most current information available. If you are using herbicides, always read the label before using the product, as these regulations are constantly changing. Be prepared to use different techniques as each situation and infestation dictate.

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Corresponding Author:
John D. Madsen, Assistant Professor
Mississippi State University
GeoResources Institute
Box 9652
Mississippi State, MS 39762–9652
Phone 662–325–2428
Fax 662–325–7692
E–mail: jmadsen@gri.msstate.edu