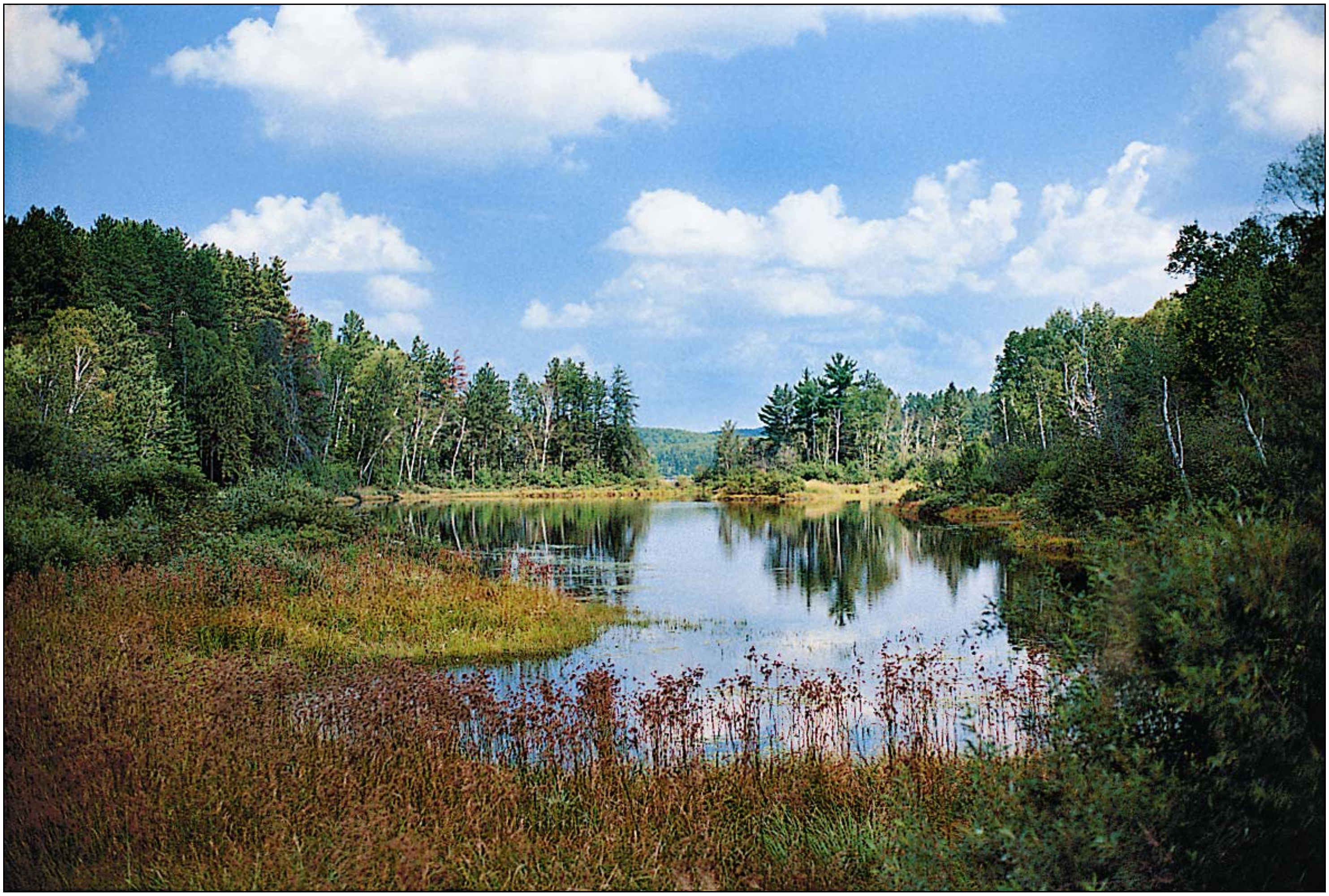

Aquatic Plant Management

Best Management Practices in Support of Fish and Wildlife Habitat

Prepared by:

Aquatic Ecosystem Restoration Foundation

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Introduction

Freshwater Aquatic Plants and Invasive Aquatic Weeds

Plants are an important part of healthy, diverse aquatic ecosystems. Aquatic plants play a major role in maintaining the integrity of lakes, ponds, streams, and rivers for fish, wildlife, other organisms, and human enjoyment (Figure 1).

Specific roles of aquatic plants include:

- Habitat and food for fish, invertebrates, amphibians, and waterfowl
- Food for other wildlife and mammals
- Spawning medium for many fish, invertebrates, and amphibians
- Oxygen production
- Protection of stream and river banks, lake and reservoir beds, and shorelines
- Stabilization of temperature, light, and ecosystem function
- Nutrient recycling and slowing of sediment transport.

The natural balance between vegetation and other aquatic organisms is disrupted when invasive or non-native (exotic) plants from other parts of the country or world are introduced to lakes, streams, rivers, or reservoirs, and become nuisance weeds. A weed is any plant growing out of control and at the expense of other plants or animals, or one that is unwanted in an area. Weed management and control is often required to restore balance when exotic plants invade. Weedy aquatic plant species can increase dramatically and out-compete diverse natural vegetation, and alter fish and wildlife habitat and activities (Figure 2). Invasive vegetation can interfere with recreational activities such as fishing, boating, and swimming; with property values;, and with enjoyment of the natural beauty of our water resources. Even native vegetation can grow to nuisance levels in some circumstances, requiring management.

Numerous invasive aquatic plant species are currently causing serious problems across the country. They include water hyacinth, hydrilla, Eurasian watermilfoil, purple loosestrife, salvinia, and water chestnut. In each case, problems occur because the species' growth habit and lack of predators enable it to produce and maintain large, dense populations very rapidly. This excessive growth can be responsible for:

- Deterioration of fish and wildlife habitat
- Potential loss of habitat for threatened and endangered fish, wildlife, and other aquatic species
- Deterioration of wetlands and water quality
- Diminished water surface area for recreational activities such as fishing and boating
- Reduction of property value adjacent to the deteriorated aquatic habitat
- Impeding commercial navigation
- Blocking pumps, sluices, and industrial, agricultural, and domestic water supply intakes

- Flooding, increased silting, and reduced reservoir capacity.

For all these reasons, plant management and control of invasive aquatic plants are very important.

Purpose and Objectives

This handbook provides nationally recognized Best Management Practices (BMPs) for chemical, mechanical-physical, biological, and cultural procedures for controlling aquatic plants, using methods that protect or restore fish and wildlife habitat. Many managers, practitioners, and researchers believe that managing invasive plant populations at levels that protect other uses of an aquatic system also maintains quality aquatic habitat.

This handbook is an introductory resource for landowners, extension agents, land and water resource managers, and applicators of invasive plant control technologies throughout the country. It recommends the integration of all appropriate aquatic vegetation management techniques suited to an individual site. While the authors recognize that a wide range of native and non-native aquatic plants can become significant nuisance problems in water bodies, this handbook specifically describes management for invasive and exotic aquatic plant species consistent with protecting aquatic ecosystems and fish habitat. This volume also provides additional reference sources with more specific information on integration and use of specific BMPs for regional and local conditions.

The Aquatic Ecosystem Restoration Foundation (AERF) obtained a grant from the National Fish and Wildlife Foundation to produce this book, and the U.S. Army Corps of Engineers (USACE) agreed to cooperate with the AERF to develop it. The AERF is a nonprofit, tax-exempt corporation created to conduct applied research in the management of aquatic pest species, with a focus on nuisance vegetation. It primarily supports research and education for control of aquatic invasive plants. The AERF membership includes groups with a strong interest in restoring and conserving aquatic resources, such as lake associations, scientific societies, resource management firms, and consultants and private sector firms, including aquatic herbicide manufacturers, formulators, and distributors.

The AERF, in consultation with the USACE and with recommendations from the Aquatic Plant Management Society, the Freshwater Anglers Association, and the North American Lake Management Society, selected national experts in the biology, ecology, and management of invasive aquatic vegetation to identify and compile optimal methods for controlling invasive weed species while protecting aquatic and fish habitat. These specialists are listed as technical contributors to this handbook.

BMP information was provided for the most significant invasive species from a national or large regional perspective. The selected species, with growth habit, are:

- Eurasian watermilfoil (*Myriophyllum spicatum* L.) – submersed
- Water chestnut (*Trapa natans* L.) – floating
- Giant salvinia (*Salvinia molesta* Mitch.) – floating
- Hydrilla (*Hydrilla verticillata* (L.f.) Royle) – submersed
- Water hyacinth (*Eichhornia crassipes* (Mart.) Solms) – floating
- Purple loosestrife (*Lythrum salicaria* L.) – emergent
- Brazilian elodea (*Egeria densa* Planch.) – submersed
- Algae.

Using This Handbook to Prepare a Site-Specific Integrated Weed Management Plan

This handbook provides general principles and specific management practices to control invasive aquatic vegetation while protecting fish and wildlife habitat. **Its focus is on controlling aquatic weeds in a way that is compatible with maintaining a well-functioning environment for fish, wildlife, and other aquatic organisms.** This book provides BMPs for each of the individual invasive species discussed, and a range of additional information sources. Managers can select suitable practices based on site-specific conditions and their management goals using both weed-specific BMPs and this general management information.

Before evaluating particular practices for controlling specific invasive weeds, the manager should review the general concepts of integrated control found in the next section of this handbook. This outlines (1) the steps in formulating management plans, and (2) the general concepts for each of the broad control categories, including biological, mechanical, cultural, and chemical, and their BMPs.

Additional Sources of Information

Sources for the information referred to here are listed in the References, Additional Readings, and Other Sources of Information section at the end of the handbook. Many of these references provide general or specific information on BMPs for management of invasive aquatic weeds, and important concepts and information on site-specific selection of appropriate management practices.

Integrated Control Options: General Concepts

Approaches to Integrated Best Management Practices (BMPs)

The extensive damage caused to many aquatic ecosystems by invasive and nuisance aquatic plant species in the United States has been well documented. Lake managers can employ a variety of practices to assist in restoring these aquatic ecosystems to health, including biological, mechanical, cultural, and chemical methods. These methods have been extensively researched over the last several decades and results have shown the benefits of combining more than one technique. Collecting and reviewing these practices for a specific site is one of the first steps in formulating an integrated control strategy.

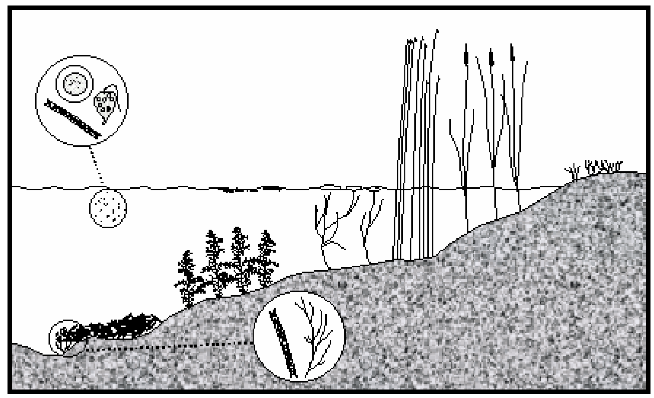

Figure 1. Main groups of aquatic plants found in both still and moving waters:
(a) emergent plants
(b) floating leaved plants
(c) submersed plants
(d) filamentous algae
(e) microscopic algae.
(Adapted from Seagrave 1988).

Research and field experience have begun to demonstrate that an integrated approach may provide the best long-term method for controlling invasive aquatic vegetation and maintaining diversity. Elements of an integrated invasive weed control plan that aquatic ecosystem managers, property owners, and the public can incorporate into local plans include:

- Correctly identifying the invasive or nuisance plant
- Determining how the weed was introduced in order to prevent re-introductions
- Identifying desired vegetation to achieve fish and wildlife habitat goals
- Establishing tolerable levels of any single plant species, including target nuisance plant(s), so that increase above threshold levels can trigger management activity
- Making decisions based on site-specific information
- Using ecosystem, watershed, and cost-benefit perspectives to determine long-term management strategies
- Developing an on-going system of integrated control methods that include mechanical, cultural, biological, and chemical BMPs as needed
- Educating local managers and the public about the importance of protecting water resources from invasive weeds to maintain healthy water quality and fish and wildlife habitat
- Assessing results of invasive weed control programs (including quantitative documentation of results of all control strategies), and re-evaluating management options.

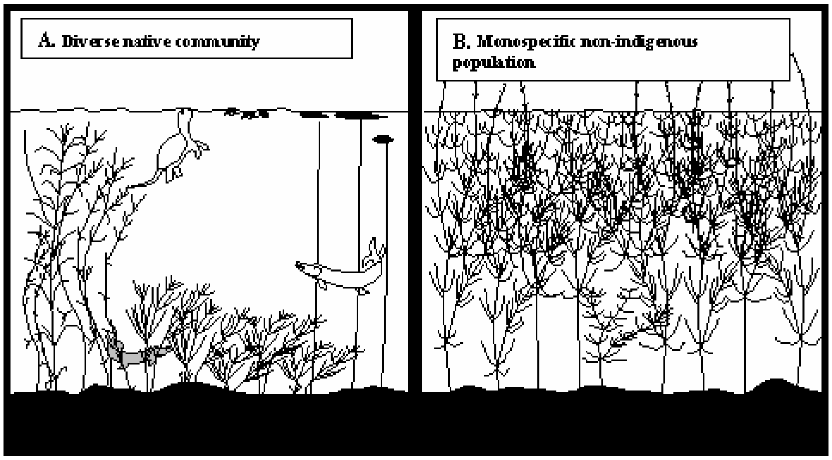

Figure 2. Comparison of (a) diverse native plant community versus (b) monospecific plant population. (Adapted from Madsen 1997).

Correct identification of each invasive weed and its source of introduction is critical (Figures 3-10) when setting up an integrated control plan. Several useful pictorial weed identification resources are listed in the Reference section of this handbook. In addition, sample plants can be collected as voucher specimens and sent to an expert for identification.

Knowing the growth habit categories of aquatic weeds is an important component of understanding integrated options for vegetation control. Aquatic plants and weeds are categorized as:

Emergent: These species grow in environments ranging from wet ground to shallow water. This group contains the erect narrow-leaved plants such as rushes and sedges. Purple loosestrife is an example of an emergent weed species. Problems caused by this group are mainly due to rapid spreading and encroachment in areas of shallow water and wetlands. Without extensive restoration, small ponds and wetlands infested with invasive emergents are difficult to reclaim and restore to open water or wetlands with diverse species.

Submersed: These plants require a completely aquatic environment for support of the plant stem and leaves, and most of the plant grows underwater. These plants supply considerable oxygen to the aquatic environment. Eurasian watermilfoil, hydrilla, and Brazilian elodea are examples of submersed aquatic weeds that can easily become excessive in growth and completely choke small shallow waters. In deeper waters, these plants can degrade the diverse habitat structure required for survival of fish and wildlife.

Free Floating: These plants grow with roots or stems under water but with considerable vegetation floating on the water surface; examples are giant salvinia, water hyacinth, and water chestnut. This category also includes plant species that are completely free floating, such as duckweed and water fern. Problems caused by this group are usually related to the potential effects of shading underneath the plants, and the physical barriers they can create at the surface.

Algae: Algae consist of three general growth forms: microscopic, mat forming, and the *Chara*/*Nitella* (stonewort) group of species.

- Microscopic algae are typically free-floating or attached to rocks, leaves, and other solid aquatic surfaces. They are an important source of oxygen and a primary food source for many aquatic invertebrate animals. When nutrient levels (especially phosphorus) are high in surface waters, microscopic algae can multiply rapidly and create blooms. This can be aesthetically unpleasing, but more importantly, algae blooms can detrimentally affect the quality of the aquatic habitat. Die-offs (crashes) and decay of the algae population can result in rapid deoxygenation of the water, which seriously endangers fish and other aquatic organisms.

- The mat-forming algae grow in long thread-like filaments that may be attached to rocks, other solid underwater surfaces, or loosely associated with the bottom sediments. They often rise to the water surface to form free-floating mats of vegetation. Although most of these species are good oxygen producers and provide food and shelter for certain invertebrates, the mat-forming algae are generally regarded as an undesirable part of the aquatic flora and as they can rapidly choke large areas of water. They are difficult to control once populations reach high levels.
- Species of the *Chara*/*Nitella* group have simple stem and leaf-like structures growing underwater from a portion of the plant embedded in the sediment. Although they provide food and structure, and are generally considered valuable as habitat, they can become overabundant in shallow parts of a water body.

Fish and Wildlife Habitat and Invasive Aquatic Weed BMPs

The value of vegetation in maintaining diverse aquatic and semi-aquatic ecosystems, and the fact that aquatic plants are an important component of functioning fish and wildlife habitat, have been well documented. Aquatic and littoral vegetation provides fish, waterfowl, and some mammals with (1) oxygen, (2) habitat, (3) food sources, (4) breeding areas, (5) refuge for predators and prey, and (6) stabilized bottom sediments and nutrients. These resources are needed for healthy aquatic and littoral ecosystems, and are important for good sport fisheries as well as other water-associated recreational activities and the aesthetic enjoyment of aquatic areas.

The spread of invasive or nuisance vegetation will alter the structure of aquatic ecosystems and result in ecosystem degradation, changes in water quality, and changes in habitat for fish and wildlife populations. Invasive aquatic vegetation spreads rapidly and colonizes water bodies with the ecological characteristics of early successional species, and will invade both degraded and healthy aquatic ecosystems. Invasive submersed aquatic vegetation typically creates monoculture stands with dense canopies above or below the surface that result in decreased water mixing and oxygen exchange, increased nutrient loading, and widely-fluctuating temperatures. This morphology reduces activity of other vegetation, so that the invasion of a lake by hydrilla, water hyacinth, Eurasian watermilfoil, or water chestnut is often accompanied by the decline of indigenous aquatic vegetation. In addition to affecting water quality and reducing the density of indigenous aquatic vegetation, invasive aquatic vegetation alters animal communities in littoral zones and wetlands.

Most professional water resource and fisheries managers believe that native vegetation is preferable to exotic, and agree, based on considerable research evidence and experience, that an intermediate level of native vegetation coverage (20 to 40 percent cover) should be maintained for fisheries and wildlife. This management goal may be difficult to attain when lakes, streams or rivers are used for other purposes such as watercraft recreation or transportation. Many of the research studies suggest that natural or anthropogenic (human-made) changes in aquatic vegetation abundance or species composition have considerable effect on biological structure and productivity of lakes, streams and rivers. The interaction between individual fish/wildlife species and aquatic vegetation is highly variable and depends on:

- Water chemistry
- Light availability
- Substrate characteristics
- Lake or stream morphology and size
- Lake or stream location and geographic area
- Aquatic vegetation abundance and species composition
- Plant form, bed architecture, and stem density
- Fish/wildlife species composition.

Fish Prey, Predators, and Aquatic Vegetation

The presence and relative abundance of diverse aquatic vegetation beneficially increase the habitat complexity of aquatic ecosystems. They provide refuge for prey species and young predator species, and plants specifically provide habitat for the invertebrates that are food for many fish. An overabundance of plants interferes with the feeding of larger predators, both fish and wildlife. In lakes with no submersed habitat due to natural conditions or overaggressive management, there may be insufficient vegetation to allow survival of structure-oriented prey or young predators. As the lake becomes filled with intermediate levels of vegetation, (1) habitat becomes more complex, (2) invertebrate densities increase, (3) vegetation-oriented prey and young predator fish find better refuge from predators, and (4) recruitment becomes sufficient to reach the fish population carrying capacity of the lake. At high levels of vegetation, especially dense monocultures formed by invasive aquatic species, it is more difficult for fish predators to forage because of visual barriers. This causes slower fish growth, favors smaller sized fish, and can reduce numbers of larger harvestable fish, all of which result in poor quality sport fishing.

Composition of Fish Species and Abundance of Aquatic Vegetation

Lakes and streams each have a carrying capacity for total abundance of fish. Within an individual lake with a given capacity to support fish, the amount of vegetation can impact the relative abundance of individual fish species. Lakes with a low abundance of vegetation, generally oligotrophic, tend to be dominated by fish species adapted to open-water habitats. Lakes with a high abundance of aquatic vegetation, generally eutrophic, tend to be dominated by fish species adapted to vegetated habitats. The total number of fish species in a lake (species richness) usually does not change as the amount of aquatic vegetation changes.

Although in general the relative abundance of many fish species is directly related to the amount of aquatic vegetation, some species, such as largemouth bass, are able to maintain stable population numbers over a large range of vegetation levels. These species usually have two or more energy resource pathways that they can alternate among, depending on foraging opportunities. As opportunist feeders, they are able to feed on small fish or on insects depending on availability, and switch as habitat changes. Maximum food benefits depend upon availability of prey of appropriate size in the vegetated habitat.

Effect of Low and High Abundance of Aquatic Vegetation

Most fisheries studies conclude that a moderate amount of vegetation is optimal for fish habitat. While lakes with very low or very high levels of vegetation can support fish populations, vegetation coverage greater than 20% encourages the formation of stable fish populations, with 20 to 40%

coverage being optimal. This is a relatively wide range, and can accommodate the diverse goals of lake and stream management and the goals of maintaining good fish and wildlife habitat.

In contrast, the probability of lowered fish populations resulting from either vegetation eradication or infestation by invasive plant species is relatively high, especially for species adapted to and relying on vegetation. Initial invasion of lakes and rivers by invasive species may benefit habitat structure by providing additional cover and food for such species as largemouth bass.

Once a monoculture of invasive weeds is established with 85% coverage or more, most fish will decrease in size and number.

Additional readings and sources of information on the relationship of fish and wildlife with aquatic vegetation are included in the References section of this handbook.

General Review of Best Management Practices

Biological Control Practices

Biological control is the introduction by humans of any parasite, predator, or pathogen into the environment for the suppression of some target plant or animal pest (Table 1). The key word in this definition is suppression. Biological control operates by reducing a target population, such as invasive aquatic weeds, to lower population levels consistent with fish and wildlife habitat and recreational use of water bodies. Therefore, the goal of biological control consistent with integrated aquatic plant management is not complete eradication or elimination of a weed from a specific area. Researchers have observed that plant community response, i.e., the ability of other species to occupy space left by damaged nuisance plants, or the stress imposed by competition between the weed and other plants, is important to successful biological control. Biological control is considered by some as one of the most environmentally acceptable BMPs for control of invasive aquatic weeds.

Several broad types of biocontrol approaches are recognized. These include:

- Classical, the introduction of host-specific organisms from the home range of the target plant into the non-native environment it has invaded
- Inundative, the use of opportunistic native or exotic pathogens or insects as predators
- Use of general feeders or non host-specific organisms. For example, the white amur (grass carp) is a general feeder that can be used for the control of most species of submersed aquatic vegetation
- Conservation or augmentation of native herbivores.

Biocontrol is typically a long-term approach for the suppression of a target plant species. A disadvantage of using biological control alone is that adequate effective results may take many years. Such a long-term suppression method is best used in low-priority areas, at sites where the use of other control strategies would be cost-prohibitive, or in conjunction with control methods with shorter effect times. Biological control is a potentially effective long-term control practice when used in conjunction with shorter-term mechanical and chemical control options.

Many organisms have been considered for biological control programs (Table 1). They include a sterile triploid form of the white amur grass carp (*Ctenopharyngodon idella* Val.), introduced insects for hydrilla and purple loosestrife, naturalized pathogens for Eurasian watermilfoil and hydrilla, native and naturalized insects for Eurasian watermilfoil, and native aquatic plant restoration.

The high level of productivity that allows introduced or invasive aquatic plants to dominate native vegetation and form large continuous monocultures is primarily an inherent characteristic of the introduced species. However, most exotic plants are also introduced into new localities without being accompanied by their normal complement of exotic herbivores, disease-causing organisms, or associated plant competitors that would otherwise act to reduce the growth potential of these plants.

Table 1. Summary of biological practices for control of aquatic weeds (modified from Madsen 1997, 2000)

Management Method	Description	Advantages	Disadvantages	Systems where used effectively	Plant species response
Grass Carp/White Amur (Ctenopharyngodon idella)	Herbivorous fish, exotic	Long-term (decades), relatively inexpensive	May not remain in feeding sites, difficult to contain in water body, tendency for "all or none" community response (eats most species), persistent	Isolated water bodies, effective against **hydrilla** and other preferred species. Operational use in U.S.	Fish have strong preference for **hydrilla** and many native plants. Avoids Eurasian watermilfoil; generally does not prefer floating plants
Neochetina spp.	Weevils, exotic	Species selective	Not effective in reducing area coverage in many situations	Released in Florida, Gulf Coast states	Leaf scars, some reduction in growth. Species include **water hyacinth**
Hydrellia spp. Bagous spp.	Fly, exotic Weevil, exotic	Species selective	Not yet widely established or effective	Released in Florida, Alabama, Texas (Research)	Limited suppression of **hydrilla**
Euhrychiopsis lecontei and other native insects	Weevil, native Other native or naturalized insects	Already established in U.S.	Less selective, currently under research, populations may be limited in many lakes	Currently under study in Vermont, New York, Minnesota and Midwest (Research)	Plants lose buoyancy, weevil interferes with transfer of carbohydrates. Promising for suppressions of **Eurasian watermilfoil**
Mycoleptodiscus terrestris (Mt)	Fungal pathogen; acts as a contact bioherbicide, native	Low dispersion, fairly broad spectrum	Expense, cross-contamination, inconsistent viability and virulence of formulation	Under research for both **Eurasian watermilfoil** and **hydrilla**	"Contact bioherbicide" Plants rapidly fall apart, but regrow from roots
Hylobius Galerucella Nanophyes	Introduced weevils and leaf beetles	Selective, established in many areas for suppression of plants	Early in development, some potential non-target impacts	Northern U.S. and Southern Canada for control of **purple loosestrife**	Reduction in plant mass, reproduction and density due to leaf, stem, flower and root feeding; takes several years for suppression
Cyrtobagous salviniae	Introduced weevil	Highly selective, has been effective around the world; is becoming established in U.S.	Under research in the U.S. - first introductions in 2001 - needs high nitrogen plants	Effective in Australia, New Guinea, Sri Lanka and South Africa. Under research in Texas and Louisiana for suppression of **giant salvinia**	Plant growth reduced, plants sink with extensive damage; in some locations very rapid control
Native Plant Community Restoration	Planting of desirable native plant species or communities	Provides habitat, may slow reinvasion or initial invasion	Expensive, techniques still under development	Under research around the country for many species	Native plants provide ecosystem benefits, slow invasion

Ideally, introduced or native biocontrol organisms will feed primarily on the target plant and not on other native species, and exert continuous pressure on the invasive by tissue removal, internal fluid removal, or general loss of plant vigor through disease. The most successful agents usually target specific structures that are vital to the productivity and propagation of the plant. Over time, with continuous feeding or disease, the target plants exhibit significant changes in morphology and physiology. They often become smaller with a thicker cuticle, or may exhibit reductions in flowering and seed set. Eventually, their production of daughter plants and other vegetative structures is reduced. When suppression of the invasive plant occurs, the previously out-competed native vegetation re-emerges as a significant component of the aquatic ecosystem, resulting in a healthy and diverse plant environment that provides improved habitat and recreation use.

Compared to pathogens and other control options, the action of the herbivores can be relatively slow, with distinct observable changes practically nonexistent. It is important that operational personnel be familiar with the subtle effects of the biocontrol agents, so their action is noted and used whenever possible. Long-term monitoring of biocontrol agents and damage done to the target invasive weeds should be included at the operational level as a means of assessing the effects that biocontrol agents have on aquatic weeds.

Some states require permits or have restrictions on the use of biological control of invasive plants. For example, some states do not allow the use of grass carp, while others require special permits. **Be sure to check on these regulations with the local, state, and federal regulating authorities.**

More detailed information on the biological control agents for various invasive aquatic weeds is discussed in the Species-Specific Integrated Best Management Practices section of this handbook. Excellent sources of general and specific information on biological control of aquatic weeds are included in the References section of this handbook.

Mechanical and Physical Control Practices

Mechanical and physical control procedures have been widely used in attempts to deal with aquatic plants, especially invasive and exotic species. Some commercial companies have developed powered and non-powered hand tools specifically designed to remove submersed aquatic plants. Mechanical and physical methods can be successful, but several issues must be considered when planning management programs based on them.

Many submersed aquatic plants spread by fragmentation, and any production of additional plant propagules of invasive species should be avoided. It is important to remember that removing aquatic plants may increase shoreline erosion, as roots are no longer present to stabilize the sediment and dampen wave action. In some situations, to prevent this problem, native species should be replanted in place of the weed being removed. This will not only help stabilize the shoreline, but could inhibit the regrowth of other exotic species.

The type and effectiveness of mechanical and physical control practices are described here and summarized in Tables 2, 3 and 4.

Table 2. Summary of major mechanical practices for the control of aquatic weeds (modified from Madsen 1997, 2000)

Management Method	Description	Advantages	Disadvantages	Systems where used effectively	Plant species response
Hand-Cutting/ Pulling	Direct hand pulling or use of hand tools	Low-technology, affordable, can be selective	Labor-intensive, cost is labor-based	Most of the undeveloped world, volunteer labor pools	Very effective in very localized areas
Cutting and Shredding	Cut or shred weeds with mechanical device (typically boat-mounted sickle bar) without collection	More rapid than harvesting	Large mats of cut weeds may become a health and environmental problem, may spread infestation	Heavily-infested systems	Nonselective, short-term
Harvesting (Cut and Remove)	Mechanical cutting with plant removal	Removes plant biomass	Slower and more expensive than cutting; resuspension of sediments	Widespread use with chronic plant problems	Non-selective, short-term
Grinder or "Juicer" (Cut and Grind)	Mechanical cutting with grinding of plant material and in-lake disposal	Immediate relief of plant nuisance; no disposal	Resuspension of sediments, decomposition of plants in lake, floating plant material	Useful for chronic plant problems where disposal of plants is problematic	Like cutting and harvesting, non-selective short-term
Diver-Operated Suction/ Harvester or Diver Dredging	Vacuum lift used to remove plant stems, roots, leaves; sediment left in place	Moderately selective (based on visibility and operator), longer-term	Slow and cost-intensive	Useful for smaller nuisance plant populations in which plant density is moderate	Typically have minimal regrowth for **Eurasian watermilfoil**; not effective for tuber-setting hydrilla
Rotovating	Cultivator on long arm for tilling aquatic sediments	Disrupts Eurasian watermilfoil stem bases, intermediate-term results	May spread large numbers of fragments; resuspension of sediments	Used extensively in the Pacific Northwest and British Columbia, with mixed results	Effective in disrupting dense **Eurasian watermilfoil** stands; not selective and only intermediate-term
Ground Mowing	Self propelled or tractor pulled equipment used to remove foliage and seed	Provides immediate reduction in vegetation	May spread fragments; timing of operation is critical; expense of equipment	Heavily-infested systems	Non-selective, short-term control of rooted vegetation
Weed Rolling	Roller compresses soil and vegetation	Equipment may be left in place; low operational effort	May disrupt other bottom dwelling organisms and fish; may spread fragments; hazard to people using area	Heavy and chronically infested areas	Non-selective, short-term control of rooted vegetation

Table 3. Summary of major physical practices for the control of aquatic weeds (modified from Madsen 1997, 2000)

Management Method	Description	Advantages	Disadvantages	Systems where used effectively	Plant species response
Dredging/ Sediment Removal	Mechanical sediment dredge used to remove sediments, deepen water	Creates deeper water, very long-term results	Very expensive, must deal with dredge sediment	Shallow ponds and lakes, particularly those filled in by sedimentation	Often creates large areas of lake temporarily free of plants, not selective
Drawdown	"De-water" a lake or river for an extended period of time; may be used with fire and subsequent flooding	Inexpensive, very effective, moderate-term	Can have severe environmental impacts, severe recreational/ riparian user effects	Only useful for manmade lakes or regulated rivers with a dam or water control structure	Selective based on timing; effective on evergreen perennials, less effective on herbaceous perennials
Benthic Barrier	Natural or synthetic materials to cover plant	Direct and effective, may last several seasons	Expensive and small-scale, nonselective	Around docks, boat launches, swimming areas, and other small, intensive use areas	Nonselective, plant mortality within one month underneath barrier
Shading / Light Attenuation	Reduce light levels by one of several means: dyes, shade cloth, plant trees along streams & rivers	Generally inexpensive, effective	Nonselective, controls all plants, may not be aesthetically pleasing	Smaller ponds, man-made water bodies, small streams	Nonselective, but may be long-term
Nutrient Inactivation	Inactivate phosphorous (in particular) using alum	Does not physically disturb bottom sediments	Impractical for rooted plants limited by nitrogen	Most useful for controlling phytoplankton by inactivating water column P	Variable

Mechanical Control Practices

Hand pulling and raking techniques are similar to weeding a garden. The whole plant, including the roots, should be removed, while leaving beneficial species intact. This method works best in softer sediments, with shallow-rooted species, and for smaller infestation areas, and the process must be repeated often to control re-growth. When hand pulling nuisance species, the entire root system and all fragments of the plants must be collected, since growth can re-establish from even small root or stem fragments. The cost of hand pulling varies widely, depending on the degree of infestation and the availability of labor.

Hand cutting can be used for small, localized areas of invasive aquatic plants where removal of vegetation can be accomplished by cutting with hand tools. Generally this approach can only be used in areas where water levels allow access, usually in water less than 4 feet deep. If the target weed spreads by fragmentation, hand cutting operations should only be conducted in lakes where the plant has expanded to most of the littoral zone since cutting pioneer weed colonies could accelerate spread to non-infested areas.

Table 4. Mechanical and physical practices for control of aquatic weeds

Technique	Eurasian Watermilfoil	Water chestnut	Giant Salvinia	Hydrilla	Water hyacinth	Purple Loosestrife	Brazilian elodea	Algae
MECHANICAL								
Cookie Cutter		X			X	X		
Cutter	X	X		X		X	X	
Diver-operated dredging	X			X			X	
Grinder	X	X	X	X	X		X	
Hand pulling	X	X	X	X	X	X	X	X[1]
Harvester	X	X	X	X	X	X	X	X[1]
Rotovator	X					X		
Shredder		X			X			
Weed Roller	X			X			X	
PHYSICAL								
Benthic Barrier	X			X			X	
Dredging	X			X			X	
Drawdown	X		X	X	X		X	X
Fire						X		
Flooding						X		
Nutrient Inactivation								X
Shading	X			X			X	X

[1] Filamentous or macroalgae only

Mechanical harvesters are machines that cut and collect aquatic plants. These machines can cut the plants from five to ten feet below the water surface, and may cut an area six to twenty feet wide. Optimally, the weeds are cut and then collected by the harvester, stored in the harvester or barge, and then transferred to an upland site. The advantages of this type of weed control are that cutting and harvesting (1) immediately open areas such as boat lanes, and (2) remove the upper canopy and shade-producing portion of the plants. Due to the size of the equipment, mechanical harvesting is limited to water areas of sufficient size and depth.

Transportation and disposal logistics should be evaluated before use of this method. The USACE provides a HARVEST model in the Aquatic Plant Information System (APIS: see Reference section on BMPs for Control of Invasive Aquatic Weeds). Mechanical harvesting leaves plant fragments in the water, and if not collected, these may spread the plant to new areas. Harvesters may also impact fish and insect populations in the area by removing them in harvested material. Cutting plant stems too close to the bottom can result in re-suspension of bottom sediments and nutrients. The use of harvesters is fairly expensive, and in many areas harvesting may have to be performed several times per growing season to maintain control of fast-growing nuisance weeds.

The cookie cutter is a barge/cutting system developed in Florida to deal with emergent aquatic vegetation and floating islands of vegetation and sediment, and to cut openings in shoreline and wetland areas through emergent wetland plants. The cookie cutter's ability to penetrate thick growth rapidly and to remove both the plant material and the underlying sediments allows the system to open channels into areas that would not otherwise be accessible to birds for feeding and nesting.

The cookie cutter does not have any type of harvest capability, it merely disrupts the mats of vegetation. There is a tendency in this type of operation for the plant material to be thrown by the cutting action further into the weed beds. If the work is primarily parallel to the shoreline, a harvesting system supporting the operation may be needed to collect and remove this material. The cookie cutter can suspend sediments if it is used on plants in shallow water or against a shoreline. This could cause environmental problems, and some states require a permit for its use. In addition, with this method the habitat impact may include removal of hydric soils as the blades throw this material aside. This can be considered dredging in some cases, and may be subject to wetland dredge and fill regulations. The operator should check with the local agencies to determine if permits are required.

Weed rollers are a fairly new method for controlling nuisance weed populations. The roller, which can be up to 30 feet long, is powered by an electric motor and is anchored in place, normally on the end of a dock. The roller travels forward and reverse in a 270-degree arc around its anchor position, compressing the bottom sediments and plants in the area. Frequent use allows only a low amount of weed growth in the area being rolled. This type of equipment requires low operational effort, and can be left in place and used as the plants begin to grow. However, the rollers may disturb bottom dwelling organisms and spawning fish, and fragmentation of the nuisance plant and subsequent regeneration may occur. Some states have specific rules on the use of weed rollers. Contact appropriate local and state agencies to determine whether weed rollers are allowed and for the appropriate permit process.

A **rotovator** is similar to an under-water rototiller. The equipment has rototiller-like blades that turn seven to nine inches below the bottom to dislodge roots. The plants and roots are removed either manually or with a rake attachment. This method of plant removal works best before plants reach their mature length as longer plants tend to wrap around the spinning blades and may damage the equipment. This method is useable year-round, and has been shown to be very effective in clearing areas rapidly and maintaining low levels of weed growth for several seasons.

Rotovating should be used in water bodies with few obstructions, since equipment can be damaged when encountering rocks, logs, or other debris. Since the rotovator significantly disturbs the sediment, there are many environmental concerns, including (1) re-suspension of contaminated sediments, (2) release of nutrients absorbed or precipitated in the sediment (e.g., phosphorus), (3) adverse impact to benthic organisms, and (4) impact on fish spawning areas. Some states have specific rules on the use of rotovators or devices that disturb the bottom sediment. Contact the appropriate local and state agencies to determine whether weed rollers are allowed and the appropriate permit process.

Several manufacturers produce similar designs of **ground-mowing** equipment for wetland and shoreline vegetation. Most large-scale mowing equipment is either self-propelled or pulled by a tractor or unit that has a live power drive. The primary goal of mowing invasive plant species is to (1) remove foliage, (2) prevent the plant from setting viable seed, (3) inhibit the plant's ability to accumulate energy reserves, and (4) weaken the root stock. Different mowing machinery is available to adapt to individual terrain and job performance criteria. This type of equipment can be used for shallow and emergent vegetation.

The British Columbia Ministry of Environment pioneered **diver dredging** procedures after Eurasian watermilfoil invaded its waterways in the early 1970s. Borrowed from the gold mining industry, diver dredging is especially effective against pioneering infestations of submersed invasive plant species. When a weed is discovered as an initial pioneer colony, this methodology should be considered. To be effective, the entire plant including the sediment portions should be removed. Floating plant fragments can be formed from this type of operation and contribute to new infestations, and as divers move through established plant stands they can disturb nearby plants, causing them to tear and break. Some operations employ personnel on the surface in canoes or kayaks to capture floating plant fragments.

Dredging is a possible first step in a consistent integrated control program. It may also be a later step after weeds are initially suppressed with an herbicide. The level of plant growth has a dramatic impact on diver dredging operations. There have been successful short-term uses of this procedure against well-established communities, but rapid re-infestation from untreated areas reverses the treatment in a fairly short period of time. Where infestations have expanded to large portions of the littoral zone of the lake or river system, other combinations of mechanical, chemical, and biological strategies may be more cost effective. Many states have specific rules on the practice of dredging, especially regarding potential effects and disposal of vegetation. Contact the appropriate local and state agencies to determine whether dredging is an allowed practice and the appropriate permit process.

Physical Control Practices

Bottom or benthic barriers have played a limited role in the management of submersed aquatic plants (Tables 3 and 4). There are two basic applications for physical barriers applied across sections of lake or river bottoms infested with invasive weeds. They are used to cover pioneering infestations and prevent the plant's spread, and they have been used in a maintenance role, in opening water around docks or swimming areas. Disadvantages of bottom and benthic barriers are their non-selectivity since they prevent the growth of all vegetation, and limitation of their coverage to less than one acre.

Bottom barriers are attached to the bottom of a water body by pins or sandbags. Common barrier materials are geotextile ground-cover cloth or erosion control materials. These materials are transported to the shoreline adjacent to where installation is to occur, cut to fit the treatment site, and rolled onto a length of pipe. Divers carry the roll into position underwater and pin the leading edge of the material. They then roll out about 3 to 6 feet of the material and pin it again, and this process is repeated until plants in the treatment are covered.

Many states require permits for the application of materials to lake or river bottoms. Since these materials cover the substrate and limit the movement of organisms from the sediment to the water column, there would be potential for seriously impacting benthic organisms if the barriers were applied lake-wide or over broad areas. It must also be remembered that bottom barriers will prevent establishment of native vegetation required for good fish and wildlife habitat. Bottom barriers are generally considered for small localized areas rather than lakewide or riverwide application.

Bottom barriers provide 100% control of weed in areas where they are installed. They also provide long-term control. An ongoing maintenance operation is required to inspect the bottom and clear the mats of sediment build-up.

Dredging or physical removal of bottom sediments employing a floating or land-based dredge is used for aquatic weed control, as well as to restore lakes or channels that (1) are filled with sediment, (2) have excess nutrients, (3) have inadequate pelagic and hypolimnetic zones, (4) need deepening, or (5) require removal of toxic substances. Dredging can create a variety of depth gradients that create multiple plant environments, allowing for greater diversity in lakes plant, fish, and wildlife communities. However, due to cost, potential environmental effects, and problem of sediment disposal, dredging is rarely used for control of aquatic vegetation alone.

Many states have specific rules on the practice of dredging, especially regarding potential effects and disposal of vegetation. Contact the appropriate local and state agencies to determine whether dredging is an allowed practice and the appropriate permit process.

Water **drawdown** is another effective management method (Tables 3 and 4) for control of submersed species such as Eurasian watermilfoil. Drawdown requires some type of water control mechanism to lower water levels, such as dams or weirs, and thus its use is limited. It is most effective when the extent of the drawdown exceeds the depth or invasion level of the target plant species. In northern areas, drawdown will result in freezing of exposed plants and roots during the winter, for an added degree of control. Drawdown is typically inexpensive and has intermediate results (two or more years). However, drawdown can have other environmental effects and interfere with functions of the water body (e.g., drinking water, recreation, or aesthetics). Drawdown can result in the rapid spread of highly opportunistic annual weed species and has caused expanded infestations of weeds such as hydrilla.

Shading is a basic manipulation of the aquatic environment to reduce or attenuate light. This reduces the amount of light available for photosynthesis and slows the conversion of CO_2 to the carbohydrates needed to support healthy plant growth. Shading techniques include use of water-soluble dyes, shading fabrics or covers, establishment of shore-line shade trees, or fertilization to enhance temporary algae growth. Light manipulation has been successful for narrow streams and small ponds but has only limited applicability in larger bodies of water.

Nutrient inactivation is commonly done for control of algae or phytoplankton. Typical nutrient inactivation involves addition of aluminum sulfate (alum) to the water column; this binds phosphorus and makes it unavailable for the growth of algae. However, larger vascular plants (e.g., Eurasian watermilfoil and purple loosestrife) are limited by nitrogen rather than phosphorus. No compounds are currently available that bind nitrogen as readily as alum sequesters phosphorus. For all the invasive species in this handbook except algae, nutrient inactivation control is a limited option still considered to be in the research and development phase. Furthermore, treatments that reduce water column nutrients and algae may permit denser infestations of nuisance, rooted plants due to improved water clarity and decreased light attenuation.

Summary

Specific information on mechanical and physical control practices for invasive aquatic weeds is discussed in the species-specific sections of this handbook. Excellent sources of general and species information on mechanical and physical control of aquatic weeds are included in the References section of this handbook.

Many states have restrictions on the type of mechanical and physical control methods that can be practiced in lakes, streams, and rivers. Permits may be required for the extent and type of practice. **Before implementing any mechanical and physical control practice, contact the appropriate local, state, and federal agencies to determine what practices are allowed and when permits are required.**

Chemical Control Practices

The use of chemicals, known as herbicides, for the control of noxious and nuisance plant species represents one of the most widely used and effective management options available. Herbicide control of invasive aquatic weeds is often the first step in a long-term integrated control program. In the last 15 to 20 years the label registration review for herbicides and their use in the field has changed significantly in order to accommodate safety, health, and environmental concerns. Currently no herbicide product can be labeled for aquatic use if it has more than a one in a million chance of causing significant harmful effects to human health, wildlife, or the environment. Because of this, the number of effective herbicides approved by the U.S. Environmental Protection Agency (EPA) for use in aquatic environments is limited. In most cases it is the cost and time of testing and registration, rather than environmental issues, that limit the number of potentially effective compounds sent through the lengthy registration process. The current EPA-approved compounds for aquatic plant use are summarized in Tables 5 and 6.

Herbicide Use and Classification

Herbicides are chemicals used to control vegetation by causing death or greatly suppressing growth. These compounds, as active ingredients, are incorporated into a variety of commercial herbicide formulations. Herbicides are an important component of integrated management plans and practices because they are effective, reliable, species-selective, cost-efficient, and easy to use. They are applied in specific formulations with a wide variety of equipment, ranging from airplanes to hand sprayers.

All herbicides must be used with care and with full awareness of the problems they may cause if applied improperly. The EPA-approved label provides guidelines to protect the health of the environment, the humans using that environment, and the applicators of the herbicide. In most states, there are additional permitting or regulatory requirements on the use of aquatic herbicides. Some states require that aquatic herbicides be applied only by trained and licensed applicators. Annual updates from state regulatory and environmental agencies are necessary to check for changes in label restrictions and application policies or permit requirements, before developing or implementing any plans for applying herbicides.

Herbicides can be grouped on the basis of their chemical structure and physiological action, or on the timing and method of their application. Herbicides labeled for aquatic use can be classified as either contact or systemic (Table 5). **Contact herbicides** act immediately on the tissues they touch, causing extensive cellular damage at the point of uptake. Typically these herbicides are faster acting, but they may not have a sustained effect and in many cases may not kill root crowns, roots, or rhizomes. In contrast, **systemic herbicides** are translocated and distributed throughout the plant. They are slower acting, but often result in mortality of the entire plant.

Table 5. Characteristics of U.S. Environmental Protection Agency-approved aquatic herbicides (modified from Madsen 2000)

Compound	Trade Name	Company(s)	Formulation	Mode of Action
Carfentrazone-ethyl	Stingray	FMC Corporation	Liquid, oil in water emulsion	Contact; PPO inhibitor
Complexed Copper	Cutrine-Plus Komeen Nautique	Applied Biochemists SePRO Corporation SePRO Corporation	Various complexing agents with copper, superior to CuSO4	Systemic; plant cell toxicant
2,4-D	Aqua-Kleen DMA 4 IVM Navigate Several others	Cerexagri Dow AgroSciences Applied Biochemists	BEE salt DMA liquid BEE salt	Systemic; selective plant-growth regulator
Diquat	Reward Weedtrine-D	Syngenta Applied Biochemists	Liquid	Contact; disrupts plant cell membrane integrity
Endothall	Aquathol K Aquathol Super K Hydrothol 191	Cerexagri	Liquid or granular polymer	Contact; inactivates plant protein synthesis
Fluridone	Avast! Sonar AS Sonar PR Sonar Q Sonar SPR	SePRO Corporation	Liquid or granular	Systemic; disrupts carotenoid synthesis, causing bleaching of chlorophyll
Glyphosate	Rodeo Many others	Dow AgroSciences	Liquid	Systemic; disrupts synthesis of phenylalanine
Imazapyr	Habitat	BASF Corporation	Liquid	Systemic; AHAS (ALS) enzyme inhibitor
Triclopyr	Renovate 3	SePRO Corporation	Liquid	Systemic; selective plant growth regulator

In treating submersed species, application is made directly to the water column, and the plants take up the herbicide from the water. The applicator needs to know the water exchange rate to determine the appropriate exposure time and concentration of the herbicide required to control a specific target plant. These parameters may vary for each target species. The exposure times and concentrations are determined in laboratory studies and field trials. Species with significant above-water vegetative surfaces, such as floating and emergent species, can be treated with direct application to the surface of the actively growing plant. For these species, care should be taken to avoid application if rain is likely, to prevent wash-off of the herbicide before it can be absorbed by the plant tissue.

Selectivity

Herbicide activity can be characterized as species-selective or nonselective (Table 6). **Nonselective or broad spectrum** herbicides control all or most vegetation, because they affect physiological processes common to all plant species. Since nonselective herbicides can kill all vegetation they contact, and not just the problem weed, care must be taken that they are not applied in such a way as to affect desirable plants.

Selective herbicides will damage only those groups of plants that carry the biological pathways targeted by the herbicides' active chemical ingredients. Some selective herbicides control only broadleaf plants (dicots) and do not affect grasses and other monocots, while others are effective on monocots alone.

Selective effects can also be produced by manipulating concentration and exposure time combinations of certain herbicides. Check the References section for specific weeds in this handbook for research results that have shown selective control of this type.

Herbicide Registration, Label Precautions, and Use Restrictions

Herbicides sold in the United States must be registered with the Federal government, and in most cases also by state regulatory agencies. They are reviewed and regulated by the EPA Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA 1974; 7 J.S.C. 135 et seq., Public Laws 92-516, 94-140, and 95-356) and recent amendments.

The printed information and instructional material that is sold with a registered herbicide is known as the "label," and constitutes a legal document. These instructions are considered a part of compliance with FIFRA and other Federal regulations. Failure to use an herbicide in accord with label restrictions can lead to severe penalties. The label provides information on the chemical compound(s) comprising the active ingredient(s) of the herbicide, directions for correct use on target plant species, warnings and use restrictions, and safety and antidote information. EPA approves product labels by site, such as aquatic, rangeland, cropland, etc. Manufactures choose the weeds to be listed for control on the label according to research and successful operational results.

State and local regulations regarding herbicide use may be more restrictive than Federal regulations. Always review and comply with all current state and local regulations before applying herbicides. The labels from which this handbook was summarized are constantly changing. The most current herbicide information should be reviewed for conditions or restrictions prior to use.

Aquatic herbicides may have important restrictions involving water use, particularly where potable water intakes are present, and may include restrictions on swimming or use of fish and shellfish following treatment. Some states prohibit the use of certain herbicides, or any application of herbicides, to sensitive areas such as irrigation canals. In these states, application without a specific use permit is illegal. The individual label lists those jurisdictions or situations where use is not allowed.

Table 6. Use considerations for U.S. Environmental Protection Agency-approved aquatic herbicides (modified from Madsen 2000)

Compound	Exposure time (Water)	Advantages	Disadvantage	Systems where used effectively	Plant response
Carfentrazone-ethyl	Short to Intermediate (12–36 hours)	Very low dosage, rapid action, few label restrictions, selective to some non-target vegetation	Does not affect underground meristems	Emergent & floating plants	Broadleaved species, little impact to grasses, symptoms in 5-7 days with necrosis by 1 month
Complexed Copper	Intermediate (18-72 hours)	Rapid action, approved for drinking water	Does not biodegrade, but biologically inactive in sediments	Lakes as algicide, as herbicide in higher exchange areas; moving and still water	Broad spectrum, acts in 7-10 days or up to 4-6 weeks
2,4-D	Intermediate (18-72 hours)	Systemic	Public perception	Water hyacinth and Eurasian watermilfoil control; Lakes and slow-flow areas, purple loosestrife; Moving and still water	Selective to broadleaves (dicots), acts in 5-7 days up to 2 weeks
Diquat	Short to intermediate (12-36 hours)	Rapid action, limited off-target movement	Does not affect underground portions; Do not use in muddy water	Shoreline, localized treatments, higher exchange rate areas; Moving and still water	Broad spectrum, acts in 5-7 days
Endothall	Short to Intermediate (12-36 hours)	Rapid action, limited off-target movement	Does not affect underground portions	Shoreline, localized treatments, higher exchange rate areas; Moving and still water	Broad spectrum, acts in 7-14 days, some rate-dependent selectivity
Fluridone	Very long (30-90 days)	Very low dosage required, few label restrictions, systemic	Very long contact period	Small lakes, slow flowing systems; Moving and still water	Broad spectrum, acts in 30-90 days, some rate-dependent selectivity
Glyphosate	Not applicable on submersed plants	Few label restrictions, systemic	Very slow action, no submersed control	Emergent & floating-leaved plants only; Moving and still water	Broad spectrum, acts in 7-10 days, up to 4 weeks
Imazapyr	Not applicable on submersed plants	Low volume, low dose, systemic translocation throughout plant	Very slow action, no submersed control	Shoreline, emergent & floating plants	Broad spectrum, acts in 30 days during the growing season
Triclopyr	Intermediate (12-72 hours)	Selective, systemic	Slow action	Lakes and slow-flow areas, purple loosestrife, emergent & floating plants	Selective to broadleaves (dicots), acts in 7-10 days, up to 2 weeks

Certain products are registered as “Restricted Use” herbicides. They can be legally applied only by trained and certified applicators or by people under their direct supervision. These are compounds or formulations that have a high potential to harm humans if not used according to label guidance, or to damage non-target vegetation and aquatic organisms through activity or long-term persistence in water or sediment. Restricted use can be designated at the federal or state level. Be sure to check federal, state, and local regulations prior to using all herbicide formulations. Of the herbicides currently listed in this handbook, none are classified as restricted use by the EPA.

Selection of an appropriate aquatic herbicide requires consideration of the temporary restrictions on water use that may be required following treatment. These restrictions provide a balance between the risks involved in use of the herbicide in an aquatic system, and the benefits that are realized from its application. Temporary restrictions are required where there may be possibility of risk to people, livestock, crops, or fish and wildlife immediately following treatment.

Application of herbicides to complex, three-dimensional aquatic systems requires training and experience. Trained and experienced applicators should be used to insure adequate and selective control of aquatic weeds. Make sure the pesticide applicators selected for aquatic herbicide application have the appropriate training and supervised experience before contracting their services.

The suitability of a herbicide for a water body or aquatic system with a particular water use is clearly specified on the product label. **Consult with appropriate state agencies (e.g., Departments of Agriculture, Natural Resources, Environmental Quality) for the most recent information on aquatic herbicide use and restrictions.**

Herbicide Guides

For the latest label information on a given herbicide, contact the manufacturer or the company that sells the product. Numerous books and publications are available on herbicides and their use in vegetation control. Some label-specific information may have changed since the copyright date of these publications. Many of these sources of general and species-specific information are included in the References section of this handbook.

Cultural Control Practices and Control Program Management

Cultural control techniques focus on a large array of institutional and field methods used to prevent or reduce the entry or spread of invasive aquatic plant species (Table 7). These processes can be an essential component of long-term management and prevention of uncontrolled aquatic weed infestations, and the following are typical program activities and processes.

Prevention is one of the best and most cost effective methods available to avoid aquatic weed infestations. A commitment of volunteer time in a lake, fisheries, or weed watch programs can save thousands of dollars in invasive plant management costs. Volunteer boat cleaning, inspections, and temporary quarantine during transfer of watercraft are all components of prevention programs. This type of program requires extensive management, education, and planning.

Table 7. Summary of cultural control strategy components for the management of aquatic weeds (modified from Madsen 1997, 2000)

Management Method	Subcomponents	Description	Examples
Prevention	Prevent nonindigeneous introductions	Quarantine plant introductions; Institute boat cleaning or drying programs; Monitor for plant presence; Remove small colonies by hand	Citizen lake watcher programs; Volunteer compliance programs; Professional survey programs; Boat launch surveillance
Assessment	Examine existing and potential problem; Obtain group involvement; Study extent of the problem; Set realistic management goals; Set goals in project management framework	State problem without assuming an answer; User groups, regulatory agencies, funding agencies; Site-specific, lakewide, & watershed master plan including personnel, budget, time-line	Hydrilla or other invasive species interferes with lake use; Transect surveys; Biomass sampling; Aerial or remote sampling
Site-specific management	Select integrated management practices tailored to site needs and site priority; Evaluate all BMPs based on technical effectiveness and environmental and economic impacts	Low-tech approaches for small or scattered colonies; More expensive, higher tech mechanisms for larger, more dense infestations	Drinking water intakes; Endangered species; High use areas
Evaluation	Evaluate integrated practices quantitatively based on effectiveness and economic and environmental effects; Manage sites to economic and environmental thresholds	On-site quantitative assessment of effectiveness of integrated BMPs Environmental and economic cost benefit analysis	Quantitative plant sampling
Monitoring	Monitor ecosystem for change; Monitor for nonindigenous species and basic conditions of system	Limnological parameters; Measure target plant spread, nontarget impacts; effects on other species - fish, waterfowl, wildlife	Volunteers; Utilize available experts
Education	Public education and awareness; Educate team members; Use of opinion leaders; Target needed audience - lake users, local & regional government leaders, local & regional regulatory agencies	Public involvement to build consensus; Group education for decision making	Use of available media; Published web sites; Workshops; Lectures; Development of full-fledged public outreach program

Assessment involves evaluation of current and potential aquatic weed problems by all stakeholder groups. Optimally, this process should occur before cultural and other integrated practices are implemented. Stakeholder groups typically involve local lakeshore associations, sports groups and associations, boaters, local businesses, local units of government, and relevant state and Federal regulatory agencies. Once the problem has been identified and quantified, goals and integrated management strategies can be established.

Assessment also involves weed identification, quantification, and mapping within a particular body of water or watershed. This can be accomplished by a combination of direct mapping and remote sensing. Based on current invasive weed species levels, the stakeholder groups can (1) predict possible infestations if no control methods are selected; or (2) establish realistic goals for vegetation control. Quantification can be accomplished by developing species lists, making transect estimates, and using remote sensing. Although the initial cost of using a geographic information system (GIS) is high, in high priority areas computerized spatial data is invaluable for predicting trends and future infestations and focusing current management efforts.

Site-specific management evaluates categories of use areas requiring different levels of management within a body of water. All areas within a lake, stream, or river should be categorized by use, restrictions, and priority. Based on these categories, appropriate management techniques are selected for different areas. Swimming beaches and boat launches are usually considered high use and high priority areas. Wildlife areas will likely have lower intensity use, and some jurisdictional restrictions. Sports fisheries areas will probably have moderate use and moderate-to-high priority designation.

Evaluation should be an important component of all aquatic plant management programs. Quantitative evaluation of the effectiveness of the control strategies demonstrates when control thresholds and treatment targets have been met, and what is the cost/benefit of a management program. Typically, occurrence, abundance, and distribution assessments are sufficient for most evaluations. Transect methods are appropriate for evaluating species distributions. Biomass collection is used to determine species abundance. Remote sensing provides a large-scale image of the species distribution of emergent and floating plants.

Monitoring is distinct from evaluating the success of plant management programs. Monitoring programs involve observation of changes in the ecosystem related to:

- Target and nontarget aquatic vegetation
- Physical and environmental parameters
- Other nontarget species such as fish, macroinvertebrates, waterfowl, and wildlife
- Residual herbicides in the water column or sediment

Education programs are not just an adjunct to an invasive aquatic plant management program, but are a long-term requirement for success. Education involves creating public awareness of the problem and the potential for resolution. Education facilitates involvement of volunteer labor and other resources to accomplish the management program. Many activities can be used for education, including workshops, public meetings, press conferences, news releases, posters and flyers, popular articles, postings at boat ramps, videos for interest groups, development of publicized web sites, and involvement of regulators, sports person associations, fish and wildlife groups, and concerned citizens and businesses.

Well-educated citizens and technically-informed agency biologists are essential components in the successful control of invasive aquatic plants. An organized interagency campaign to increase public awareness and understanding of the dangers of invasive species is a good first step. Educational efforts should focus on:

- Educating the nursery and aquarium trade, sportsmen and boaters, the general public, and policy makers
- Encouraging reporting to a central source
- Verifying and mapping new reports
- Preventing spread to new water bodies

Summary

In general, prevention programs should include the following components:

- Citizen lake-watcher programs
- Volunteer compliance programs including boat cleaning and quarantines
- Professional survey programs
- Boat launch surveillance
- Assessment and Monitoring Programs
- Education and media approaches, including:
    - published web sites
    - workshops and lectures
    - development of full-fledged public outreach programs via university extension service or Sea Grant programs.

Excellent sources of general and species-specific information on cultural and institutional control of invasive aquatic weeds are included in the References section of this handbook.

Species-Specific Integrated Best Management Practices

<u>Eurasian Watermilfoil (*Myriophyllum spicatum* L.)</u>

Description Eurasian watermilfoil is a submersed, rooted, perennial dicot that is submersed except for the upper flower-bearing portions (Figure 3). The stem branches underwater and produces many whorled, finely divided leaves near the water surface. The leaves can have a grayish cast and feathery appearance. Eurasian watermilfoil is one of several aquatic invasive weeds that reproduce primarily by fragmentation. Viable propagules can be as small as a stem portion carrying a single leaf node.

Habitat & Range Eurasian watermilfoil is a highly invasive aggressive species that colonizes a variety of habitats including reservoirs, lakes, ponds, low-energy streams and rivers, and brackish waters of estuaries and bays. Its rapid growth rate allows this milfoil to cover water surfaces and form thick underwater stands of tangled stems, enabling it to displace native vegetation in a few growing seasons. Since Eurasian watermilfoil elongates from shoots initiated in the fall and is tolerant of low water temperatures, it can begin spring growth earlier than other aquatic plants and grow quickly to the surface to form dense canopies, overtopping and shading out surrounding vegetation.

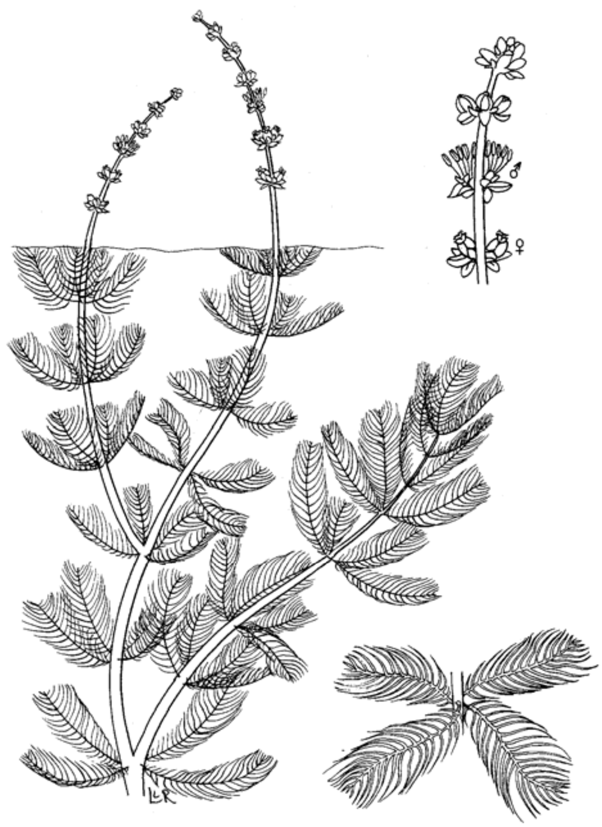

Figure 3. Eurasian Watermilfoil

Native to Europe, Asia, and North Africa, the history of the spread of this species in the U.S. is made unclear by its initial confusion with *M. sibiricum* Romoro (northern watermilfoil), a native species. The first documented case of an intentional introduction was in 1942 in a pond in Washington D.C. This plant is now considered one of the worst aquatic weeds in North America, occurring in at least 45 states and the Canadian provinces of British Columbia, Ontario, and Quebec.

Eurasian watermilfoil spreads by dispersal of plant fragments into lakes and streams, and water currents disperse vegetative propagules through drainage areas. Motorboat traffic contributes to natural seasonal fragmentation and distribution of propagules, and transport on boating equipment plays the largest role in introduction to new water bodies. Road checks in Minnesota have found aquatic vegetation on almost a quarter (23%) of all trailered watercraft inspected. To avoid problems associated with accurate plant identification, the transport of any aquatic vegetation is now illegal in Minnesota and Washington.

Effects on Fish & Wildlife

Problems associated with this species include its aggressive displacement of native vegetation, and alteration of fish and wildlife habitat by formation of impenetrable mats with dense upper canopies that reduce light and decrease water flow. These significant changes in habitat quality quickly affect fish, wildlife, and other aquatic organisms.

Over time, Eurasian watermilfoil will out-compete or eliminate more beneficial native aquatic plants, severely reducing natural plant diversity within a lake. Eurasian watermilfoil is rarely used for food by wildlife, and can displace many aquatic plants that are valuable food sources for waterfowl, fish, and insects. Dense stands of Eurasian watermilfoil provide habitat for mosquitoes and may increase populations of some species of these insects.

Fish populations may initially experience a favorable increase when Eurasian watermilfoil first invades a site. However, the abundant and aggressive growth of this weed will counteract any short-term benefits. Its typically dense growth habit make Eurasian watermilfoil beds poor spawning areas for fish and may lead to populations of small-sized specimens. Loss of oxygen and light caused by the dense mats can also affect the characteristics of fish populations. At high densities, Eurasian watermilfoil's foliage supports a lower abundance and diversity of invertebrates to serve as fish food. While dense cover does allow high survival rates of young fish, larger predator fish lose foraging space and are less efficient at obtaining their prey. Thus dense Eurasian watermilfoil stands are reported to reduce expansion and vigor of warm-water fisheries.

The growth and senescence of dense Eurasian watermilfoil colonies also reduce water quality and water circulation, and cause lower levels of dissolved oxygen.

Control Options

As a nationally pervasive and potentially detrimental invasive aquatic weed, considerable effort has been expended to develop control techniques for Eurasian watermilfoil.

Typically, prevention of invasion of lakes, streams, and rivers is the best method of avoiding the development of uncontrolled monocultures of this aquatic weed. Chemical and mechanical methods are well developed, but provide short- to medium-term control, and often must be used every 1 to 3 years to provide nuisance control. Research on long-term biological control of Eurasian watermilfoil is continuing in North America and throughout the world. At this time, no classical biocontrol agents are available; though native and naturalized insects are being investigated for inundative control. The effectiveness of these insects for long-term suppression is currently being analyzed.

Additional research on Eurasian watermilfoil levels in water bodies, its relation to other aquatic vegetation, and fish and wildlife habitat factors, are necessary to establish threshold levels that trigger various control options.

Chemical Control

Herbicides currently used for the management of Eurasian watermilfoil, as well as information on various commercial formulations and the expected degrees of control are shown in Table 8. Since Eurasian watermilfoil is a dicot it is amenable to selective control using herbicides that specifically target this group. Effective broad spectrum chemicals are also available for this species. Chemical control can provide short- to medium-term control (1 to 3 years), and is often appropriate for immediate use on small initial infestations, with additional potential for use on larger scale or whole-lake infestations where deemed necessary.

Many criteria and evaluations are used to select an appropriate herbicide suited to site-specific and environmental conditions at the time of application. Specific herbicide guidelines and information to consider are provided in the Chemical Control Practices section and Tables 5 and 6 of this handbook.

Because the labels from which this handbook was summarized can change, the most current herbicide label should always be reviewed for conditions or restrictions before use. More information on label guidelines is provided in the Chemical Control Practices: Herbicide Registration, Label Precautions, and Use Restrictions section found in this handbook.

Table 8. Herbicides used for Eurasian watermilfoil management[1,2]

Herbicide Name	Example Trade Name	Formulation	Plant Response
2,4-D Butoxyethlester (BEE)	Aqua-kleen Navigate	Granular	Selective, systemic growth regulator
2,4-D Dimethylamine (DMA)	DMA 4 IVM	Liquid	Selective, systemic growth regulator
Diquat	Reward Weedtrine-D	Liquid	Nonselective, contact
Endothall Dipotassium salt	Aquathol K Aquathol Super K	Liquid Granular	Rate and timing dependent selectivity, contact
Endothall Dimethylalkylamine salt	Hydrothol 191	Liquid or Granular	Nonselective, contact
Fluridone	Avast! Sonar A.S. Sonar PR Sonar Q Sonar SRP	Liquid emulsion Liquid emulsion Precision release pellets Quick release pellets Slow release pellets	Selective (based on application rate), systemic
Triclopyr	Renovate 3	Liquid	Selective, growth regulator

[1] Only pesticides specifically labeled for aquatic sites and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under direct supervision of properly registered, certified, and trained personnel. All pesticide use should comply strictly with local, state, and federal regulations. Following label recommendations, obtaining certification to apply pesticides, and training in the appropriate pesticide application techniques are essential.

[2] Inclusion of pesticides on this list does not imply any endorsement by the AERF or any of the authors.

Mechanical & Physical Control

Mechanical control of Eurasian watermilfoil is a short- to medium-term strategy that can be deployed for initial control of small to moderate infestations (see Tables 2 and 4). One disadvantage of some mechanical control methods is the fragmentation of stems that can create vegetative propagules, and potentially cause further spread. Physical control options provide medium to long-term control of this invasive aquatic weed (Tables 3 and 4).

The more successful mechanical and physical control practices include the following options:

Hand cutting tools have been used to control all submersed aquatic weeds and are effective on Eurasian watermilfoil. Harvesting of Eurasian watermilfoil also is an effective option for short-term clearance of the vegetation from the upper portions of the water column. Since aquatic weeds such as Eurasian watermilfoil can grow up to one foot per week, harvesting may need to be performed several times in a growing season to maintain usability of the water. Following harvesting, Eurasian watermilfoil should be collected and disposed of in a manner that does not contaminate other water bodies. Select a good upland disposal site, with no possibility for the plant fragments to wash back into any water body. This removal and transport of the harvested material is often a limiting factor for large areas. Selective rotovation of Eurasian watermilfoil is an effective technique when used properly. This plant grows back each year from a root crown in the upper few inches of lake sediments, and as there is virtually no reproduction from seed, this structure is the key to Eurasian watermilfoil survival. Rotovation targets the root crown and associated plant tissue, uprooting them from the sediment during the tilling process. Rotovation provides dramatically longer periods of control than do other harvesting methods, but as it can be disruptive to sediment and native plant communities, it is not allowed in many states. Diver dredging has been especially effective against Eurasian watermilfoil. Both the plant and root crown are dislodged, and these structures may then be removed from the lake system. Diver dredging systems are best utilized against small, pioneering infestations of Eurasian watermilfoil. Where new colonies are discovered interspersed with native plants this technology can selectively remove only the Eurasian watermilfoil, and with careful planning and implementation diver dredging has minimal impact on the native flora. This treatment has been successful against well-established communities, but the high cost of operations for extensive infestations limits the application of this technology.

Bottom barriers have been successfully used to manage Eurasian watermilfoil in certain circumstances. They have effectively covered pioneering infestations of this weed and prevented spread of the plant. They have also been used in a maintenance role, keeping water around docks or swimming areas open for use.

Biological Control

Biological control is a BMP that should be included in an integrated plan for control of Eurasian watermilfoil where possible. Basic and applied research is being conducted throughout North America on native and naturalized insects that actively attack Eurasian watermilfoil. Several native aquatic insects have been associated with declines of Eurasian watermilfoil.

Three taxa have been considered for the biological control of Eurasian watermilfoil:

- *Acentria ephemerella* (Denis & Schiffermüller), a naturalized pyralid moth
- *Cricotopus myriophylli* Oliver, an indigenous chironomid midge
- *Euhrychiopsis lecontei* (Dietz), an indigenous weevil.

Acentria ephemerella: The caterpillar of this moth consumes many species of aquatic macrophytes. It has been in North America since the 1920's and has expanded its range westward into the Midwest. Although the caterpillar has been associated with some watermilfoil declines, it does not appear to be a major factor in the reported New England watermilfoil declines. Nor has it attained high densities in Minnesota and the Midwest. The caterpillar has been associated with declines in New York, where it is under more intensive investigation. Research is actively being pursued to determine the effectiveness of this and other caterpillar consumers of Eurasian watermilfoil.

Cricotopus myriophylli: This midge has been associated with watermilfoil declines in the Pacific Northwest. Problems with mass rearing and lack of funding have inhibited further investigation of this potential biological control agent. The midge also is present in the upper Midwest, and may be a factor in suppressing watermilfoil. High densities have not been achieved at several research sites. Due to low densities and difficulties working with such a small agent, recent research has not focused on this midge.

Euhrychiopsis lecontei: This weevil appears to be the most promising agent for long-term biological suppression of Eurasian watermilfoil. It has been associated with documented watermilfoil declines in New England, Wisconsin, Minnesota and elsewhere. The weevil appears widespread across northern North America. Recent surveys in Wisconsin indicate that the weevil likely occurs in most lakes with northern or Eurasian watermilfoil. Research also has shown good suppression of Eurasian watermilfoil in the laboratory, tanks, and field enclosures.

The milfoil weevil is native to North America and is a specialist herbivore of watermilfoils. Once exposed to the exotic Eurasian watermilfoil, the weevil prefers Eurasian to its native host northern watermilfoil *(M. sibiricum)*. Adult weevils live underwater and lay eggs on watermilfoil meristems. The larvae eat the meristem and bore down through the stem, consuming the cortex, and then pupate (metamorphose) lower down on the stem. The consumption of meristem and stem mining by larvae are the two main effects of weevils on the plant, and this damage can suppress plant growth, reduce root biomass and carbohydrate stores, and cause the plant to sink from the top of the water column. Watermilfoil declines often occur over winter, in early summer, or persist over several years. Therefore, it is likely that long-term effects, such as reduced overwinter survival or reduced competitive abilities, are important to sustained control of Eurasian watermilfoil.

The effectiveness of this weevil has been mixed, with good results at some sites and poor results at others. Factors associated with predictability of suppression by the milfoil weevil are currently being investigated, as well as factors limiting weevil populations. Predation by abundant sunfish appears to be a limiting factor to the weevil and other herbivorous insects in some lakes. It is known that weevils can control watermilfoil, but additional research is needed to improve the predictability of its effects, and to determine the appropriate circumstances for successful biocontrol. Many states regulate the use and transport of these agents, and state authorities should be contacted before introduction or augmentations are conducted.

The native fungus *Mycoleptodiscus terrestris* (Gerdemann) Ostazeski also is being investigated for inundative control of Eurasian watermilfoil (e.g., Washington). The fungus acts as a contact bio-herbicide, and infection causes destruction of the plant. Early formulations had difficulties with field application, but recent work with new formulations is promising.

Sterile triploid grass carp *(Ctenopharyngodon idella)* are used in some states for control of Eurasian watermilfoil (e.g., Washington). The introduction of grass carp is considered illegal in other states, including Minnesota, Vermont, and Wisconsin. Eurasian watermilfoil is not a preferred plant and consequently desirable native plants can be predated. Generally, grass carp should not be used for Eurasian watermilfoil control.

Cultural Control

Because this plant is so difficult to control once it has become established, prevention of infestation and early detection of Eurasian watermilfoil growth is essential in stopping the plant from becoming a widespread problem in a lake, stream, or river. Human recreational activities usually account for the spread of non-native aquatic plants, and this is especially so for Eurasian watermilfoil. Fragments of the plant cling to the propellers of boat motors or trailers and, if not removed, can start new populations when the boat is launched into another water body. To stop further spread, it is imperative that **all** plant fragments are removed from boats before putting into or leaving a lake's access area. Once removed, plant material should be properly disposed of in a trash receptacle or on high, dry ground where there is no danger of it washing into any water body.

Unfortunately, once Eurasian watermilfoil has been introduced into a lake, there is currently no combination of control practices that will completely eradicate it in all cases. Therefore, the prevention of introduction remains the best way to avoid Eurasian watermilfoil infestations (see Table 7). Prevention programs are described in the general section on Cultural Control Practices and Control Program Management In general, such programs can include the following components:

- Citizen lake-watcher programs
- Volunteer compliance programs including boat cleaning and quarantines
- Professional survey programs
- Boat launch surveillance
- Assessment and Monitoring Programs
- Education and media approaches, including:
  - published web sites
  - workshops and lectures
  - development of full-fledged public outreach programs via university extension service or Sea Grant programs.

Water Chestnut (*Trapa natans* L.)

Description The water chestnut is an annual aquatic plant (dicot) with both surface and submersed leaves (Figure 4). Surfacing leaves are triangular with toothed edges and an inflated petiole, or floating leaf stalk, and form a rosette on the water surface. Submersed leaves are feather-like, with each leaf divided into segments whorled around the leaf stem. Large nut-like seeds with sharp barbed spines are produced at the surface and then fall to the sediment where they create a swimming and wading hazard. Water chestnut is an annual, and over-winters entirely by these spiny seeds, which may remain viable for 12 years.

Studies have shown that the success of this invasive weed at colonizing aquatic habitats is due to its ability to quickly produce an abundance of vegetative growth in response to low densities of other aquatic vegetation. This trait is enhanced by the ability of clonal mats of water chestnut to produce greater biomass of reproductive structures and fruit compared to native vegetation.

Habitat & Range Originally an Asian species, water chestnut was established in the northeastern United States in the late 1800's. It continues to advance into eastern Canada, New England, and the Mid-Atlantic states. Water chestnut grows rapidly in calm, shallow nutrient-rich bodies of water with soft, muddy bottoms, and generally roots in quiet streams, ponds, freshwater regions of estuaries, and mud flats. Uncontrolled, water chestnut can create nearly impenetrable mats across wide areas of water. This weed currently ranges from Massachusetts, to western Vermont, eastern New York, Maryland, and Virginia.

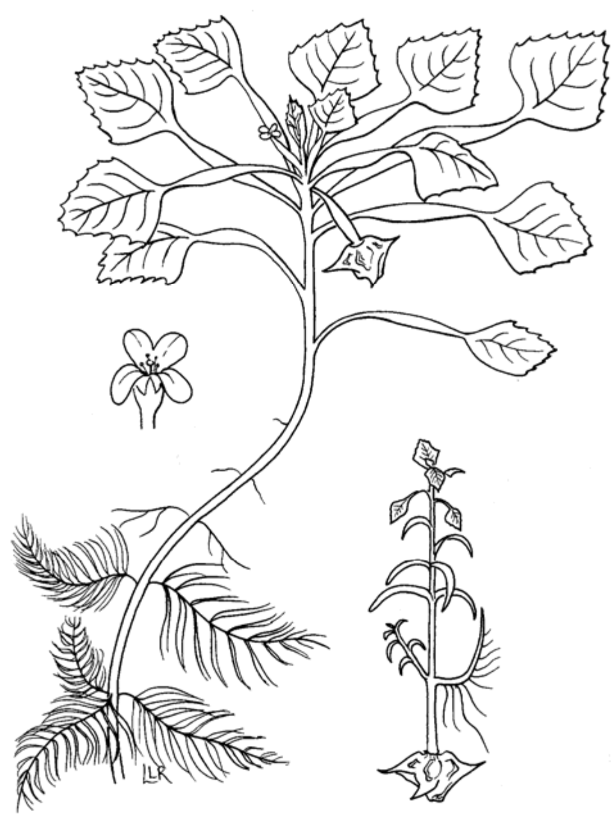

Figure 4. Water Chestnut

Effects of Fish & Wildlife Problems associated with this species primarily derive from its formation of impenetrable surface mats and underwater growth made up of stems and/or leaves. These displace native vegetation and interfere with normal development of fish and wildlife habitat. In South Lake Champlain and other New England lakes, many previously fished bays are now inaccessible due to floating mats of water chestnut. The plant severely shades the water it overlays, eliminating light necessary for well-functioning water-column ecosystems. The dense masses of vegetation reduce oxygen levels, increasing the possibility of fish kills. In autumn, the abundant detritus and its decomposition further lower oxygen in shallow waters, and can affect fish survival. The surface mats also provide many pockets of water that serve as breeding grounds for mosquitoes.

The sharp spiny fruits are painful to step on and present a hazard to swimmers, waders, and walkers.

Control Options

As a regionally pervasive and potentially detrimental invasive aquatic weed, traditional methods of chemical and mechanical control have been used to control water chestnut. In Vermont and Maryland, prevention of invasion of lakes, streams, and estuaries has been attempted to avoid further spread. Chemical and mechanical control methods have provided short-to medium term (1 to 3 years) control of this aquatic weed. Because of the large number of long-lived seeds produced each year by established water chestnut populations, these methods must be used at least annually to provide nuisance control. Additional research on water chestnut levels in lakes, streams, and estuaries in relation to other aquatic vegetation and fish and wildlife habitat are necessary to establish threshold levels that should trigger various control options.

Chemical Control

The herbicide most commonly used to control water chestnut is 2,4-D, with its selective activity on dicots (Table 9). It has been tested extensively by federal and state agencies. Herbicide election is also based on such information as site-specific and environmental conditions at the time of application. Specific herbicide guidelines and information to consider are provided in the Chemical Control Practices section and Tables 5 and 6 of this handbook.

Because the labels from which this handbook was summarized can change, the most current herbicide label should always be reviewed for conditions or restrictions before use. More information on label guidelines is provided in the Chemical Control Practices: Herbicide Registration, Label Precautions, and the Use Restrictions sections found in this handbook.

Table 9. Herbicides used for water chestnut management[1,2]

Herbicide Name	Example Trade Name	Formulation	Plant Response
2,4-D Butoxyethlester (BEE)	Aqua-kleen Navigate	Granular	Selective, systemic growth regulator

[1] Only pesticides specifically labeled for aquatic sites and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under direct supervision of properly registered, certified, and trained personnel. All pesticide use should comply strictly with local, state, and federal regulations. Following label recommendations, obtaining certification to apply pesticides, and training in the appropriate pesticide application techniques are essential.

[2] Inclusion of pesticides on this list does not imply any endorsement by the AERF or any of the authors.

Mechanical & Physical Control

Mechanical and physical control of water chestnut are short-term methods used for initial control of small to moderate infestations (see Tables 2 and 4). In New England, mechanical harvesting and hand removal have been the main means of controlling water chestnut invasions. Experience on the east coast has shown that mechanical methods can be successful at temporarily controlling and reducing infestations if sites are treated repeatedly for five or more years. Long-term commitment to control is necessary, since water chestnut over-winters entirely by seeds that may remain viable for many years. Because of this, mechanical control should be done before seed set.

Mechanical cutting devices have been proposed for control of floating and emergent aquatic weeds such as water chestnut. The cookie cutter technology has some potential for use against the characteristic clonal mats. Cookie cutter operations should take place well before formation of flowers to ensure that this management method does not assist in the distribution of water chestnut seeds. If the equipment is cutting these plants during periods of seed production, spread of the plant can occur. The equipment should be cleaned to ensure that the weed is not spread to the next site where work is conducted.

Hand removal, harvesting, and rotovation also have been used for control of water chestnut. Harvesting water chestnut is a very effective option for short-term clearance of the vegetation from the upper portions of the water column. Since water chestnut grows very rapidly, harvesting must be performed several times in a growing season to maintain usability of the water. Harvesting should be timed and handled in such a way as not to spread viable seed. When harvesting methods are used, the plant tissues should be collected and disposed of in a manner that does not contaminate other water bodies. Select a good upland disposal site, with no possibility for the plant fragments to wash back into any water body. For further details on harvesting and hand removal see the overview of Mechanical and Physical Control Practices.

Biological Control

Biological control has received limited attention as a BMP for integrated control of water chestnut. Attempts were made to find suitable biocontrol insects in China, Japan, South Korea and the Russian Far East (1992-93), and Europe, including France, Germany, Italy and Poland (1995), but no appropriate candidates were found. Potential natural enemies have been reported from warmer climates such as India, though these insect species may not be suitable for the cooler regions of the northeastern United States. Warm-climate naturalized insects may become suitable subjects for study as biocontrol agents if water chestnut extends its range further southward into warmer areas of the United States. Currently no biocontrol agents are available for long-term suppression of water chestnut.

Cultural Control

Because water chestnut is so difficult to control once it has become established, prevention of infestation and early detection of this aggressive aquatic weed is essential in stopping the plant from becoming a widespread problem in a lake, stream, or river. Recreational activities usually account for the spread of water chestnut. Seeds of the aquatic plant cling to the propellers of boat motors or to boat trailers and, if not removed, can start new populations when the boat is launched into another water body. Thus it is imperative that **all** seeds and plant fragments are removed from boats before putting in or leaving a lake's access area. After removal, plant material should be properly disposed of in a trash receptacle or on high, dry ground where there is no danger of it washing into any water body.

Once water chestnut has been introduced into a lake, there is currently no combination of control practices that will completely eradicate it. Therefore, cultural prevention approaches remain the best way to avoid water chestnut (see Table 7). Prevention programs are described in the general section on Cultural Control Practices and Control Program Management. In general, prevention programs can include the following components:

- Citizen lake-watcher programs
- Volunteer compliance programs including boat cleaning and quarantines
- Professional survey programs
- Boat launch surveillance
- Assessment and Monitoring Programs
- Education and media approaches, including:
    - published web sites
    - workshops and lectures
    - development of full-fledged public outreach programs via university extension service or Sea Grant programs.

<u>Giant Salvinia (*Salvinia molesta* Mitchell)</u>

Description

Giant salvinia is a free-floating fern with irregularly branched stems, and lacking true roots (Figure 5). Its leaves, which are actually fronds, are in whorls of three; two floating and one submerged. The opposite floating leaves are round to oblong, 20 mm long and 13 mm wide. Salvinia species have two distinct kinds of spores, megaspores, or female spores, and microspores, or male spores. Giant salvinia is not known to reproduce by spores in the United States; it reproduces aggressively by vegetative propagation. New plants quickly develop as fragments break off from mature individuals.

Salvinia molesta is native to southeastern Brazil. Introduction of this mat-forming fern is thought to have arisen from the water gardening and/or aquarium trade, where it is sold directly, or occurs as a contaminant in water garden stock.

Habitat & Range

Giant salvinia establishes itself extremely successfully and rapidly in tropical, sub-tropical, and warm temperate areas of the world. It is found in ditches, ponds, lakes, slow-moving rivers, and irrigation canals. Giant salvinia grows best where it is protected from wind and current. Its growth is favored by high nutrient content, as found in eutrophic waters such as fertilized fields, and it may be especially problematic in rice fields and other waters polluted by waste or runoff which is high in nutrients. The weed is highly adaptable, but does not colonize in brackish or marine environments.

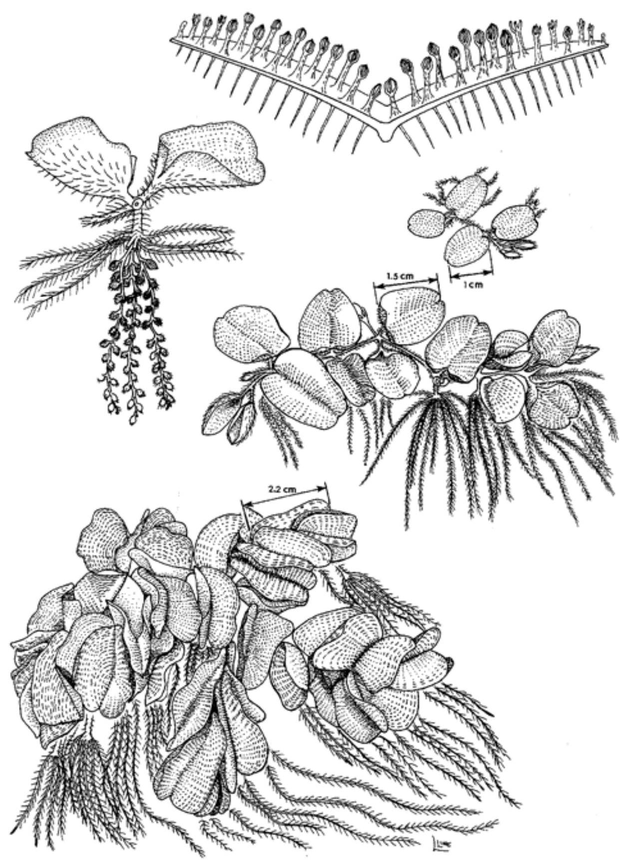

Figure 5. Giant Salvinia

Giant salvinia is an extremely aggressive, competitive species that in favorable environments may double its biomass within about a week. It is a major problem worldwide. It was first reported in North America in South Carolina in 1995. It was eradicated at that site using herbicides, but was found in Texas in 1998. Since then it has been recorded in over 70 locations in 31 freshwater drainage basins of Texas, Louisiana, Mississippi, Alabama, South Carolina, North Carolina, Georgia, Florida, Arizona, California and Hawaii. The predicted range of the plant in the United States approximates the current distribution of water hyacinth.

Effects on Fish & Wildlife

Giant salvinia is considered to be one of the world's worst invasive aquatic weeds and it is prohibited in the United States by Federal law. The rapid growth rate of giant salvinia can result in complete coverage of water surfaces, causing the degradation of natural habitats. Its dense growth creates mats of vegetation that out-compete and shade desirable native vegetation.

Giant salvinia may damage aquatic ecosystems by overgrowing and replacing native plants that provide food and habitat for native animals and waterfowl. Dense floating mats prevent oxygen from entering the water surface, while decaying salvinia drops from the underside of the mat and consumes dissolved oxygen needed by fish and other aquatic organisms. Such excessive oxygen depletion can result in fish kills. As light becomes limited underneath its growth area it affects the growth and survival of phytoplankton and vascular plants. Its extensive mats may exacerbate the situation by preventing water circulation and mixing over wide areas.

Habitat is most noticeably altered by the obliteration of open water. Migrating birds may not recognize or stop at water bodies covered with giant salvinia. In Texas, local fishermen have found it impossible to cast in smothered lakes. Sportfishing has been abandoned in lakes which once had excellent populations of bass, crappie and sunfish.

Control Options

As an internationally pervasive and detrimental invasive aquatic weed, all possible control options should be integrated to manage giant salvinia. Chemical and mechanical methods have provided short- to medium-term control of this aquatic weed. These measures must be used at least annually to provide nuisance control. Unfortunately, giant salvinia may reproduce so rapidly that infestations become impossible to eradicate or even control. Mats have been reported up to three feet thick, which hinders almost every chemical or mechanical management method.

Biological control is still in the research stage to determine which native and naturalized insect species can provide long-term suppression.

Prevention of infestation is the most straightforward management technique. Cultural control by limiting nutrients in runoff from rural and urban watersheds can help reduce the suitability of fresh water areas for infestation. Additional research on giant salvinia levels in lakes, streams, and ponds in relation to their aquatic vegetation and fish and wildlife habitat is necessary to establish the threshold levels that would trigger various control options.

Chemical Control

Herbicides currently used for the management of giant salvinia, as well as information on various commercial formulations and the expected degrees of control, are shown in Table 10. Research and field trials on the success of chemical control of giant salvinia is limited. Diquat, glyphosate, and fluridone have shown a range of effectiveness, although 2,4-D and imazapyr are not effective on this fern. Many criteria and questions are used to select an appropriate herbicide, and any selection must be based on such information as site-specific and environmental conditions at the time of application. Specific herbicide guidelines and information to consider are provided in the Chemical Control Practices section and Tables 5 and 6 of this handbook.

Because the labels from which this handbook was summarized can change, the most current herbicide label should always be reviewed for conditions or restrictions before use. More information on label guidelines is provided in the Chemical Control Practices: Herbicide Registration, Label Precautions, and Use Restrictions section found in this handbook.

Table 10. Herbicides used for giant salvinia management[1,2]

Herbicide Name	Example Trade Name	Formulation	Plant Response
Carfentrazone-ethyl	Stingray	Liquid	Contact, need good coverage
Diquat	Reward	Liquid	Nonselective, contact
Glyphosate	Rodeo	Liquid	Nonselective, systemic

[1] Only pesticides specifically labeled for aquatic sites and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under direct supervision of properly registered, certified, and trained personnel. All pesticide use should comply strictly with local, state, and federal regulations. Following label recommendations, obtaining certification to apply pesticides, and training in the appropriate pesticide application techniques are essential.

[2] Inclusion of pesticides on this list does not imply any endorsement by the AERF or any of the authors.

Mechanical & Physical Control

Mechanical control is optimally a short-term technique for control of initial and small infestations of giant salvinia. Hand removal and harvesting have had some success (Tables 2 and 4), and drawdown within the water body has potential as a physical control practice (Tables 3 and 4). These methods should be used in conjunction with chemical and biological control for longer-term control.

Mechanical and hand harvesting of giant salvinia have been used for short-term clearance of the vegetation from the water. Due to the aggressive growth of this weed, harvesting must be performed several times in a growing season to maintain usability of the water. When harvesting methods are used, all of the giant salvinia vegetation should be collected and disposed of in a manner that does not contaminate the treated and other water bodies. Select a good upland disposal site, with no possibility for the plant fragments to wash back into any water body. Mechanical harvesting can be costly for large-scale operations.

The purpose of drawdowns in giant salvinia control programs is to strand the plants on the shoreline for a sufficient period to cause mortality by desiccation or freezing. If water control structures are available on a body of water, this method can be effective in controlling fairly large areas at a low cost. However, this technique may have significant detrimental effects on the aquatic ecosystem, and on wildlife and recreational access to water. It is probable that viable individuals of the plant will remain in the water to re-infect the system. These plantlets may require brief repeats of chemical or mechanical control methods, or long-term biological control, to avoid continued infestation.

Biological Control

Biological control is an important component of any plan for management and integrated control of giant salvinia. *Cyrtobagous salviniae* Calder & Sands is a small weevil ranging in length from 1.5 to 2.0 mm, prefers feeding on newly formed leaf buds. The weevil larvae feed within the roots, rhizomes, and leaf buds. Combined feeding action can be devastating. with reported impact to field populations of giant salvinia observed in several months. Other biological control agents may take years to achieve similar levels of suppression.

The use of *C. salviniae* promises to be an effective control method for the management of giant salvinia based on its reported efficacy in other areas of the world. Longer times for suppression have been observed in cooler subtropical or warm temperate areas, but eventually good control has been noted in these areas as well. This biocontrol is highly cost effective, since the level of suppression is realized for years without re-introduction, and this significantly reduces the cost of an integrated control program.

This management option is a long-term control method. It may take 5 to 10 years to achieve suitable levels of suppression, but it will not totally eradicate the target plant from a given area. To date, an exact biocontrol methodology has not been determined, as this agent's effectiveness can vary tremendously, depending on conditions such as temperature, plant nutritional status, and other abiotic and biotic conditions.

Cultural Control

Because giant salvinia is extremely difficult to control once it has become established, prevention of infestation and early detection of this very aggressive aquatic weed is essential in stopping the plant from becoming a widespread problem in suitable water bodies. Human recreational activities often account for the spread of this non-native aquatic plant, and any salvinia plants clinging to the propellers of boat motors or to boat trailers can start new populations when the boat is launched into another water body. One way to help stop the further spread of this invasive aquatic species is to remove **all** plant fragments from boats before putting in or leaving a lake's access area. Once removed, this plant material should be properly disposed of in a trash receptacle or on high, dry ground where there is no danger of it washing into any body of water.

Plant shipments for aquatic revegetation projects or water gardens should be inspected carefully for salvinia contamination.

Once giant salvinia has been introduced into a lake, there is currently no combination of control practices that will completely eradicate it. Therefore, cultural prevention approaches remain the best way to avoid giant salvinia infestations (see Table 7). In general, effective prevention programs can include:

- Citizen lake watcher programs
- Volunteer compliance programs including boat cleaning and quarantines
- Professional survey programs
- Boat launch surveillance
- Assessment and Monitoring Programs
- Education and media approaches, including:

- published web sites
- workshops and lectures
- development of full-fledged public outreach program via university extension service or Sea Grant programs.

Since giant salvinia requires nutrient-rich water, careful attention to cleaning up polluted lakes and streams must be considered. Cultural control of nutrients in runoff from rural and urban watersheds can help control the suitability of freshwater for infestation by giant salvinia. Shoreland protection projects, use of agricultural BMPs, stormwater and erosion control practices, establishment of vegetative buffer zones, and zoning restrictions on use of fertilizer or manure applications within shoreland areas are all components of water quality protection.

On the other hand, low nutrients may limit the effectiveness of biocontrol agents in oligotrophic systems. This may require fertilization of plants to increase effectiveness of the biocontrol agent.

Hydrilla (*Hydrilla verticillata* (L.f.) Royle)

Description

The physical appearance of hydrilla (Figure 6)varies due to water quality, making it difficult to identify correctly, and easily confused with native elodea. This monocot grows submersed as a rooted annual or perennial, and forms underground vegetative propagules called tubers. It also produces vegetative reproductive structures called turions on its shoots.

Habitat & Range

Hydrilla is capable of growing in virtually any type of water body. The range of the monoecious hydrilla biotype includes the mid-Atlantic states south to South Carolina. The dioecious type with male flowers is found elsewhere. Hydrilla is now well established in most of the southern states, mid-Atlantic to Connecticut, California, and Washington.

In areas where hydrilla, Eurasian watermilfoil, and Brazilian elodea coexist, hydrilla usually out-competes the other two nuisance species. Hydrilla has the potential to cause greater adverse impacts on aquatic ecosystems than either Eurasian watermilfoil or Brazilian elodea. In states where hydrilla has become established, millions of dollars are spent every year for management and control.

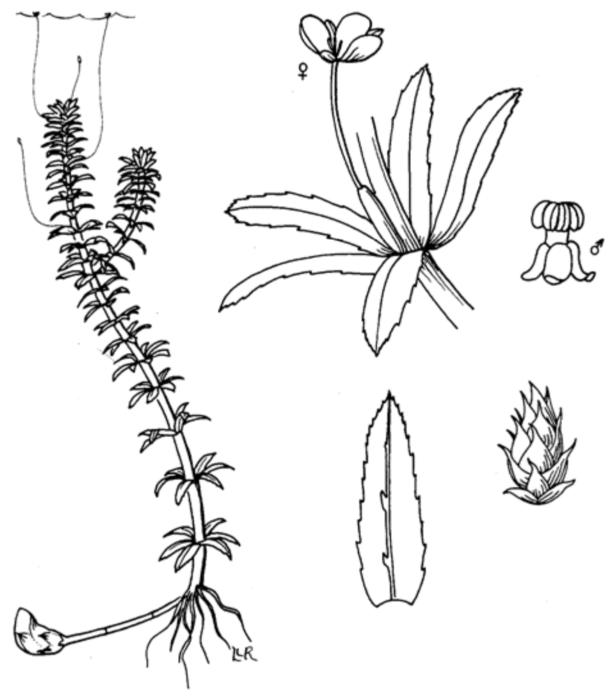

Figure 6. Hydrilla

Effects on Fish & Wildlife

Hydrilla forms large, dense populations that disrupt ecosystem functioning, displace native aquatic species, and impair fish and wildlife habitat. Stagnant areas created by hydrilla mats provide increased breeding habitat for mosquitoes.

Hydrilla out-competes native vegetation, and provides poor habitat for fish and other wildlife, although it is eaten by some waterfowl and is considered by some biologists to be an important wildlife food source. Dense mats alter water quality by raising pH, decreasing oxygen under the mats, and increasing temperature. Loss of oxygen can result in fish kills, depleted fish populations, and reduced fish size. While dense vegetation may contain large numbers of fish, the density achieved by monoculture stands of hydrilla may support few or no harvestable-size sport fish.

Control Options

As a pervasive and detrimental invasive aquatic weed, considerable effort has been expended to develop control techniques for hydrilla. Typically, prevention of invasion of lakes, streams, and rivers is the best method of avoiding the development of uncontrolled monocultures of hydrilla. In addition, hydrilla is managed differently in different types of water bodies, depending on the water uses.

Chemical and mechanical control options provide short- to medium-term control of this aquatic weed. These methods must be used at least annually to provide nuisance control. Research on long-term biological suppression of hydrilla is continuing in North America and throughout the world. Several potential biocontrol agents are being actively evaluated. At this time the only potential available biological agents are native or naturalized insects. The effectiveness of these insects for long-term suppression is currently being investigated. The native fungus *Mycoleptodiscus terrestris* is also being investigated as an inundative bioherbicide and recent work with improved formulations of this organism appears promising. Grass carp are an additional biological control method for hydrilla.

Chemical Control

Herbicides currently used for the management of hydrilla as well as information on various commercial formulations and the expected degrees of control are shown in Table 11. The herbicide active ingredients copper, diquat, endothall, and fluridone can be used to control hydrilla, depending on the associated plant community and other ecosystem criteria.

Copper, diquat, and endothall are fast-acting contact herbicides that have relatively broad spectrum effect on submersed aquatic plants. They are used to control hydrilla selectively by injection of liquid herbicides from trailing hoses under floating leafy vegetation. Granular endothall can be used in the same manner.

Fluridone is only effective for whole-pond applications, or large scale (<15 acres) applications in large bodies of water. Fluridone selectivity is dependent on application rates, contact times, and timing of applications. Although fluridone has been used effectively, there is evidence of development of herbicide resistance in hydrilla. The resistant strains currently have only been detected in the state of Florida. Herbicide resistance management should be considered as part of any long-term chemical control program.

The criteria and issues to be considered when selecting an appropriate herbicide are based on such information as site-specific and environmental conditions at the time of application. Specific herbicide guidelines and information to consider are provided in the Chemical Control Practices section and Tables 5 and 6 of this handbook.

Because the labels from which this handbook was summarized can change, the most current herbicide label should always be reviewed for conditions or restrictions before use. More information on label guidelines is provided in the Chemical Control Practices: Herbicide Registration, Label Precautions, and Use Restrictions section found in this handbook.

Table 11. Herbicides used for hydrilla management[1,2]

Herbicide Name	Example Trade Name	Formulation	Plant Response
Complexed Copper	Cutrine-plus Komeen Nautique	Liquid	Plant Cell Toxicant
Diquat	Reward	Liquid	Nonselective, contact
Endothall Dipotassium salt	Aquathol K Aquathol Super K	Liquid Granular	Rate and timing dependent selectivity, contact
Endothall Dimethylalkalamine salts	Hydrothol 191	Liquid or Granular	Nonselective, contact
Fluridone	Avast! Sonar A.S. Sonar PR Sonar Q Sonar SRP	Liquid emulsion Liquid emulsion Precision release pellets Quick release pellets Slow release pellets	Selective (based on application rate), systemic

[1] Only pesticides specifically labeled for aquatic sites and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under direct supervision of properly registered, certified, and trained personnel. All pesticide use should comply strictly with local, state, and federal regulations. Following label recommendations, obtaining certification to apply pesticides, and training in the appropriate pesticide application techniques are essential.

[2] Inclusion of pesticides on this list does not imply any endorsement by the AERF or any of the authors.

Mechanical & Physical Control

Mechanical control of hydrilla has short-term effectiveness, and can be used to control initial small to moderate infestations (see Tables 2 and 4). The disadvantage of some mechanical control options is the possible shredding of shoots with potential further spread of vegetative propagules. Physical control options provide medium- to longer-term control of this invasive aquatic weed (see Tables 3 and 4). Used in combination with cultural, chemical, and biological control options, mechanical control provides longer-term management of hydrilla. The more successful mechanical and physical control practices are given here.

Harvesting of hydrilla is effective for short-term clearance of vegetation from the upper portions of the water column. Due to rapid regrowth of the submerged vegetation, harvesting must be performed several times in a growing season to maintain usability of the water. When harvesting methods are used, hydrilla should be collected and disposed of in a manner that does not contaminate other water bodies. Select a good upland disposal site, with no possibility for the plant fragments to wash back into any water body.

Diver dredging can be effective against hydrilla by removing both the plant and root crown from the lake system. These systems are best utilized against pioneering infestations of hydrilla, as the tubers associated with established plants are more difficult to remove. Where pioneering colonies of the plant are discovered interspersed with native plants, this technology can selectively remove the hydrilla. With careful planning and implementation, diver dredging has minimal impact on surrounding native plants. This treatment has been successful against well-established communities, but the high cost of the operation for extensive infestations limits its application.

The use of drawdown for aquatic plant management is limited to those water bodies that have sufficient control structures and hydrologic characteristics to adequately control water level, and should not interfere with other primary water use such as domestic or irrigation supplies, navigation, or hydrologic power. Based on hydrilla's life-cycle, drawdown may be used successfully for management by timing to prevent tuber formation in the fall, and vegetative regrowth in the spring. Large-scale tests in Florida have demonstrated that hydrilla can be temporarily controlled with drawdowns, but tubers remained dormant and viable in organic hydrosoils.

Since bottom barriers have effectively been used to cover pioneering infestations of submerged, rooted aquatic weeds and prevent their spread, this technique has been suggested for hydrilla. Barriers have been used in a maintenance role, opening water around docks or swimming areas for use.

Biological Control

Several insects offer promise as biological suppressants for hydrilla, but as yet none has been shown to fit management programs consistently and effectively. *Bagous affinis* Hustache, a weevil discovered in Pakistan and India, is currently being evaluated in the United States. While not truly an aquatic insect, the adult lays its eggs on rotting wood and other organic matter. After hatching, the larvae burrow through sediment until they encounter hydrilla tubers, which they feed on while completing their life cycle. Another unnamed *Bagous* spp. has been released in the United States but has not become established. *Hydrellia pakistanae* Deonier, a leaf-mining fly, is also promising as a hydrilla biosuppressant. *H. pakistanae* is established in Florida, but its impact in hydrilla control is undetermined.

The native fungus *Mycoleptodiscus terrestris* is also being investigated as an inundative bioherbicide. The fungus infects the plant and destroys leaf and vascular tissue. Recent field trials with improved formulations of this bioherbicide appears promising in obtaining consistent infection and control.

The manatee, or sea cow, (*Trichechus manatus*) has been considered for control of hydrilla in the past, but is not presently considered for use because its numbers are too few, it is not well suited for moving from place to place, and it is an endangered species. Sterile triploid grass carp have also shown a preference for hydrilla as a food source, and this fish has been effective in managing hydrilla in controlled waterways. But, grass carp are a nonspecific herbivore, and although hydrilla is highly preferred, it is very important to use the appropriate stocking rate to control and minimize damage to native plant species. Although of all invasive aquatic weed species, hydrilla is most appropriate for control by grass carp, this species is rarely used in multi-use lakes where aquatic vegetation is desirable for sport fish and wildlife habitat. Some states require permits for grass carp use in small ponds, lakes, and streams, while others do not allow its use. Until methods to recapture the carp are developed, their practical effectiveness will be limited.

Cultural Control

As with all aquatic weeds, hydrilla is so difficult to control once it has become established that prevention of infestation and early detection are essential in stopping the plant from becoming a widespread problem in a lake, stream, or river. Human recreational activities usually account for the spread of non-native aquatic plants, especially hydrilla. Fragments of the aquatic plant cling to the propellers of boat motors or to boat trailers and, if not removed, can start new populations when the boat is launched into another water body. To stop the further spread of non-native aquatic species, it is imperative that **all** plant fragments are removed from boats before putting in or leaving a lake's access area. Once removed, plant material should be properly disposed of in a trash receptacle or on high, dry ground where there is no danger of it washing into any body of water.

Cultural prevention approaches remain the best way to avoid hydrilla infestations (see Table 7). Prevention programs include combinations of:

- Citizen lake watcher programs
- Volunteer compliance programs including boat cleaning and quarantines
- Professional survey programs
- Boat launch surveillance
- Assessment and Monitoring Programs
- Education and media approaches, including:
    - published web sites
    - workshops and lectures
    - development of full-fledged public outreach program via university extension service or Sea Grant programs.

Water Hyacinth (*Eichhornia crassipes* (Mart.) Solms)

Description

Water hyacinth is a free-floating monocot that grows up to three feet in height. The plant has very prominent black, stringy roots, and when it occasionally becomes stranded in mud, it may appear rooted. Its growth rate is among the highest of any plant known, and populations can double in as little as 12 days. By forming new plantlets, a population can completely dominate and obstruct a body of water in a short period of time. These weeds are notorious for clogging canals and waterways in the southern United States. Until only a few years ago this floating plant was a major problem in Florida, but a statewide maintenance program has brought it under control.

Water hyacinth is increasingly popular for water gardening and home ponds and is now sold by many nurseries for its unusual appearance, attractive flowers, and ability to remove nutrients from the water. Water hyacinth is thought to be cold sensitive and unable to survive temperatures below 20 degrees F. However, water hyacinth should never be deliberately introduced to lakes, rivers, streams or drainage ditches.

Habitat & Range

Water hyacinth grows in a wide variety of aquatic and wetland environments, including lakes, streams, ponds, waterways, ditches and backwater areas. The plants obtain nutrients directly from the water and prefer and grow most prolifically in nutrient-enriched waters. Water hyacinth has been used successfully in wastewater treatment facilities.

New plant populations often form from single, rooted parent plants, and wind and currents contribute to their wide distribution. Water hyacinth originated in tropical South America but has become naturalized in many warm areas of the world, including Central America, North America (California and southern states), Africa, India, Asia, and Australia. Water hyacinth is found in the southern U.S., Virginia to southern Florida, west to Missouri, Texas and California.

Figure 7. Water Hyacinth

Effects on Fish & Wildlife

As an extremely aggressive aquatic weed, water hyacinth may damage aquatic ecosystems by overgrowing and replacing native plants that provide food and habitat for wild animals and waterfowl. Mats of floating plants prevent oxygen from entering water bodies via the surface, and decaying vegetation consumes additional dissolved oxygen as it is sloughed into the water. The process depletes oxygen needed by fish and other aquatic organisms and can adversely affect fish habitat and result in fish kills. Water hyacinth growth also limits light to the lower water, affecting the growth and survival of phytoplankton and vascular plants. Extensive mats may prevent water circulation and mixing. In general, water hyacinth infestations reduce fisheries, shade out submersed plants, crowd out native aquatic plants, and reduce biological diversity in aquatic ecosystems.

Wildlife habitat can be extensively altered by the loss of open water under dense rafts of water hyacinth. Migrating birds may not recognize or stop at water bodies covered with water hyacinth, and the floating mats provide excellent habitat for disease-carrying mosquitoes. On the other hand, the fibrous root system of water hyacinth does provide good habitat for invertebrates and insects, and coots occasionally use leaf blades and petioles. However, the benefits this aquatic weed provides to wildlife are greatly overshadowed by its detrimental environmental impact.

Control Options

As a rapidly-spreading, pervasive, and detrimental aquatic weed with worldwide infestations, water hyacinth has become impossible to eradicate, and difficult to control. Chemical and mechanical methods have provided short- to medium-term control, and are both hindered by the plant's tall dense mats. Long-term control as achieved in Florida has been gained only by using a combination of chemical and mechanical techniques. Generally, these measures must be used annually to provide nuisance control. In Florida, even a single year of not controlling water hyacinth could result in millions of dollars in additional control costs needed to return to current maintenance levels.

As biological control is still in the stage of determining which native and naturalized insect species will provide long-term control, prevention of infestation remains the easiest management technique. Cultural control of nutrients in runoff from rural and urban watersheds can help reduce the suitability of freshwater areas to widespread invasion by water hyacinth, but research remains to be done to determine the threshold levels of infestation that should trigger various control options.

Chemical Control

The use of herbicides to control of water hyacinth is common. The chemicals currently used and labeled for water hyacinth include a range of herbicide activities. They are summarized in Table 12, along with information on various commercial formulations and the degree of control to be expected. The U.S. Army Corps of Engineers has reported excellent control of water hyacinth with the use of the aquatic herbicides 2,4-D, triclopyr, diquat, glyphosate, imazapyr, or a combination of diquat and complexed copper.

Many criteria and factors are used to select an appropriate herbicide for any specific treatment. Selection is based on such information as site-specific and environmental conditions at the time of application. Specific herbicide guidelines and information to consider are provided in the Chemical Control Practices section and Tables 5 and 6 of this handbook.

Because the labels from which this handbook was summarized can change, the most current herbicide label should always be reviewed for conditions or restrictions before use. More information on label guidelines is provided in the Chemical Control Practices: Herbicide Registration, Label Precautions, and Use Restrictions section found in this handbook.

Table 12. Herbicides used for water hyacinth management[1,2]

Herbicide Name	Example Trade Name	Formulation	Plant Response
Carfentrazone-ethyl	Stingray	Liquid	Contact, need good coverage. Best control on small plants
2,4-D Dimethylamine (DMA)	DMA 4 IVM Riverside Weedar 64	Liquid	Selective, systemic growth regulator
Diquat	Reward	Liquid	Nonselective, contact
Glyphosate	Rodeo	Liquid	Nonselective, systemic
Imazapyr	Habitat	Liquid	Nonselective, systemic
Triclopyr	Renovate 3	Liquid	Selective, systemic

[1] Only pesticides specifically labeled for aquatic sites and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under direct supervision of properly registered, certified, and trained personnel. All pesticide use should comply strictly with local, state, and federal regulations. Following label recommendations, obtaining certification to apply pesticides, and training in the appropriate pesticide application techniques are essential.

[2] Inclusion of pesticides on this list does not imply any endorsement by the AERF or any of the authors.

Mechanical & Physical Control

For water hyacinth, mechanical practices are a short-term method used to control initial small to moderate infestations (see Tables 2 and 4). The disadvantage of some mechanical control options is the potential to break apart mats and colonies, and to spread offshoots or daughter plants. Physical control options, such as drawdowns of the water column, provide medium to longer-term control of this invasive aquatic weed (see Tables 3 and 4). Mechanical control techniques such as harvesting have been used on their own for nearly 100 years in Florida. When used alone, these methods are ineffective for large scale control, very expensive, and unable to keep pace with the rapid plant growth in large water systems. When used in combination with cultural, chemical, and biological options, physical and mechanical control provides longer sustained control of water hyacinth. The following is a brief description of the more successful mechanical and physical control practices.

Harvesting of water hyacinth is effective for short-term clearance of the vegetation from the upper portions of the water column when used in conjunction with other control options, such as herbicides, to target small pockets of vegetation remaining after treatment. Due to rapid regrowth of the floating vegetation mats, harvesting must be performed several times in a growing season to maintain usability of the water. When harvesting methods are used, water hyacinth should be collected and disposed of in a manner that does not contaminate other water bodies, and this can be difficult because of the large biomass involved. Select a good upland disposal site, with no possibility for the plant fragments to wash back into any water body.

Mechanical cutting devices have been proposed for control of floating and emergent aquatic weeds, including water hyacinth. The cookie cutter technology, a barge/cutting system developed in Florida to deal with emergent aquatic vegetation and floating islands of vegetation and sediment, has some potential for control of clonal mats of water hyacinth, particularly where extensive growth needs to be reduced very rapidly. It can be used to open areas in heavily infested wetlands and shoreline to improve wildlife habitat and access. The cookie cutter's ability to penetrate thick growth, and remove both the plant material and the underlying sediments, allows the system to open channels into areas that would not otherwise be accessible to waterfowl and shore birds for feeding and nesting.

Drawdown of the water column has been suggested for control of water hyacinth, but is limited to lakes or ponds that have sufficient water control structures and hydrologic characteristics to manipulate water levels, and where a drawdown will not interfere with other primary water uses such as domestic or irrigation supplies, navigation, or hydrologic power.

Biological Control

Three naturalized insects have been released for the biological control of water hyacinth, two weevil species (*Neochetina* spp.) and a moth (*Niphograpta albiguttalis* Warren). Although large-scale reductions in water hyacinth populations did not occur following release, insect predation did reduce plant height, decrease number of seeds produced, and decrease seasonal growth of the plants. As one component of an integrated control program, these biocontrol agents are having a significant impact on water hyacinth populations.

The chevroned water hyacinth weevil (*Neochetina bruchi* Hustache) was introduced in Florida in 1974, and individuals were released in Alabama, California, Louisiana, and Texas in the following years. Currently, the chevroned water hyacinth weevil is distributed throughout most of the U.S. range of water hyacinth. The mottled water hyacinth weevil (*Neochetina eichhorniae* Warner) was first introduced in Florida in 1972 and was released in Alabama, California, Louisiana, and Texas in the following four years. Currently, the mottled water hyacinth weevil is well distributed throughout most of the U.S. range of water hyacinth.

Eggs of the weevils are deposited directly within the tissue of the water hyacinth plant. Adult female weevils chew a hole in the lamina or petiole of the leaf and deposit a single egg. Larvae are essentially "worm-like", bearing no legs or prolegs, and only small enlargements with setae (small hairs) where legs would normally be found. Adults and larvae of both weevil species feed exclusively on water hyacinth plant tissues. Damage to water hyacinth by adults may significantly impact the photosynthetic processes in the leaf if adult infestations are high.

Neochetina spp. have proven to be quite effective in reducing the flowering and potential growth of water hyacinth in the U.S. This is especially true in southern Florida, where large persistent populations of this species have become permanently established. *Neochetina* spp. appear to take at least 3 to 5 years for any persistent control to occur, and their impact on the plant is more subtle. For example, the growth of the plant is reduced to the extent that other less weedy species can effectively out-compete it, or that adverse environmental conditions, such as freezing temperatures can reduce the plant to more realistic levels.

Frequent and repeated treatment of water hyacinth with herbicide applications can adversely affect the ability of the two weevil species to impact the plant. Care should be taken when using chemical control to leave unsprayed areas (refugia) to allow the buildup of damaging population levels of these two agents.

Niphograpta albiguttalis (Warren), the water hyacinth moth, is a pyralid moth native to the Amazon Basin of South America, and was formerly known as *Sameodes albiguttalis*. The moth was released in Florida as a biocontrol agent of water hyacinth in 1977. While adult moths do not feed on water hyacinth, they are commonly found resting on the underside of water hyacinth leaves.

The water hyacinth moth is the only agent, other than the two water hyacinth weevils, that has the capacity to overcome the primary defensive strategy of water hyacinth. Water hyacinth moth caterpillars impact water hyacinth by boring into the bases of leaf petioles and thereby damaging the developing leaves or meristematic tissues (leaf buds). Feeding by caterpillars can cause the entire petiole to break and die and in some instances can tremendously damage water hyacinth in the field. This is especially true for those plants growing in more open water. In most cases, damage from the feeding action of this moth is most likely to be sporadic and by itself non-threatening to the water hyacinth population. Nevertheless, taken together with the combined feeding action of the two species of water hyacinth weevils, *Niphograpta* spp. damage can be quite effective.

Cultural Control

Because water hyacinth is extremely difficult to control once it has become established, prevention of infestation and early detection of this very aggressive aquatic weed is essential in stopping the plant from becoming a widespread problem in a lake, stream, or river. Human recreation activities account for much of the spread of this non-native aquatic plant. Small daughter plants, or fragments of clonal mats cling to the propellers of boat motors, or to boat trailers, and if not removed, can start new populations when the boat is launched into another water body. To stop the further spread of this invasive aquatic species, it is imperative that **all** plant fragments are removed from boats before putting in or leaving a lake's access area. This plant material should be properly disposed of in a trash receptacle or on high, dry ground where there is no danger of it washing into any water body.

Once the water hyacinth has been introduced into a lake, there is currently no combination of control practices that will completely eradicate it. Therefore, cultural prevention approaches remain the best way to avoid water hyacinth infestations (see Table 7). Prevention programs include:

- Citizen lake watcher programs
- Volunteer compliance programs including boat cleaning and quarantines

- Professional survey programs
- Boat launch surveillance
- Assessment and Monitoring Programs
- Education and media approaches, including:
    - published web sites
    - workshops and lectures
    - development of full-fledged public outreach program via university extension service or Sea Grant programs.

Since water hyacinth infestations are enhanced by nutrient rich water, careful attention to cleaning up polluted lakes and streams must be considered. Cultural control of nutrients in runoff from rural and urban watersheds can help reduce the suitability of freshwater for infestation by water hyacinth. Shoreland protection projects, use of agricultural BMPs, use of stormwater and erosion control practices, establishment of vegetative buffer zones, and zoning restrictions on use of fertilizer or manure applications within shoreland areas are all necessary components of water quality protection.

Purple Loosestrife (*Lythrum salicaria* L.)

Description Purple loosestrife is an erect, emergent perennial herb. This non-native but naturalized dicot has a square, woody stem and opposite or whorled leaves that are lance-shaped, stalkless, and heart-shaped or rounded at the base (Figure 8). Depending on conditions, purple loosestrife grows from four to ten feet high. It produces a showy display of magenta-colored flower spikes throughout much of the summer, which makes it appealing as a cultivated plant.

Purple loosestrife enjoys an extended flowering season, generally from June to September, which allows it to produce vast quantities of seed. The flowers require pollination by insects, for which it supplies an abundant source of nectar. A mature plant may have as many as thirty flowering stems capable of producing an estimated two to three million minute seeds per year. Purple loosestrife also readily reproduces vegetatively through underground stems at a rate of about one foot per year. Many new stems may emerge from a single rootstock of the previous year. Unfortunately, so-called "guaranteed sterile" horticultural cultivars can be highly fertile and are able to cross freely with purple loosestrife and other native *Lythrum* species. Therefore, outside of its native range, planting purple loosestrife of any form should be avoided.

Habitat & Range Purple loosestrife is a beautiful, but very aggressive invader of many types of wetland, including freshwater wet meadows, tidal and non-tidal marshes, river and stream banks, pond edges, reservoirs, and ditches. Purple loosestrife also adapts readily to natural and disturbed wetlands. As it becomes established and expands, it out-competes native grasses, sedges, and other flowering plants, producing dense stands that approach monocultures. It is estimated that 200,000 acres of wetlands in the U.S. are lost annually through invasions of this species. Purple loosestrife was introduced to the northeastern U.S. and Canada in the 1800's for ornamental and medicinal uses. Due to its attractive flowers, it has been planted as an ornamental garden species, and has escaped from cultivation throughout the United States and Canada. It is still widely sold as an ornamental, except in states such as Minnesota, Wisconsin, and Illinois, where regulations now prohibit its sale, purchase, and distribution. According to the U.S. Fish and Wildlife Service, purple loosestrife occurs in every state except Florida, and is found in all

Figure 8. Purple Loosestrife

Canadian provinces.

Effects on Fish & Wildlife

Because purple loosestrife is a very aggressive emergent aquatic/wetland weed, once it enters a wetland, it can completely dominate the ecosystem, eventually choking out or suppressing the original habitat, and altering the structure and function of the hydrology. This also will occur in shallow aquatic systems and moist uplands.

This plant contributes almost no sources of food to the wildlife community, while crowding out much more beneficial species. For example, wild rice areas in shallow lakes and bays can be eliminated by invasions of purple loosestrife.

Control Options

Considerable effort has been expended to develop control techniques for purple loosestrife. Except in cases of low density and small invasions, integrated best management practices will control, but not eliminate, stands of purple loosestrife. In several states control programs have shown that early detection and prevention of invasion of wetlands and shallow aquatic systems is the best method of avoiding the development of uncontrolled monocultures of purple loosestrife.

Chemical and mechanical methods provide short- to medium-term control of low to medium density infestations of purple loosestrife. At higher densities these methods are expensive. Chemical and mechanical control must be used at least annually, and are not highly successful.

Research and evaluation on long-term biological control of purple loosestrife is continuing in North America, and several biological control agents are available for use. Five insect species from Europe have been approved by the U.S. Department of Agriculture for use as biological control agents. Two flower-feeding beetles (*Nanophyes*) that feed on various parts of purple loosestrife plants are still under investigation.

Chemical Control

At low to medium density, for isolated to medium acreage, herbicide control can be effective when used in combination with mechanical and cultural control options. The USACE has reported relatively good control of purple loosestrife using the herbicides 2,4-D, glyphosate, triclopyr, and imazapyr. For older plants, spot treating with glyphosate-type herbicide has been recommended. This herbicide requires use of a nonionic surfactant to ensure foliage penetration, since uptake is through the leaves. Glyphosate may be most effective when applied late in the season when plants are preparing for dormancy. It may be best to do a mid-summer and a late season treatment, to reduce the amount of seed produced.

Herbicides currently used and labeled for the management of purple loosestrife, as well as information on various commercial formulations and the degree of control to be expected, are shown in Table 13. Many criteria and factors are used to select an appropriate herbicide. Selection is based on such information as site-specific and environmental conditions at the time of application. Specific herbicide guidelines and information to consider are provided in the Chemical Control Practices section and Tables 5 and 6 of this handbook.

Because the labels from which this handbook was summarized can change, the most current herbicide label should always be reviewed for conditions or restrictions before use. More information on label guidelines is provided in the Chemical Control Practices: Herbicide Registration, Label Precautions, and Use Restrictions section found in this handbook.

Table 13. Herbicides used for purple loosestrife management[1,2]

Herbicide Name	Example Trade Name	Formulation	Plant Response
2,4-D Dimethylamine (DMA)	DMA 4 IVM Weedar 64	Liquid	Selective, systemic growth regulator
Glyphosate	Rodeo	Liquid	Nonselective, systemic
Imazapyr	Habitat	Liquid	Nonselective, systemic
Triclopyr	Renovate 3	Liquid	Selective, systemic

[1] Only pesticides specifically labeled for aquatic sites and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under direct supervision of properly registered, certified, and trained personnel. All pesticide use should comply strictly with local, state, and federal regulations. Following label recommendations, obtaining certification to apply pesticides, and training in the appropriate pesticide application techniques are essential.

[2] Inclusion of pesticides on this list does not imply any endorsement by the AERF or any of the authors.

Mechanical & Physical Control

Mechanical control of purple loosestrife is a short-term method used to control low- to medium-density infestations. It is usually most effective when used in combination with chemical and biological control, especially when medium to large areas are infected. Cutting, hand pulling, harvesting, and rotovating are suggested mechanical control options (Table 4). Fire and flooding have been suggested as physical control options but information on the efficacy of these methods is very limited.

Pulling purple loosestrife by hand is easiest when plants are young (up to two years) or when growing in sand, and should preferably be done before seed set. Older plants have larger roots that can be eased out with a garden fork. As much of the root system as possible must be removed, because broken roots may sprout new plants. This technique is most suited to small infestations of young plants. Cutting flowering spikes on all ages of plants will prevent seeds from producing more plants in future years. Dry seed heads should be removed, as they may still contain seeds. Cutting, harvesting, or rotovating stems at the ground level will inhibit growth.

The response of various growth stages of purple loosestrife to water levels is not well known. As purple loosestrife is very adaptable to upland conditions, drawdown of water levels is not an option. Raising water levels may provide some control. It has been reported that submerged purple loosestrife can survive for many years. The density of loosestrife can be curtailed by the combined effects of competition with cattails, damage by biological control agents, and damage by submergence. Manipulating wetland edge soils is another habitat enhancement technique attempted in southeastern Missouri. Moist soil management involves scarifying (e.g., disking) the topsoil to encourage the establishment of the seedlings or propagules of desirable food or cover plants. The planted site is then flooded for part or all of the growing season, and later exposed with a gradual drawdown.

Biological Control

Biological suppression may be the only effective long-term control option for extensive dense stands of purple loosestrife. Basic and applied research is being conducted throughout North America on native and naturalized insects that actively attack purple loosestrife. Five insect species from Europe have been approved by the U.S. Department of Agriculture for use as biological control agents. These plant-eating insects include a root-mining weevil (*Hylobius transversovittatus* Goeze), and two leaf-feeding beetles (*Galerucella calmariensis* L. and *Galerucella pusilla* Duft), which are now established in North America. Two flower-feeding beetles (*Nanophyes* spp.) that feed on various parts of purple loosestrife plants are still under investigation. One species has been released and is established. *Galerucella* spp. and *Hylobius* spp. have been released experimentally in natural areas in 16 northern states, from Oregon to New York. Although these beetles have been observed occasionally feeding on native plant species, their potential impact to non-target species is considered to be low.

Hylobius transversovittatus is a root-boring weevil. Adult weevils feed on foliage and stem tissue. The larvae feed on root tissue for one to two years, depending on environmental conditions. Pupation occurs in the upper part of the root, and adults emerge between June and October. Adults can live for several years. The weevil occurs in all purple loosestrife habitats, except for permanently flooded sites. Adults and larvae can survive extended submergence, depending on temperature, but excessive flooding prevents access to plants by adults, and eventually kills developing larvae. Otherwise, the species appears quite tolerant to a wide range of environmental conditions. While adult feeding has little control effect, feeding by larvae can be very destructive to the purple loosestrife root stock. Currently this biological control organism is being mass-produced by Bernd Blossey at Cornell University.

Galerucella calmariensis and *Galerucella pusilla* are leaf-eating beetles that seriously affect growth and seed production by feeding on the leaves and new shoot growth of purple loosestrife. Both beetles look alike, and share similar life history characteristics. Adults overwinter in leaf litter, and emerge in the spring soon after shoot growth of purple loosestrife. Adults feed on shoot tips, while young larvae feed on developing leaf buds, and older larvae predate all above-ground plant parts. Both species occur throughout the native range of purple loosestrife in Europe and Asia, and have been released in over 27 states and six Canadian provinces. *G. calmariensis* is more commonly found since the species was easier to mass produce that *G. pusilla.* Adults are very mobile and possess good host finding abilities. Peak dispersal of overwintered beetles is during the first few weeks of spring. New generation beetles have dispersal flights shortly after emergence, and can locate host patches as far as 1 km away within a few days. Successful mass rearing methods have been developed by Bernd Blossey at Cornell University (see Reference section on Purple Loosestrife).

Nanophyes marmoratus Goeze is a flower-eating beetle that severely reduces seed production of purple loosestrife. A similar flower-eating beetle (*Nanophyes brevis* Boh.) also is being considered as a potential biological control agent for purple loosestrife, but has not been released. *N. marmoratus* is widespread in Eurasia, and tolerates a wide range of environmental conditions. The species has been introduced into seven states. The larvae consume the flower, and mature larvae form a pupation chamber at the bottom of the bud. Attacked buds do not flower, and are later aborted, thus reducing the seed output of purple loosestrife. The new generation beetles appear mainly in August, and feed on the remaining green leaves of purple loosestrife. Adults overwinter in the leaf litter. Development from egg to adult takes about 1 month, and there is one generation per year.

Rearing and release programs have been developed for all four species, and are highly developed for the leaf beetles. These programs, which provide detailed instructions and assistance, are available in many states, often through Extension programs (e.g., Loos and Ragsdale 1998). Rearing and release programs involve obtaining adult insects on loosestrife planted in children's wading pools, and releasing to approved sites about 2 to 3 months later. Consult the Reference Section or your local extension agent for more information.

Cultural Control

Because purple loosestrife is extremely difficult to control once it has become established, early detection and prevention of infestation of this very aggressive wetland weed is essential in stopping the plant from becoming a widespread problem. Human activities, vegetative propagation, and natural seed dispersal account for much of the spread of this non-native wetland/aquatic plant. Equipment, clothing, and recreational vehicles and boats all need to be cleaned of purple loosestrife seeds prior to moving to a new location. When this plant is removed from a site, it should be placed in plastic bags and taken to a sanitary landfill. Composting is not advised as this process may not kill all of the loosestrife seeds. To stop the further spread of this invasive plant, it is imperative that seeds, and any root stock pieces, are removed from clothes, equipment, and boats before putting in or leaving a lake's access area.

Purple loosestrife is still available in some states as a garden plant. Education programs should inform the public of the danger of this plant, since contamination of wetlands from home gardens does happen. Be sure that citizens know to check the labels of all wildflower seed mixes for the absence of purple loosestrife. Wildflower mixes containing purple loosestrife should be avoided. Several states and provinces have noxious weed laws preventing the sale of purple loosestrife to the public. All horticultural cultivars of purple loosestrife should also be avoided.

Once purple loosestrife has been introduced into a wetland or shallow lake, there is currently no combination of control practices that will completely eradicate it. Therefore, cultural prevention approaches remain the best way to avoid water purple loosestrife infestations (see Table 7). Prevention programs include:

- Citizen lake watch programs
- Volunteer compliance programs including boat cleaning and quarantines
- Professional survey programs
- Boat launch surveillance
- Assessment and Monitoring Programs

- Education and media approaches, including:
  - published web sites
  - workshops and lectures
  - development of full-fledged public outreach program via university extension service or Sea Grant programs.

<u>Brazilian Elodea (*Egeria densa* Planch.)</u>

Description

Brazilian elodea is a submersed, freshwater perennial herb (Figure 9). This monocot can be drifting or rooted to bottom sediments in depths of up to 20 feet. Brazilian elodea's leaves are 1 to 3 cm long, up to 4 mm broad, and are in whorls of four to eight. Brazilian elodea is a popular aquarium plant and can be found for sale in most pet shops, usually under the name *Anacharis*. It is easily confused with the native plant *Elodea canadensis* Michx. Accidental or deliberate introduction into lakes and ponds can cause infestation. Brazilian elodea forms dense monospecific stands that restrict water movement, trap sediment, and cause fluctuations in water quality. Dense beds interfere with recreational uses of lakes and rivers by interfering with navigation, fishing, swimming, and water skiing.

Habitat & Range

This weed is found in both still and flowing waters, in lakes, ponds, pools, ditches, and quiet streams. It tends to form dense stands that can cover hundreds of acres and persist until senescence in the fall. Two major growth flushes occur, in the spring and fall. Each is followed by periods of senescence, with a loss of biomass through sloughing and decay of tips and branches. Brazilian elodea is native to the central Minas Geraes region of Brazil and to the coastal areas of Argentina and Uruguay. Due to its popularity as an aquarium plant, Brazilian elodea has also spread to New Zealand, Australia, Hawaii, Denmark, Germany, France, Japan, and Chile. In the United States, this plant has aggressively invaded fresh inland waters from Washington to Massachusetts, California, and Florida.

Figure 9. Brazilian Elodea

Effects on Fish & Wildlife

Problems associated with this elodea species arise from its rapid growth rate, coverage of water surfaces, and the reduction of light under its dense canopies. It also forms thick underwater stands of entangling stems. These characteristics enable it to displace native vegetation and interfere with normal development of fish and wildlife habitat. Formation of a dense canopy and light reduction are significant in the decline of native plant abundance and diversity, and such changes in habitat quality quickly affect fish, wildlife, and other aquatic organisms.

Brazilian elodea's dense stands provide habitat for mosquitoes and may increase population numbers of some mosquito species.

Brazilian elodea competes aggressively to displace and reduce the diversity of native aquatic plants, and fish and wildlife habitat. Over time, Brazilian elodea will out-compete or eliminate more beneficial native aquatic plants, severely reducing natural plant diversity within a lake.

Since its growth is typically dense, Brazilian elodea weed beds are poor spawning areas for fish, and may lead to populations of small fish. Fish populations may initially experience a favorable edge-effect increase in abundance during early establishment of this invasive weed. The abundant and aggressive growth of Brazilian elodea will counteract any short-term benefits it may provide fish in healthy waters. At high densities, its foliage supports a lower abundance and diversity of invertebrates that serve as fish food. While the dense cover does allow high survival rates of young fish, larger predator fish lose foraging space, and are less efficient at obtaining their prey. The growth and senescence of thick vegetation also reduces water quality and levels of dissolved oxygen.

Brazilian elodea has lower value as a food source for waterfowl compared to the native plants it displaces.

Control Options

As a potentially detrimental invasive aquatic weed, regional effort has been expended to develop control techniques for Brazilian elodea. Chemical and mechanical techniques provide short- to medium-term control of this aquatic weed. Research on long-term biological suppression of Brazilian elodea is continuing in North America and throughout the world. Recent research in Brazil has identified a fungus pathogen as a potential biocontrol agent, and it is being actively evaluated. At this time, the only available biological agent is sterile triploid grass carp. Additional research on Brazilian elodea levels in lakes, streams and rivers in relation to other aquatic vegetation and fish and wildlife habitat is needed to establish the threshold levels of infestation that should trigger various combinations of control options.

Chemical Control

Excellent control of Brazilian elodea has been reported with diquat and complexed copper. Control with fluridone has ranged from good to excellent, depending on use conditions. California reports good control using complexed copper alone. While fluridone and copper are permitted for aquatic use in Washington waters, copper is generally permitted only as an algicide.

Herbicides currently used and labeled for the management of Brazilian elodea, as well as information on various commercial formulations and the degree of control to be expected, are shown in Table 14. Many criteria and conditions need to be considered when selecting herbicides appropriate for a specific site and environment. Specific herbicide guidelines and information to consider are provided in the Chemical Control Practices section and Tables 5 and 6 of this handbook.

Because the labels from which this handbook was summarized can change, the most current herbicide label should always be reviewed for conditions or restrictions before use. More information on label guidelines is provided in the Chemical Control Practices: Herbicide Registration, Label Precautions, and Use

Restrictions section found in this handbook.

Table 14. Herbicides used for Brazilian elodea management[1,2]

Herbicide Name	Example Trade Name	Formulation	Plant Response
Diquat	Reward Weedtrine-D	Liquid	Nonselective, contact
Fluridone	Avast! Sonar A.S. Sonar PR Sonar Q Sonar SRP	Liquid emulsion Liquid emulsion Precision release pellets Quick release pellets Slow release pellets	Selective (based on application rate), systemic

[1] Only pesticides specifically labeled for aquatic sites and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under direct supervision of properly registered, certified, and trained personnel. All pesticide use should comply strictly with local, state, and federal regulations. Following label recommendations, obtaining certification to apply pesticides, and training in the appropriate pesticide application techniques are essential.

[2] Inclusion of pesticides on this list does not imply any endorsement by the AERF or any of the authors.

Mechanical & Physical Control

Because this plant may spread through fragmentation of the surface mat, mechanical controls such as cutting, harvesting, and rotovation should be used only when the infestation has already colonized and filled all available environmental niches. Using mechanical controls while the plant is still actively invading will tend to enhance its dispersal and spread. Mechanical control of Brazilian elodea is a short-term method used for initial control of small to moderate infestations (see Tables 2 and 4). Physical control options provide medium to longer-term control of this invasive aquatic weed (see Tables 3 and 4). When used in combination with cultural, chemical, and biological control options, physical and mechanical control provides longer and sustained control of Brazilian elodea. A brief description of the more successful mechanical and physical control practices follows.

Hand cutting tools have been used to control all submersed aquatic weeds, including Brazilian elodea. Harvesting is a very effective option for short-term clearance of the vegetation from the upper portions of the water column, but it must be performed several times in a growing season to maintain usability of the water. When harvesting methods are used, Brazilian elodea should be collected and disposed of in a manner that does not contaminate other water bodies. Select a good upland disposal site, with no possibility for the plant fragments to wash back into any water body.

Rotovation of Brazilian elodea may be an effective technique when used properly. It targets the roots by tilling the sediment and releasing the root crown. The problem is that Brazilian elodea reproduces primarily by fragmentation, with new shoots emerging from double leaf nodes which occur at regular intervals along the stem. When a shoot fragment that contains a double node sinks, it has great potential to form a new plant, and thus fragmentation needs to be controlled.

Diver dredging has been used against Brazilian elodea, and these techniques are best utilized against pioneering infestations. Where early colonies of the plant are discovered interspersed with native plants this technology can selectively remove the Brazilian elodea, and with careful planning and implementation diver dredging has minimal impact on the native plants. The high cost of the operation for extensive infestations limits the application of this technology.

Localized control (in swimming areas and around docks) can be achieved by covering the sediment with an opaque fabric that blocks light from the plants. Where managers of reservoirs or lake systems have the ability to lower the water level, drawdowns may be considered as a method of managing Brazilian elodea. Consecutive drawdowns may be more effective than a single instance, and in general their success is dependent on factors such as degree of desiccation, the composition of substrate (sand vs. clay), air temperature (the exposed sediments need to freeze down to 8-12 inches), and presence of snow.

Biological Control

Currently, no insects or pathogens with field biocontrol potential for Brazilian elodea are known. Recent research in Brazil has identified a fungus (*Fusarium* spp.) which damaged Brazilian elodea in laboratory tests. This may have potential as a biocontrol against it.

Sterile triploid grass carp (older than fingerlings) find Brazilian elodea highly palatable, and have been successfully employed as a management tool. Since Brazilian elodea is highly preferred over most native species, it should theoretically be possible to remove Brazilian elodea while favoring the growth of native species. In practice, grass carp often remove the entire submersed aquatic community, and should be used with great care. It is important to use the appropriate stocking rate to obtain control and minimize damage to native species. Grass carp are not suitable for use in bodies of water where inlets and outlets cannot be screened. Some states require permits for their use in small ponds, lakes, and streams. Other states do not allow the use of this herbivorous fish. Grass carp are rarely used in multi-use lakes where aquatic vegetation is desirable for sport fish and wildlife habitat. Until methods to recapture the white carp are developed, its practical effectiveness will be limited.

Cultural Control

Because Brazilian elodea is so difficult to control once it has become established, prevention of infestation and early detection of growth is essential in stopping the plant from becoming a widespread problem in a lake, stream, or river. Human recreational activities usually account for the spread of non-native aquatic plants. Fragments of the aquatic plant cling to the propellers of boat motors, or to boat trailers and, if not removed, can start new populations when the boat is launched into another body of water. To stop the further spread of this non-native aquatic, it is imperative that **all** plant fragments are removed from boats before putting in or leaving a lake's access area. Plant material collected should be properly disposed of in a trash receptacle or on high, dry ground where there is no danger of it washing into any body of water. Unfortunately, once Brazilian elodea has been introduced into a lake, there is currently no combination of control practices that will completely eradicate it. Therefore, cultural prevention approaches remain the best way to avoid Brazilian elodea infestations (see Table 7). Prevention programs include:

- Citizen lake watcher programs
- Volunteer compliance programs including boat cleaning and quarantines
- Professional survey programs
- Boat launch surveillance
- Assessment and Monitoring Programs
- Education and media approaches, including:
    - published web sites
    - workshops and lectures
    - development of full-fledged public outreach program via university extension service or Sea Grant programs.

Algae

Description It is important to understand differences among the three major groups of algae when considering solutions to algae problems. Based on growth form, the three groups are the microscopic algae (primarily phyto-planktonic), the filamentous mat-forming algae, and the *Chara/Nitella* group. Many of the problems the public associates with algae occur in more or less still bodies of water such as ponds, lakes, and reservoirs with long residence times.

Excessive growths of microscopic algae, called blooms, cause green, yellow-green, brown, and sometimes red colors to the water. These algae can only be identified only with a microscope because they consist of single cells, colonies of cells, or very small filaments. The most common problem-causing group is the blue-green algae (cyanobacteria) that form pea-soup green water and surface scums. These are the organisms responsible for the “death” of Lake Erie in the 1960’s and 70’s. These organisms still cause frequent problems in many lakes and reservoirs around the country.

The mat-forming algae typically start growing on, or attached to, the bottom sediments. As they photosynthesize and produce oxygen, the oxygen bubbles become trapped in the mats and cause the mats to float to the surface. Serious problems occur when these organisms completely choke the water body from top to bottom. Free-floating mats are generally restricted to static waters such as ponds and the sheltered littoral zones of lakes and reservoirs. Attached forms are found in both static and flowing systems, including the wave-scoured edges of lakes, fast-flowing streams, and the extensive irrigation systems of the western United States. The mats formed by green algae are typically green or yellow-green in color, while the color of mat-forming blue-green algae is often dark green to black.

Chara and *Nitella* are more complex in their growth form than the microscopic and mat-forming algae. They produce root-, stem-, and leaf-like structures that are anchored in sediments. They are easily confused with submersed aquatic flowering plants. Although *Charra* and *Nittella* seldom pose serious problems, they need to be identified as algae if the situation warrants treatment. Since they are an important component of the native submersed vegetation and provide valuable habitat, they should only be controlled if their growth is preventing use of shallow water areas.

Habitat & Range

Algae are found in all fresh and marine waters, and some species are also found growing on wet, poorly drained soils. Some grow in extremely inhospitable environments such as the boiling water of hot springs and the frigid waters of the Antarctic. Some species are considered to be invasive. For example, *Cylindrospermopsis*, a microscopic blue-green algae that is toxic, appeared in Florida lakes in the early 1990's, and has now spread to other parts of the country.

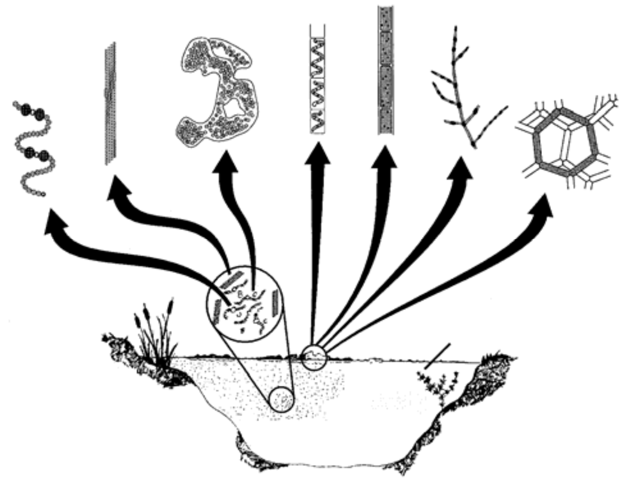

Figure 10. Algae

Effects on Fish & Wildlife

Algae have many important and beneficial roles in freshwater environments. They produce oxygen and consume carbon dioxide, act as the base of the aquatic food chain, remove nutrients and pollutants from water, and stabilize sediments. Excessive algal growths may cause detrimental effects on aquatic systems, endangering the organisms that live and depend on these systems. They may also hamper or prevent human uses of infested waterways. Population crashes (death) and the microbial decomposition of the dead algal cells result in depletion of oxygen dissolved in water. Oxygen-depleted conditions can cause fish kills in all sizes of water bodies. A shift in microscopic algae populations from green algae and diatoms to blue-green algae, which are not readily consumed by zooplankton, can alter food chain dynamics, and seriously impair the quality and quantity of the organisms at the higher trophic levels. Some forms of microscopic blue-green algae are toxic. At toxic levels they can injure or kill wildlife that drink infested waters. Blue-green algae also can taint fish flesh with foul tastes, and make water so foul-tasting that it is unpalatable to humans.

Excessive growths of mat-forming algae can impair fishing and the harvest of fish in aquaculture facilities. Their impact on fish and wildlife is less well known that that of the microscopic bloom-formers, but their presence reduces the diversity of habitats that aquatic organisms can occupy, and their death and decomposition can also lead to oxygen depletion. The term eutrophication was initially applied to describe the consequences of excessive algal growth in lakes, and it is still a major problem that has to be confronted all across the U.S.

Control Options

Management practices for nuisance algae are divided into two major categories: nutrient manipulation, and direct control techniques. Nutrient manipulation, particularly reduction of nutrient inputs, should be viewed as the best approach for long term control of algae problems. There are situations

where significant nutrient reduction is impractical or ineffective. Under these conditions, direct control of the algal biomass may be the only alternative available. Direct control methods should only be viewed as temporary solutions, and should be coupled with longer-term strategies for reducing nutrient inputs.

Chemical Control

Chemical formulations, and the degree of control to be expected, are shown in Table 15. Chemical control of algae is accomplished with copper and endothall dimethylalklamine salt. Algicides currently used and labeled for the management in aquatic systems, as well as information on various commercial criteria and treatment-specific factors, are used to select an appropriate algicide. Selection is based on such information as site-specific and environmental conditions at the time of application. Specific herbicide guidelines and information to consider are provided in the Chemical Control Practices section and Tables 5 and 6 of this handbook.

Because the labels from which this handbook was summarized can change, the most current herbicide label should always be reviewed for conditions or restrictions before use. More information on label guidelines is provided in the Herbicide Registration, Label Precautions, and Use Restrictions section found in this handbook.

Table 15. Algicides used for algae management[1,2]

Herbicide Name	Example Trade Name	Formulation	Plant Response
Complexed copper	Captain Clearigate Cutrine-Plus K-Tea	Liquid Liquid Liquid or Granular Liquid	Plant Cell Toxicant
Copper	Triangle Copper sulfate crystal	Granular	Plant Cell Toxicant
Endothall Dimethylalklamine salts	Hydrothol 191	Liquid or Granular	Nonselective, contact
Growth Retardant Dye	Aquashade	Liquid	Inhibits photosynthesis

[1] Only pesticides specifically labeled for aquatic sites and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under direct supervision of properly registered, certified, and trained personnel. All pesticide use should comply strictly with local, state, and federal regulations. Following label recommendations, obtaining certification to apply pesticides, and training in the appropriate pesticide application techniques are essential.

[2] Inclusion of pesticides on this list does not imply any endorsement by the AERF or any of the authors.

Mechanical & Physical Control

Mechanical harvesting can sometimes be useful with mat-forming algae. Because most of these algae are free-floating, it is difficult to collect them effectively, and prevent mats from drifting to other parts of the site. Although hand-raking is a temporary solution, it is often done around boat docks, swimming areas, and fishing holes.

Physical control methods mostly involve in-water reductions of nutrients, particularly phosphorus, which is a major stimulant to algal growth. These methods include alum treatment, dredging, and, to some extent, aeration.

The addition of alum (aluminum sulfate, $Al_2[SO_4]_3$) to a body of water causes phosphorus to precipitate on the bottom sediments where it becomes unavailable for algal growth. The presence of alum on the sediments also prevents the internal cycling of phosphorus from the sediments back into the water. The addition of sodium aluminate ($AlNaO_2$), or other good buffering material, to an alum treatment is recommended. Addition of buffering material prevents severe shifts in pH, which can be detrimental to fish populations. Some alum treatments have been effective in reducing algal populations in lakes for as long as 10 to 15 years. Uneven distribution or redistribution by wind or currents after application reduces the effectiveness of alum. Also, the effect will not be long-lived if external inputs of water are still phosphorus-laden.

Dredging and removing the bottom sediments and vegetation also are useful in preventing internal nutrient cycling. Dredging can be expensive compared to other methods, but it can be extremely useful on older sites that have built up an extensive layer of nutrient-laden muck and decomposing vegetation.

The major function of mechanical aerators is to improve fish habitat by oxygenating the total water column and upper portions of the sediment. One of the effects of oxygenation is prevention of the release of reduced forms of phosphorus from the bottom sediments back into the water. The reduction in phosphorus and changes in other water quality parameters have been thought to decrease microscopic algal blooms. The phosphorus reduction is possibly related to shifts from noxious bluegreen algae to more desirable green algae. Although the exact outcome from aeration is difficult to predict, it is always a good option from the standpoint of fish management.

Another approach to physical control is the use of water-soluble dyes. Mostly blue in color, they intercept sunlight that is required for plants to photosynthesize and grow. Although mostly used for submersed flowering plant control, they can inhibit mat-forming algal growth in waters that are deeper than about 2 to 3 feet. Algae that are growing along the edge are seldom affected and may spread over the water surface. The combination of a chemical treatment to reduce algal growth or sink it to the bottom with a follow-up treatment of a dye may lessen the amount of mat-forming algae that will rise back to the surface.

Biological Control

Grass carp, particularly when young, may feed on mat-forming algae. However, sterile triploid grass carp are not generally considered to be effective biocontrol agents for algae. Tilapia is used in some southern states for algae control. Although research is ongoing, few organisms are currently being used specifically for algae control. Biomanipulation to promote abundant populations of large-bodied zooplankton (e.g., *Daphnia*) has been used in a number of lakes. Biomanipulation can be accomplished by reducing abundance of zooplanktivorous fish such as bass, walleye, and northern pike. Reductions of large piscivores should be avoided as not to promote an abundance of zooplanktivores and reduced zooplankton and thus increased algal populations.

Cultural Control

It has long been known that inputs of nutrients, particularly phosphorus (P), stimulate algal growth. Many studies have shown a strong correlation between total phosphorus (TP) and microscopic (phytoplanktonic) algal biomass. But, some lakes are nitrogen (N) limited, particularly in the western part of the U.S., and both nitrogen and phosphorus limitation have been implicated in the regulation of mat-forming algal growth.

Although both nitrogen and phosphorus are required to support algal growth, most reduction efforts concentrate on phosphorus because it is easier to reduce from a technical standpoint than is nitrogen. Clearly where nitrogen fixation by planktonic blue-green algae is a response to nitrogen reduction, phosphorus should be the more reliable means to lower algal biomass. There are three general approaches to achieving phosphorus reduction: (1) decrease external phosphorus loading, (2) suppress internal phosphorus loading, and (3) increase phosphorus output from the system.

Decreasing external inputs of phosphorus can be achieved with diversion and advanced wastewater treatment, retention basins and wetlands, and by the initiation of other watershed management techniques. Many local and some state ordinances now mandate the construction of retention ponds in new housing developments, industrial parks, and similar sites. These ponds serve as settling basins for storm water, sediments, nutrients, and pollutants, which are related in part to algal blooms and mat formation. The suppression of internal phosphorus loading can be achieved with alum applications, dredging, and aeration (see section on Mechanical and Physical Control). These approaches are best used after external loading is reduced or controlled. The approach of releasing phosphorus-laden waters from the site, which can be achieved with hypolimnetic withdrawal, is seldom used because of its expense.

The emphasis on a broad watershed management program to reduce both point and nonpoint sources of fertilizers and other pollutants is gaining increased recognition at local, state, and federal levels. In agricultural areas, the promotion of best management practices (BMPs) has resulted in widespread acceptance of practices that reduce erosion of nutrient-laden soils. Such practices include no-till and conservation tillage, vegetated buffer strips and grass waterways, lowering fertilizer application rates, and proper handling of animal manures.

References, Additional Readings, and Other Sources of Information

These references served as the source material for this handbook. The list is intended to provide additional reading and information resources for water, fisheries, and resource managers; it does not attempt to be an exhaustive literature database.

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