Best Management Practices Handbook for Aquatic Plant Management in Support of Fish and Wildlife Habitat

Prepared by

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Introduction

Freshwater Aquatic Plants and Invasive Aquatic Weeds

Plants are an important part of healthy, diverse aquatic ecosystems. Aquatic plants have a major role in maintaining the integrity of lakes, ponds, streams, and rivers for fish, wildlife, other organisms, and human enjoyment (Figure 1; Figure 2). 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
- Production of oxygen
- Protection of stream and river banks, lake and reservoir beds and shorelines
- Stabilization of temperature, light, and functioning of a diverse aquatic ecosystem
- Recycle nutrients and reduce sediment transport

The natural balance of vegetation and aquatic organisms is disrupted when invasive, non-native, or exotic plants from other parts of the country or world are introduced to lakes, streams, rivers, or reservoirs. Invasive species become a nuisance when these plants increase dramatically in number and compete with the diverse natural vegetation. A weed is a plant growing out of control at the expense of other plants and animals. It is usually very obvious when a dense bed of a single species becomes a nuisance. Under these conditions fish and wildlife habitat and activities are altered. Invasive vegetation also interferes with recreational activities such as fishing, boating, swimming, property values, and enjoyment of the natural beauty of our water resources.

Currently, many invasive aquatic plants cause serious problems across the country. On a national and regional level, problem aquatic plants include water hyacinth, hydrilla, Eurasian watermilfoil, purple loosestrife, and water chestnut, among others. Problems with invasive aquatic plants occur primarily because of their growth habits enabling them to rapidly reach very large and dense population levels. Excessive growth of many of these invasive aquatic species often is 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
- Reducing the 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

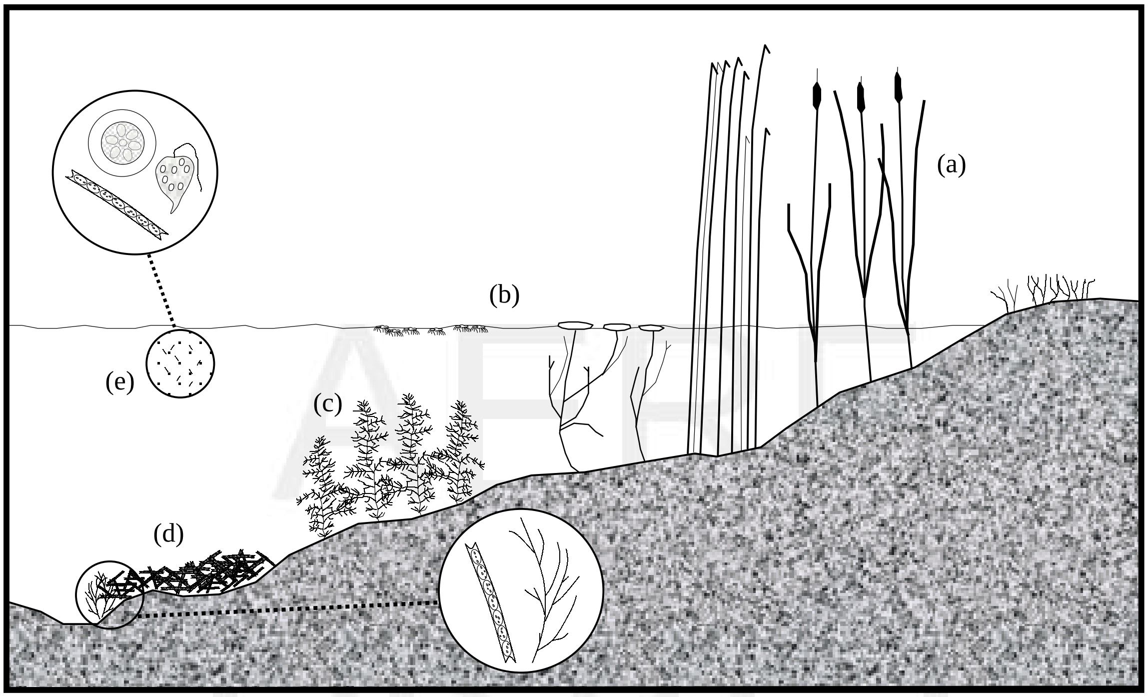

Figure 1. Main groups of aquatic plants found in both still and moving waters: (a) emergent plants, (b) floating leaved plants, (c) submersed plants, (d) filamentous algae, and (e) microscopic algae (adapted from Seagrave 1988).

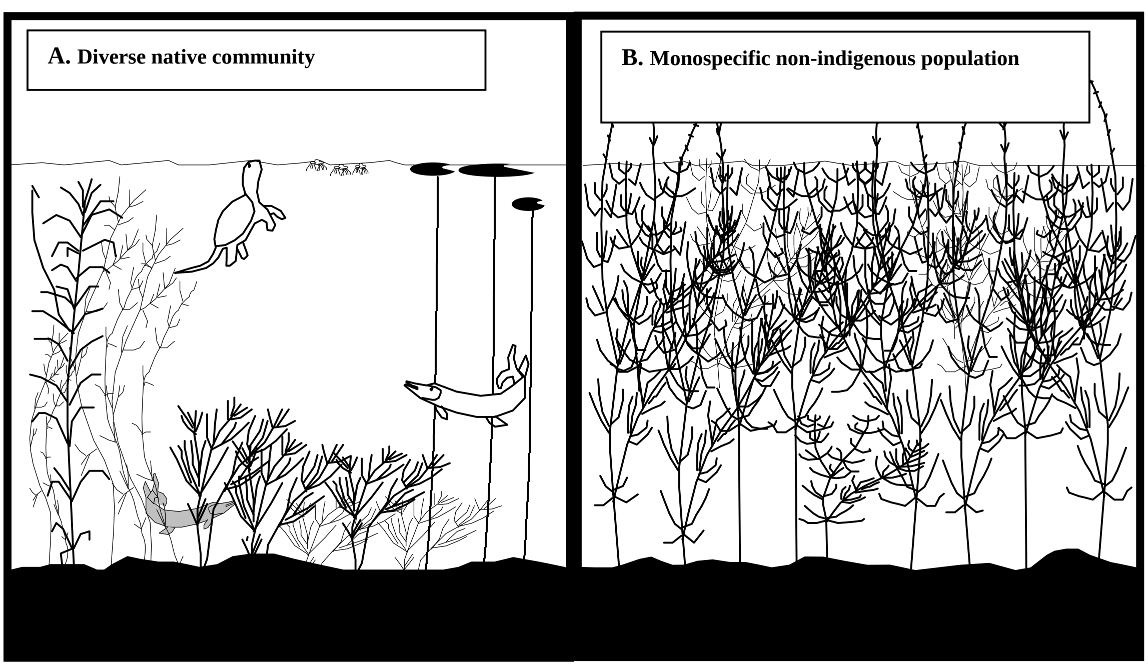

Figure 2. Comparison of (A) diverse native plant community versus (B) monospecific plant population (adapted from Madsen 1997).

Purpose and Objectives

The primary goal of this handbook is to provide nationally recognized chemical, mechanical-physical, biological, and cultural Best Management Practices (BMPs) for controlling aquatic plants in a manner that protects or restores fish and wildlife habitat. Many managers, practitioners and researchers believe that quality aquatic habitat can be maintained by managing invasive plant populations at levels that protect other uses of an aquatic system. It is important to consider the integration of all appropriate aquatic vegetation management techniques for each individual site.

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. This handbook describes how to manage invasive and exotic aquatic plant species while protecting aquatic ecosystems and fish habitat. The handbook provides additional sources of information that provide 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 handbook. The U.S. Army Corp of Engineers (USACE) agreed to cooperate with the AERF to develop this handbook. 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. The AERF primarily supports research and education for the control of aquatic invasive plant species. The AERF membership includes parties with a vested interest in restoring and conserving aquatic resources, such as lake associations, scientific societies, resource management firms, consultants and private sector firms including aquatic herbicide manufacturers, formulators, and distributors.

The AERF and in consultation with the USACE selected national experts on biology, ecology, and management of invasive aquatic vegetation to identify and compile the BMPs to control invasive weed species in order to protect aquatic and fish habitat. These experts are listed as the technical contributors to this handbook. These experts were selected by the AERF based on recommendations by the USACE, The Aquatic Plant Management Society, the Freshwater Anglers Association, and the North American Lake Management Society. Information on the BMPs was provided by the technical experts for the most significant invasive species from a national or large regional perspective. The species selected include:

- 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

How to Use This Handbook to Prepare a Site Specific Integrated Weed Management Plan

This handbook provides the general principles and range of management practices to control invasive aquatic vegetation while protecting fish and wildlife habitat. Management goals and the combination of BMPs must be selected based on local conditions. This handbook has a section of specific BMPs for each of the identified invasive species. Based on the BMPs and additional sources of information provided in this handbook, the manager can select specific practices based on site-specific conditions and management goals. **The focus of this handbook is on maintaining a level of invasive aquatic plant species in a way that is compatible with a functioning environment for fish, wildlife, and other aquatic organisms.** Before reviewing specific practices for controlling specific invasive weeds, the manager should consider reviewing the general concepts of integrated control found in the next section of this handbook. The section on general integrated control options 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 BMPs.

Additional Sources of Information

All of the sources of information are listed in the Reference, Additional Readings, and Other Sources of Information Section found at the end of the handbook. Many of these references will provide either general or specific information on BMPs for management of invasive aquatic weeds. These sources will provide important concepts and information on site-specific selection of the appropriate management practices.

Integrated Control Options: General Concepts

Approaches to Integrated Best Management Practices

In the United States extensive damage caused to aquatic ecosystems by invasive aquatic plant species has been well documented. Lake managers employ a variety of practices to assist in restoring healthy aquatic ecosystems. These practices include biological, mechanical, cultural, and chemical methods. Each of these methods has been extensively researched over the last several decades. Compiling and considering these practices for a specific site is one of the first steps in formulating an integrated control strategy.

Research and field experience is beginning to demonstrate that an integrated approach may provide the best long-term method for controlling invasive aquatic vegetation to maintain diverse and healthy aquatic ecosystems. The elements of an integrated invasive weed control plan include:

- Identifying correctly the invasive plant
- Determining how the weed was introduced in order to prevent re-introductions
- Identifying the desired vegetation to achieve the fish and wildlife habitat goals
- Establishing the tolerable levels of any single plant species
- Making decisions based on site specific information
- Using ecosystem, watershed, and cost perspectives to determine long-term management strategies
- Developing a system of integrated control methods, including mechanical, cultural, biological, and chemical BMPs
- Educating local managers and the public of the importance of protecting water resources from invasive weeds to maintain healthy water quality and fish and wildlife habitat.
- Assessing the results of the invasive weed control program, which includes quantitatively documenting the results of all control strategies and reevaluating management options

This handbook provides many of the BMPs to achieve these elements. Aquatic ecosystem managers, property owners, and the public must establish these elements at a local level. Identification of each invasive weed and its source is critical (Figures 3-9). Several pictorial weed identification sources are listed in the Reference section of this handbook. In addition, voucher specimens should be sent to an expert for identification.

Knowing the categories of aquatic weeds is an important component of understanding the integrated options for control of vegetation in a diverse and healthy aquatic ecosystem. 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 very difficult to reclaim back to open water or wetlands with diverse species.

Submersed: These plants require a complete aquatic environment for support of the plant stem and leaves where 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. These submersed plants can easily become excessive in growth and completely choke small shallow waters. In deeper waters, these plants can easily degrade the diverse habitat structure required for survival of fish and wildlife.

Free Floating: These plants grow underwater with considerable vegetation floating on the water surface, such as 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 potential shading effects.

Algae: Algae consist of three general growth forms: microscopic, mat forming, and the *Chara*/*Nitella* group. 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. However, when nutrient levels in surface waters are high, especially phosphorus, microscopic algae will multiply rapidly and create blooms. This can be aesthetically unpleasing, but more importantly, algae blooms have a detrimental effect on the quality of the aquatic habitat for fish and wildlife. Die-offs (crashes) 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, which 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 can rapidly choke large areas of water. They are difficult to control once high population levels occur.

The plants of the *Chara*/*Nitella* group of species are embedded in sediment and have very simple stem and leaf-like structures. Although generally considered valuable habitat, they can sometimes 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 has been well documented. Aquatic vegetation is an important component of functioning fish and wildlife habitat. 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 not only important for good sport fisheries, but also for other recreational activities, aesthetic enjoyment of water resources, and maintenance of healthy aquatic and littoral ecosystems.

The spread of invasive or nuisance vegetation will alter the structure of aquatic ecosystems resulting in ecosystem degradation, changes in water quality, and changes in the habitat structure for fish and wildlife populations. Typically invasive aquatic vegetation creates monoculture stands with dense canopies. These dense canopies, aerial or submersed, result in decreased water mixing and oxygen exchange, increased nutrient loading, and fluctuating temperatures.

Invasive aquatic vegetation spreads and rapidly colonizes water bodies with the ecological characteristics of early successional species. The canopy-forming morphology of the major invasive species greatly reduces the importance of other vegetation. Invasion of lakes by hydrilla, water hyacinth, Eurasian watermilfoil, and water chestnut are often accompanied by the decline of indigenous aquatic vegetation. Studies have shown that invasive aquatic species will invade both degraded and healthy aquatic ecosystems and over several years develop dense canopies of monoculture 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.

Based on considerable research evidence, most professional water resource and fisheries managers believe an intermediate level of vegetation (15 to 85 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 changes in aquatic vegetation abundance or species composition have considerable effect on biological structure and productivity of lakes, streams and rivers. However, the interaction between individual fish/wildlife species and aquatic vegetation is highly variable. The interaction between fish and wildlife species and aquatic vegetation (abundance and species composition) depends on the:

- 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 increases the habitat complexity of aquatic ecosystems providing refuge for prey species and young predator species. Plants also provide habitat for invertebrates that are food for many fish. An overabundance of plants however, interferes with the feeding of larger predators, both fish and wildlife. In lakes with no submersed habitat, from 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 monoculture formed by invasive aquatic species, it is more difficult for fish predators to forage because of the visual barrier. This causes slower fish growth, favor smaller sized fish, and can reduce number of larger, harvestable fish resulting in poor quality sport fishing.

Composition of Fish Species and Abundance of Aquatic Vegetation

Lakes and streams each have a carrying capacity for the total abundance of fish. Within a given individual lake with a given capacity to support fish, the abundance of vegetation can impact the relative abundance of individual fish species. Lakes with a low abundance of vegetation, generally oliogtrophic, 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 aquatic vegetation. The total number of fish species in a lake (species richness), usually does not change within a lake as the amount of aquatic vegetation changes. However, the relative abundance of many fish species is directly related to the amount of aquatic vegetation. There are some species, such as largemouth bass, that are able to maintain stable population numbers over a large range of vegetation abundance. These species usually have two or more energy resource pathways, which can be changed depending on the foraging opportunities. As opportunist feeders, they are able to feed on small fish or insects depending on availability and switch as habitat changes. The 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. Lakes with very low levels of vegetation or very high levels of vegetation can support fish populations. However, the probability of depressed fish populations with vegetation eradication or infestation by invasive plant species is relatively high, especially for those species that are adapted to and rely on vegetation. Vegetation coverage between 15 to 85 percent encourages the formation of stable fish populations with 20 to 40 percent coverage being optimal. This is a relatively wide range, which can meet the diverse goals of lake and stream management and meet the goals of maintaining good fish and wildlife habitat. Initial invasion of lakes and rivers by invasive species will benefit habitat structure by providing additional cover and food for such species as largemouth bass. However, once a monoculture of invasive weeds is established with 85 percent 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, Additional Readings, and Other Sources of Information section of this handbook.

General Review of Best Management Practices

Biological Control Practices

Biological control is the introduction by man 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. 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" or introduction of host-specific organisms from the home range of the target plant into the current environment of the target plant

- Inundative, or the use of opportunistic native or exotic pathogens or insects

- The use of general feeders or non host-specific organisms. An example of a general feeder is the white amur (grass carp), which is used for the control of most types 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 effectiveness may take many years. Such a long-term method of suppression 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 the short-term mechanical and chemical control options.

Many organisms have been considered for biological control programs (Table 1). They include: grass carp (white amur or *Ctenopharyngodon idella*), 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.

One of the main reasons introduced or invasive aquatic plants can dominate native vegetation and form large continuous monocultures is their very high levels of productivity. Most of this high productivity is an inherent characteristic of the introduced plants. However, most exotic plants are introduced into new localities without their compliment of exotic herbivores, disease-causing organisms, or associated plant competitors that act in concert to reduce the potential growth of the plants.

Ideally, introduced or native biocontrol organisms will feed primarily on one plant species (and not on other native plant species), exerting continuous pressure on the plants by tissue removal, internal fluid removal, or general loss of plant vigor by 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 they may exhibit reductions in flowering and seed set. In time, their production of daughter plants and other vegetative structures is reduced. When suppression of the invasive plant occurs, the normally out-competed native vegetation re-emerges as a significant component of the aquatic ecosystem. This promotes a healthy and diverse plant environment for good fish and wildlife habitat and recreation use of lakes and streams.

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 must be included at the operational level as a means of assessing the effects that biocontrol agents have on aquatic weeds and fish and wildlife habitat structure.

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

Specific information on biological control agents for invasive aquatic weeds is discussed in the Specific Integrated Best Management Practices section of this handbook. Excellent sources of general and species specific information on biological control of aquatic weeds are included in the References, Additional Readings, and Other Sources of Information section of this handbook.

Mechanical and Physical Control Practices

Mechanical and physical control practices have been used in widespread attempts to control aquatic plants, especially invasive and exotic species. The type and effectiveness of mechanical control practices are summarized in Table 2, Table 3 and Table 4.

Mechanical Control Practices

Hand pulling and raking aquatic weeds are similar to weeding a garden. The whole plant including the roots should be removed, while leaving the beneficial species intact. This technique works best in softer sediments, with shallow rooted species and for smaller infestation areas. The process must be repeated often to control regrowth. When hand pulling nuisance species the entire root system and all fragments of the plants must be collected since even small root or stem fragments could result in additional growth of the species. It is important to remember that removing aquatic plants may result in increased shoreline erosion, as roots are no longer present stabilize the sediment and dampen wave action. In some situations, it is suggested that native species be replanted in place of the exotic species to correct this potential problem. This will not only act to stabilize the shoreline but could inhibit the regrowth of some exotic species. The cost of hand pulling operations very widely depending on the degree of infestation and the availability of labor.

Table 1. Summary of example biological practices for control for aquatic plants (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. Avoid Eurasian watermilfoil, and generally do 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	Has not yet been widely established or effective	Released in Florida, Alabama, and 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 R&D, 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 suppression of Eurasian watermilfoil
Mycoleptodiscus terrestris (Mt)	Fungal pathogen; acts as a contact bio-herbicide, native	Low dispersion, fairly broad spectrum	Expense, cross-contamination, inconsistent viability and virulence of formulation	Under R&D for both Eurasian watermilfoil and hydrilla	"Contact Bio-herbicide", plants rapidly fall apart, but regrow from roots

Table 1. Summary of example biological practices for control for aquatic plants (Modified from Madsen 1997, 2000) (continued).

Management Method	Description	Advantages	Disadvantages	Systems where used effectively	Plant species response
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 US and Southern Canada for suppression 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 very effective around the world; is becoming established in US	Is only under research in the US –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 suppression
Native Plant Community Restoration	Planting of desirable native plant species or community	Provides habitat, may slow reinvasion or initial invasion	Expensive, techniques still under development	Under R&D around the country for many species	Native plants provide ecosystem benefits, slow invasion

Hand cutting is a method that can be used for localized removal of invasive aquatic plants. The removal of small patches of vegetation can be accomplished by cutting with hand tools. Many of these approaches can only be conducted in areas were the water level allows access, usually less than 4 feet deep. A number of companies have developed both powered and non-powered hand tools specifically designed to remove submersed aquatic plants. Many submersed aquatic plants spread by fragmentation. Fragmentation of specific invasive species should be considered when planning management programs. If the plant spreads by fragmentation, hand-cutting operations should only be conducted in lakes where the plant has expanded to most of the littoral zone. Cutting pioneer colonies could accelerate the spread of the weed to non-infested areas. Hand cutting tools are often used on submersed aquatic weeds to control the plants in small sections of lake or river systems.

Mechanical harvesters are machines which 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. 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 opens an area such as boat lanes; and (2) removes the upper 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 for this method. The USACE provides a HARVEST model in the Aquatic Plant Information System (See Reference Sections for APIS). Mechanical harvesting also leaves plant fragments in the water, which if not collected may spread the plant to new areas. Additionally harvesters may 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 may have to be performed several times per growing season to maintain control of the nuisance aquatic weeds.

Weed rollers are a fairly new method to control 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 reverses in a 270 degree arc around its anchor position. The roller compresses the sediment and plants in the area. This type of equipment requires low operational effort. The equipment can be left in place and used as the plants begin to grow. Frequent use allows only a low amount of weed growth in the area being rolled. The use of rollers may disturb bottom dwelling organisms and spawning fish. Additionally, fragmentation of the nuisance plant may occur with subsequent regeneration. Some states have specific rules on the use of weed rollers. Contact the appropriate local and state agencies to determine whether weed rollers are allowed and the appropriate permit process.

A **rotovator** is similar to an under-water rototiller. The equipment has rototiller-like blades, which turn seven to nine inches below the bottom to dislodge and remove roots. The plants and roots are removed either manually or with a rake attachment. This method of plant removal works best when the plants have not reached their mature length. Longer plants tend to wrap around the spinning blades and may cause damage to the equipment. Since the rotovator greatly disturbs the sediment, there are many environmental concerns including: (1) re-suspension of contaminated sediments; (2) release of nutrients adsorbed or precipitated in the sediment (e.g. phosphorus); (3) adversely impact benthic organisms; and (4) impact on fish spawning areas. This method is useable year-round and has been shown to be very effective in rapidly clearing areas 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. 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 **ground-mowing** equipment for wetland and shoreline vegetation, but the design concepts are similar. Most large-scale mowing equipment is either self-propelled or is pulled by a tractor or unit that has 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 produce food; 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 the **diver dredging** procedure 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 in a pioneering state, this methodology should be considered. To be effective, the entire plant, including the sediment portions, should be removed. There have been successful short-term uses of this procedure against well-established communities, but rapid reinfestation from untreated areas occurs that renders the treatment useless in a fairly short period of time. Dredging is a first step in a consistent integrated control program. It also may be a last step after weeds are initially suppressed with a herbicide. The level of plant growth has a dramatic impact on diver dredging operations. Unless checked, plant fragments also can be formed from this type of operation. As divers move through established plant stands, they can disturb nearby plants causing them to tear and break. The floating fragments can contribute to new infestations. Some operations employ personnel on the surface in canoes or kayaks to capture floating plant fragments. In cases where the infestation has 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.

<u>Physical Control Practices</u>

Bottom or benthic barriers have played a limited role in the management of submersed aquatic plants (Table 3; Table 4). They have two basic applications. These practices are used to cover pioneering infestations and prevent the spread of the plant. They also have been used in a maintenance role, opening water around docks or swimming areas. Bottom barriers are applied across sections of lake or river bottoms infested with invasive weeds. The disadvantage of bottom and benthic barriers is their non-selectivity and limitation of cover to less than one acre. Physical barriers prevent the growth of all vegetation, which is a necessary component of fish and wildlife habitat.

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

Many states require permits for the application of materials to lake or river bottoms. These materials cover the substrate and limit the movement of benthic organisms from the sediment to the water column. If applied lake-wide or over wide areas, there would be potential for seriously impacting these organisms. Bottom barriers are generally considered for small localized areas rather than lakewide or riverwide application.

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 Eurasian watermilfoil dense stands; not selective and only intermediate-term
Ground Mowing	Self propelled or tracer 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 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 perennation strategy; effective on evergreen perennials, less effective on herbaceous perennials
Benthic Barrier	Natural or synthetic materials to cover plants	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 phosphorus (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

Table 4. Effectiveness of mechanical and physical practices for the 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]
Rotovater	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

Bottom barriers provide 100% control of this weed in areas where they are installed. They also provide long-term control. An ongoing maintenance operation is required to inspect the bottom barrier and clear the mats of sediment buildup. Bottom barriers will prevent establishment of native vegetation required for good fish and wildlife habitat.

Dredging or physical removal of bottom sediments using a floating or land-based dredge is used not just for aquatic weed control but also to restore lakes or channels, which: (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 creating multiple plant environments allowing for greater diversity in lakes plant, fish, and wildlife communities. However due to the cost, potential environmental effects, and the 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 aquatic plant management method (Table 3, Table 4). It is used for control of submersed species such as Eurasian watermilfoil. Drawdown requires some type of mechanism to lower water levels, such as dams or water control structures and use is thus limited. It is most effective when the drawdown depth exceeds the depth or invasion level of the target plant species. In northern areas, drawdown will result in plant and root freezing during the winter for an added degree of control. Drawdown is typically inexpensive and has intermediate effects (2 or more years). However, drawdown can have other environmental effects and interfere with other 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 infestations of weeds such as hydrilla to expand.

Shading is a basic manipulation of the aquatic environment to reduce or attenuate light. Shading is used to reduce the amount of light available for photosynthesis, which controls the rate of conversion of CO_2 to carbohydrates needed to support healthy plant growth. Shading techniques include use of water soluble dyes, shading fabrics or covers, establishing 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, which binds phosphorus making 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, which is still considered in the research and development phase. Furthermore, treatments that reduce water column nutrients and algae may permit denser infestations of nuisance rooted plant due to better water clarity and decreased light attenuation.

Specific information on mechanical and physical control practices for invasive aquatic weeds is discussed in the Specific Integrated Best Management Practices section of this handbook. Excellent sources of general and species information on mechanical and physical control of aquatic weeds are included in the References, Additional Readings, and Other Sources of Information 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 such as dredging, weed rolling, rotovating, and harvesting. 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, such as herbicides, for the control of noxious and nuisance plant species represents one of the most widely known and effective management options available. Herbicide control of invasive aquatic weeds in is often the first step in a long-term integrated control program. In the last 15 to 20 years the use and review of herbicides 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 and U.S. Environmental Protection Agency (EPA) approved herbicides for aquatic weeds are limited. In most cases the cost and time of testing and registration, rather than environmental issues, limits the number of potentially effective compounds. The current U.S. federally approved compounds for aquatic plant use are summarized in Table 5 and Table 6.

<u>Herbicide Use and Classification</u>

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, safe 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 (Table 7). 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 is additional permitting or regulatory requirements on the use of aquatic herbicides. Some states require that aquatic herbicides may 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 contacted, causing extensive cellular damage at the point of uptake. Typically, these herbicides are faster acting, but they may not have a sustained effect, in many cases not killing root crowns, roots, or rhizomes. In contrast, systemic herbicides are translocated throughout the plant. They are slower acting but often result in mortality of the entire plant.

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. This value may be different 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 events are likely.

Selectivity

Herbicide activity can be characterized as species selective or nonselective (Table 5). 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 do not affect desirable plants. Selective herbicides will damage only those groups of plants that carry the biological pathways the chemical active ingredient targets. Some selective herbicides control only broadleaf plants (dicots) and do not affect grasses and monocots. Others are effective on monocots alone.

Herbicide Registration, Label Precautions, and Use Restrictions

Herbicides sold in the United States must be registered with the Federal government and in most cases 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 (Table 7). These instructions are considered a part of compliance with FIFRA and other Federal regulations, and failure to use a 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.

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 the most recent conditions or restrictions prior to use.

Extremely, few herbicides are labeled for application directly to water (Table 5). 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 the 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.

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.

Selection of an appropriate aquatic herbicide requires consideration of the 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. Restrictions are required where there may be unnecessary risk to people, livestock, or fish and wildlife.

Application of herbicides to complex, three-dimensional aquatic systems requires training and experience. Trained and experienced applicators should be used for insuring adequate and selective control of aquatic weeds. Make sure the pesticide applicator selected for aquatic herbicide

application has had the appropriate training and supervised experience before contracting their services.

Whether a herbicide is appropriate for a water body or aquatic system with a particular water use is clearly specified on the product label. Instructions on the current product label must be followed. Consult with appropriate state agencies (e.g. Departments of Agriculture, Natural Resources, Environmental Quality) for the most recent information on aquatic herbicide use.

<u>Herbicide Guides</u>

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. However, 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, Additional Readings, and Other Sources of Information section of this handbook.

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

Compound	Trade Name	Company(s)	Formulation; Contact vs. Systemic	Mode of Action
Complexed Copper	Cutrine-Plus Komeen Koplex K-Tea Several others	Applied Biochemists (Cutrine) Griffin LLC	Various complexing agents with copper, superior to $CuSO_4$; Systemic	Plant cell toxicant
2,4-D	Navigate Aqua-Kleen IVM 44 Many others	Applied Biochemists Cenexagri Dow AgroSciences LLC	BEE salt BEE salt DMA liquid; Systemic	Selective plant- growth regulator
Diquat	Reward Weedtrine	Syngenta Applied Biochemists	Liquid; Contact	Disrupts plant cell membrane integrity
Endothall	Aquathol K Hydrothol 191 Aquathol granular	Elf Atochem (All Formulations)	Liquid or granular; Contact	Inactivates plant protein synthesis
Fluridone	Sonar AS Sonar SRP Sonar PR Avast!	SePRO Griffin LLC	Liquid or granular; Systemic	Disrupts carotenoid synthesis, causing bleaching of chlorophyll
Glyphosate	Rodeo Eagre	Dow AgroSciences LLC Griffin LLC	Liquid; Systemic	Disrupts synthesis of phenylalanine
Triclopyr	Garlon 3A Renovate	Dow AgroSciences LLC SePRO	Liquid; Systemic	Selective plant growth regulator

Table 6. Use suggestions for U. S. Environmental Protection Agency approved aquatic herbicides (Modified from Madsen 2000).

Compound	Exposure Time (Water)	Advantages	Disadvantages	Systems where used effectively	Plant species response
Complexed Copper	Intermediate (18-72 hours)	Inexpensive, rapid action, approved for drinking water	Does not biodegrade, but biologically inactive in sediments	Lakes as algicide, 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)	Inexpensive, systemic	Public perception	Water hyacinth and Eurasian watermilfoil control, Lakes and slow-flow areas, purple loosestrife Moving and still water	Selective to broad-leaves, 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; Should not be used 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
Fluridone	Very long (45-60 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
Glyphosate	Not Applicable on submersed plants	Few label restrictions, systemic	Very slow action, no submersed control	Nature preserves and refuges; Emergent and floating-leaved plants only Moving and still water	Broad spectrum, acts in 7-10 days, up to 4 weeks
Triclopyr	Intermediate (12-72 hours)	Selective, systemic	For still or quiescent waters only	Lakes and slow-flow areas, purple loosestrife	Selective to broad-leaves, acts in 7-10 days, up to 2 weeks

Table 7. Application restrictions of U. S. Environmental Protection Agency-approved aquatic herbicides.

Compound	Persistence (half-life, in days)	Maximum water concentration	Safety Factor	Recommended for
Complexed Copper	3	1.0 mg/L	>50	Algae, Hydrilla, other submersed spp.
2,4-D	7.5	2.0 mg/L	>25	Eurasian watermilfoil, water-hyacinth, and others
Diquat	1-7	0.37mg/L	5	All
Endothall	4-7	5.0 mg/L	>10 (Aquathol) <1.0 (Hydrothal)	All submersed spp.
Fluridone	21	0.15 mg/L (150 ppb)	>20	Most submersed spp.
Glyphosate	14	0.2 mg/L	>20	Most emergent and floating spp.
Triclopyr	3-7	2.5 mg/L	>50	Eurasian watermilfoil, water-hyacinth, others

Cultural Control Practices

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 8). Cultural control practices can be an essential component of long-term management and prevention of uncontrolled aquatic weed infestations. The following are typical cultural control practices.

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 program 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. However, this type of program does require management, education, and planning. The Minnesota Sea Grant Program and Minnesota Department of Natural Resources have established a program based on volunteer prevention and education.

Assessment involves evaluation of current and potential aquatic weed problems by all stakeholder groups. 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 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, transect estimates, and 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 establishes high use areas for 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 high use and high priority areas. Wildlife areas would likely have lower intensity use with some jurisdictional restrictions. Sports fisheries areas would likely 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 thresholds have been met and the cost benefit of the management program. Typically, occurrence, abundance, and distribution methods 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 environment 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 both 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

Excellent sources of general and species specific information on cultural and institutional control of invasive aquatic weeds are included in the References, Additional Readings, and Other Sources of Information section of this handbook.

Table 8. Summary of components of cultural control strategies for the control of aquatic weeds (Modified from Madsen 1997, 2000).

Management Method	Subcomponents	Description	Examples
Prevention	Prevent nonindigenous introductions	Quarantine plant introduction; 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 sensing
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; Develop full fledged public outreach program

Specific Integrated Best Management Practices

Eurasian Watermilfoil [*Myriophyllum spicatum* L.]

Description: Eurasian watermilfoil is a submersed, rooted, perennial dicot that is submersed except 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.

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. Native to Europe, Asia,, and North Africa, the history of the spread of this species in the U.S. is made unclear by the existence of herbarium specimens that were mislabeled and by the confusion regarding the distinctness of *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. Eurasian watermilfoil is 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. Water currents disperse vegetative propagules through drainage areas. Motorboat traffic contributes to natural seasonal fragmentation and the distribution of fragments throughout lakes. Transport on boating equipment plays the largest role in introducing fragments to new waterbodies. Road checks in Minnesota have found aquatic vegetation on 23% of all trailered watercraft inspected. To avoid obstacles associated with 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 aggressive displacement of native vegetation and alteration of fish and wildlife habitat by formation of impenetrable mats, and decreased water flow. The rapid growth rate of this species allows it to cover water surfaces and displace native vegetation in a few growing seasons. It can form thick underwater stands of tangled stems.

Eurasian watermilfoil elongates from shoots initiated in the fall, beginning spring growth earlier than other aquatic plants. This species is tolerant of low water temperatures; it quickly grows to the surface, forming dense canopies that overtop and shade out surrounding vegetation. When Eurasian watermilfoil invades a body of water, formation of a dense canopy and light reduction are the two significant factors in the decline of native plant abundance and diversity. This change in habitat quality quickly affects fish, wildlife, and other aquatic organisms. Over time, Eurasian watermilfoil will out-compete or eliminate the more beneficial native aquatic plants, severely reducing natural plant diversity within a lake. Since its growth is typically dense, watermilfoil weed beds are poor spawning areas for fish and may lead to populations of small fish. Loss of oxygen and light caused by dense mats of Eurasian watermilfoil also can affect fish populations. Although many aquatic plants serve as valuable food sources for wildlife, waterfowl, fish, and insects, Eurasian watermilfoil is rarely used for food. Dense stands of Eurasian watermilfoil provide habitat for mosquitoes and may increase populations of some species of mosquitoes.

Fish populations may experience a favorable increase in population when Eurasian watermilfoil initially invades a site. However, the abundant and aggressive growth of Eurasian watermilfoil will counteract any short-term benefits. At high densities, its foliage supports a lower abundance and diversity of invertebrates, which serve as fish food. Dense cover does allow high survival rates of young fish. However, larger predator fish lose foraging space and are less efficient at obtaining their prey. Dense cover of Eurasian watermilfoil reportedly reduces the growth and vigor of warm-water fisheries. The growth and senescence of thick vegetation also reduces water quality, water circulation, and 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 Eurasian watermilfoil. Chemical and mechanical methods are well developed, but provide short- to medium-term control of this aquatic weed. These methods often must be used at every one to three 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, but native and naturalized insects are being investigated for inundative control. The effectiveness of these insects for long-term suppression is currently being investigated. Additional research on Eurasian watermilfoil levels in lakes, streams and rivers in relation to other aquatic vegetation and fish and wildlife habitat are necessary to establish threshold levels that trigger different 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 9.

Many criteria or questions 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: Herbicide Guides found in the General Review of Best Management Practices section found in this handbook.

The labels from which this handbook was summarized are constantly changing. The most current herbicide label should be reviewed for the most recent 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.

Mechanical & Physical Control:

Mechanical control of Eurasian watermilfoil is a short- to medium-term method used to initially control small to moderate infestations (See Table 2 and Table 4). The disadvantage for some mechanical control options is the shredding of stems and leave that can potentially further spread vegetative propagules. Physical control options provide medium to longer-term control of this invasive aquatic weed (See Table 3 and Table 4). The following is a brief description of the more successful mechanical and physical control practices.

Hand cutting tools have been used to control all submersed aquatic weeds, including 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. Aquatic weeds such as Eurasian watermilfoil can grow up to one foot per week. Under these conditions harvesting must be performed several times in a growing season to maintain usability of the water. When harvesting methods are used, Eurasian watermilfoil should be collected and disposed in a manner that does not contaminate other water bodies. Selection of a good upland disposal site, with no possibility of the plant fragments washing back into a lake, creek, or river is important. 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. The plant will grow back each year from a root crown in the upper few inches of lake sediments. As there is virtually no reproduction from seeds, the root crown is the key to survival of the plant. Rotovation targets this root crown and the associated plant tissue. Rotovators till the sediment resulting in the uprooting of the root crown. Rotovation provides dramatically longer periods of control than does other harvesting methods, but can be disruptive to sediment and native plant communities. Rotovation is not allowed in many states.

Diver dredging has been especially effective against Eurasian watermilfoil. This system removes both the plant and root crown can be removed from the lake system. Diver dredging systems are best utilized against small, pioneering infestations of Eurasian watermilfoil. Where pioneering colonies of the plant are discovered interspersed with native plants this technology can selectively remove the Eurasian watermilfoil. With careful planning and implementation, diver dredging has minimal impact on the native plants. This treatment has been successful against well-established communities, but the high cost of the operation for extensive infestations limits the application of this technology.

Bottom barriers have been successfully used to manage Eurasian watermilfoil. Bottom barriers have effectively been used to cover pioneering infestations of this weed and prevent the spread of the plant. They have been used in a maintenance role, opening water around docks or swimming areas for use.

Table 9. Herbicides used for Eurasian watermilfoil management[1]

Herbicide Name	Example Trade Name	Formulation	Quality of Control	Mode of Action
2,4-D Butoxyethlester (BEE and DMA)	Aqua-kleen	Granular	Excellent	Selective, systemic growth regulator
	Navigate	Granular	Excellent	Selective, systemic growth regulator
Diquat	Reward	Liquid	Excellent	Nonselective, contact
	Weedtrine-D	Liquid	Excellent	Nonselective, contact
Endothall Dipotassium salt	Aquathol K	Liquid	Excellent	Selective at low rates
	Aquathol Super K	Granular	Excellent	Selective at low rates
Endothall Dimethylalkylamine salt	Hydrothol 191	Liquid or Granular	Excellent	Nonselective, contact
Fluridone	Sonar A.S. Avast!	Liquid emulsion	Good to Excellent	Selective (based on application rate), systemic
	Sonar SRP Sonar PR Avast! SRP	Slow release pellets	Good to Excellent	Selective (based on application rate), systemic
Triclopyr	Garlon 3A	Liquid	Excellent	Selective, growth regulator
	Renovate	Liquid	Excellent	Selective, growth regulator

[1]Only pesticides specifically labeled and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under the 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 is essential.

Inclusion of pesticides on this list does not imply any endorsement by the AERF, any of the authors, or Spectrum Research, Inc.

Biological Control:

Biological control is a BMP that should be included in an integrated plan for control of Eurasian watermilfoil. 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 American. 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 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. Researchers have observed that plant community response, i.e., the ability of other species to occupy space left by damaged watermilfoil or the stress imposed by competition with other plants, is important to successful biological control.

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. Additional research is needed to improve the predictability of the effects and appropriate circumstances for use of biocontrol. It is known that weevils can control watermilfoil. However predicting exactly when, where and by what means this will occur has proven nearly impossible. Ongoing research to determine what controls weevil populations and what role plant competition plays in successful suppression. This research may result in development of operational suppression procedures. Many states regulate the use and transport of these agents and states authorities should be contacted before introduction or augmentations are conducted.

The native fungus *Mycoleptodiscus terrestris* also is being investigated for inundative control of Eurasian watermilfoil. 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.

Grass carp (*Ctenopharyngodon idella*) are used in some states for control of Eurasian watermilfoil (e.g. Washington). However, introduction of grass carp is considered illegal in other states (e.g. Minnesota, Vermont, and Wisconsin). Eurasian watermilfoil is not a preferred pant and the grass carp will eliminate preferred native plants before consuming Eurasian watermilfoil. Thus grass carp should generally not be used for control of Eurasian watermilfoil.

Cultural Control:

Because Eurasian watermilfoil is so difficult to control once it has become established, prevention of infestation and early detection of 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, especially Eurasian watermilfoil. 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 waterbody. 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. 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 waterbody.

Unfortunately, once Eurasian watermilfoil has been introduced into a lake, there is currently no combination of control practices that will completely eradicate it in most cases. Therefore, cultural prevention approaches remain the best way to avoid Eurasian watermilfoil infestations (See Table 8). 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
    - Published web sites
    - Workshops and lectures
    - Develop full fledged public outreach program 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 surfacing and submersed leaves (Figure 4). Surfacing leaves are triangular with toothed edges and an inflated petiole, or leaf stalk, and form a rosette on the water surface. Submersed leaves are feather-like while each leaf is divided into segments that are whorled around the leaf stem. Water chestnut over-winters entirely by seeds that 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 produce an abundance of vegetative growth quickly in response to low-density of other aquatic vegetation. This biological condition is further augmented by the ability of clonal mats of water chestnut to produce greater biomass of reproductive structures and fruit compared to native vegetation.

Habitat & Range: Water chestnut grows rapidly in calm, shallow nutrient-rich waters with soft, muddy bottoms. Uncontrolled, water chestnut creates nearly impenetrable mats across wide areas of water. Water chestnut is generally rooted in the mud of quiet streams, ponds, freshwater regions of estuaries, and mud flats.

Water chestnut currently ranges from Massachusetts, to western Vermont, eastern New York, Maryland, and Virginia. Originally an Asian species, water chestnut was established in the northeastern United States in the late 1800's. Water chestnut continues to advance into eastern Canada, New England, and the Mid-Atlantic states.

Effects on Fish & Wildlife: Problems associated with this species include displacement of native vegetation and interference with normal development of fish and wildlife habitat by the formation of impenetrable mats. In South Lake Champlain and other New England lakes, many previously fished bays are now inaccessible due to floating mats of chestnut. This noxious plant severely shades light from water, an important element of well-functioning aquatic ecosystems. The dense mats also reduce oxygen to levels, which may increase the potential for fish kills. The abundant detritus in the fall of each year and its decomposition further lowers oxygen levels in shallow waters and can affect fish and other aquatic organisms. Loss of oxygen and light may affect fish in the same manner as the affects caused by dense mats of Eurasian watermilfoil. The sharp spiny fruits also can be hazardous to swimmers. The dense surface mats created by water chestnut provide additional breeding ground for mosquitoes.

Control Options: As a regionally pervasive and potentially detrimental invasive aquatic weed, the 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 of water chestnut. Chemical and mechanical control methods have provided short- to medium- term control of this aquatic weed. 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 trigger different control options.

Chemical Control: The best herbicide used to control water chestnut is 2,4-D (Table 10). It has been tested extensively by federal and state agencies. Many criteria or questions 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: Herbicide Guides found in the General Review of Best Management Practices section found in this handbook.

The labels from which this handbook were summarized are constantly changing. The most current herbicide label should be reviewed for the most recent 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 water chestnut management[1]

Herbicide Name	Example Trade Name	Formulation	Quality of Control	Mode of Action
2,4-D Butoxyethlester (BEE)	Aqua-kleen	Granular	Good-Excellent	Selective, systemic growth regulator
	Navigate	Granular	Good-Excellent	Selective, systemic growth regulator

[1]Only pesticides specifically labeled and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under the 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 is essential.

Inclusion of pesticides on this list does not imply any endorsement by the AERF, any of the authors, or Spectrum Research, Inc.

Mechanical & Physical Control: Mechanical control of water chestnut is a short-term method used to initially control small to moderate infestations (See Table 2 and Table 4). In New England, mechanical harvesting and hand removal have been the main means controlling water chestnut invasions. Experience on the east coast has shown that mechanical methods can be successful at temporarily controlling and reducing the infestation if infested 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. Mechanical control should be done before seed set.

Mechanical cutting devises have been proposed for control of floating and emergent aquatic weeds such as water chestnut. The cookie cutter is a barge/cutting system developed to control emergent aquatic vegetation, floating islands of vegetation and sediment, and to cut openings in shoreline and wetland areas through emergent wetland plants. This technology has some potential for control of the clonal mats of water chestnut. The cookie cutter's ability to rapidly 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 birds (feeding and nesting).

The cookie cutter does not have any type of harvest capability; it merely cuts 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 to collect and remove this material may be needed. The cookie cutter can suspend sediments if it is working against plants in shallow water or against a shoreline. This could cause environmental problems and some states may require a permit. In addition, the habitat improvement includes 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.

Cookie cutter operations should take place well before the water chestnut flowers form to ensure that this management method does not assist in the distribution of seeds. If the equipment is cutting these plants during periods of seed production, spread of the plant can occur. The equipment should also be cleaned to ensure that the weed is not spread to the next site where work will be conducted.

Hand removal, harvesting, and rotovation also have been used for control of water chestnut. For details on harvesting and hand removal see the overview of Mechanical Control options.

Harvesting water chestnut is a very effective option for short-term clearance of the vegetation from the upper portions of the water column. Aquatic weeds such as water chestnut grow very rapidly. Under these conditions harvesting must be performed several times in a growing season to maintain usability of the water. When harvesting methods are used, water chestnut should be collected and disposed in a manner that does not contaminate other water bodies. Selection of a good upland disposal site, with no possibility of the plant fragments or seeds washing back into a lake, creek, or river is essential.

Biological Control:

Biological control has received limited attention as a BMP for integrated control of water chestnut. Attempts have been made to find suitable biocontrol insects in searches conducted in 1992-93 in China, Japan, South Korea and the Russian Far East. No appropriate candidates were found. A similar attempt was made in 1995 in Europe, including France, Germany, Italy and Poland without success. Potential natural enemies have been reported from warmer climates such as in India. However, 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.

Human 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 waterbody. To stop the further spread of non-native aquatic species, it is imperative that **all** seeds and plant fragments are removed from boats before putting in or leaving a lake's access area. 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 waterbody.

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 8). 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
    - Published web sites
    - Workshops and lectures
    - Develop full fledged public outreach program via university extension service or Sea Grant programs

Giant Salvinia [*Salvinia molesta* Mitchell]

Description: Giant salvinia is a free-floating fern with irregularly branched stems and an absence of 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. However, 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 the mat forming fern is thought to have arisen from the water gardening and/or aquarium trade where plants are either sold directly or occur as contaminants 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. High nutrient content is favorable for growth as would be found in eutrophic waters such as fertilized fields and may be especially problematic in rice fields and other waters polluted by waste or runoff high in nutrients. The weed is highly adaptable but does not colonize in brackish or marine environments.

Giant salvinia 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. Giant salvinia is prohibited in the United States by Federal law. Giant salvinia is an extremely aggressive, competitive species that in favorable environments may double in size within about a week. Excessive growth of giant salvinia can result in complete coverage of water surfaces, which degrades natural habitats. Heavy growth of dense mats out competes and shades 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. Mats of floating plants prevent oxygen from entering the water while decaying salvinia drops to the bottom. This process consumes dissolved oxygen needed by fish and other aquatic organisms. Excessive oxygen depletion can result in fish kills. As light becomes limiting, it affects the growth and survival of phytoplankton and vascular plants. Extensive mats may exacerbate a situation because they prevent water circulation and mixing.

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

Control Options:

As an internationally pervasive and detrimental invasive aquatic weed, all integrated control options are used to manage giant salvinia. Chemical and mechanical control methods have provided short- to medium-term control of this aquatic weed. These methods must be used at least annually to provide nuisance control. Giant salvinia may reproduce so rapidly that infestations rapidly become impossible to eradicate or even control. The mats have been reported to be up to three feet thick which hinders management by chemical or mechanical control. Biological control is still in the research stage to determine which native and naturalized insect species will provide long-term suppression. Prevention of infestation is the most straightforward management technique. Cultural control of nutrients in runoff from rural and urban watersheds can help control the suitability of freshwater for infestation by giant salvinia. Additional research on giant salvinia levels in lakes, streams, and ponds in relation to other aquatic vegetation and fish and wildlife habitat is necessary to establish threshold levels that trigger different 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 11. Research and field trials on the success of chemical control of giant salvinia is limited. Diquat and glyphosate have shown effectiveness. 2,4-D is not effective for giant salvinia control. Many criteria or questions 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: Herbicide Guides found in the General Review of Best Management Practices section found in this handbook.

The labels from which this handbook were summarized are constantly changing. The most current herbicide label should be reviewed for the most recent 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 giant salvinia management[1]

Herbicide Name	Example Trade Name	Formulation	Quality of Control	Mode of Action
Diquat	Reward	Liquid	Good to excellent	Nonselective, contact
Fluridone	Sonar A.S. Avast!	Liquid emulsion	Fair	Selective (based on application rate), systemic
Glyphosate	Rodeo	Liquid	Good to excellent	Nonselective, systemic

[1]Only pesticides specifically labeled and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under the 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 is essential.

Inclusion of pesticides on this list does not imply any endorsement by the AERF, any of the authors, or Spectrum Research, Inc.

Mechanical & Physical Control:

Mechanical control of giant salvinia is a short-term method used to control initial and small infestations. Hand removal and harvesting have had some success with control (Table 2; Table 4). Drawdown of water within a water body is a potential physical control practice to control giant salvinia (Table 3; Table 4). These methods should be used in conjunction with chemical and biological control for longer-term control.

Mechanical and hand harvesting of giant salvinia has been used for short-term clearance of the vegetation from the water floating. 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 in a manner that does not contaminate the treated and other water bodies. Selection of a good upland disposal site, with no possibility of the plant fragments washing back into a lake, pond, or bay is essential. 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 sufficient period to cause mortality by desiccation or freezing. If water control structures are available on a body of water, this can be effective for control of fairly large areas at a low cost. This technique may have significant detrimental effects on the aquatic ecosystem and access to the water body. To a certain extent viable individuals of these floating plant will remain in the water to re-infect the system. These individuals may require further long-term biological control or repeated mechanical control to avoid continued infestation.

Biological Control:

Biological control is an important component of any plan for management and integrated control of giant salvinia. *Cyrtobaqous salviniae*, the salvinia weevil, has achieved great success in some parts of the world. This insect does not completely kill off the host salvinia, but it should be effective as a central component of integrated chemical, mechanical, biological, and cultural control. The weevil has already been introduced to the United States (Florida). All field evidence indicates that it is totally specific for *Salvinia* sp., so there should be little problem in using this biocontrol insect in other states.

Cyrtobagous salviniae is a small weevil ranging in length from 1.5 to 2.0 mm. The weevils prefer feeding on newly formed leaf buds. 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 just 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. It is highly cost effective since the level of suppression is realized for years without re-introduction. This condition significantly reduces the cost of this part of an integrated control program. This management option is a long-term control method, which may take 5 to 10 years to achieve suitable levels of suppression. However, this biological control will not totally eradicate the target plant from a given area. To date an exact control methodology has not been determined as this agent's effectiveness can vary tremendously depending on climatic 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 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 waterbody. 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. 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. Plant shipments for 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 8). 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
    - Published web sites
    - Workshops and lectures
    - Develop 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 suitability for infestation by giant salvinia. 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 components of water quality protection. 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 varies due to water quality and can be difficult to correctly identify and can easily be confused with native elodea (Figure 6). This monocot grows submersed, annual or perennial, and forms underground vegetative propagules called tubers and structures on shoots called turions.

Habitat & Range: Hydrilla is capable of growing in virtually any type of water body. The range of monoecious hydrilla biotype includes the Mid-Atlantic States south to South Carolina. The dioecious biotype with male flowers are 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 noxious species. Hydrilla has the potential to cause greater adverse impacts to 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.

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 to be an important food source by some biologists. 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, density levels 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. Hydrilla is managed differently in different types of waters, which depends on the water uses. Typically, prevention of invasion of lakes, streams, and rivers is the best method of avoiding the development of uncontrolled monocultures of hydrilla. 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 also is being investigated as an inundative bio-herbicide. Recent work with improved formulations of this bio-herbicide appears promising. Grass carp also are used for biological control of 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 12. The herbicide active ingredients, copper, diquat, endothall, and fluridone can be used to control hydrilla, depending on the associated plant community. Copper, diquat and endothall are fast acting contact herbicides that have relatively broad spectrums on submersed aquatic plants. They are used to selectively control hydrilla by injection of liquid herbicides from trailing hoses under floating leafed vegetation. 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. Herbicide resistance management should be considered for any long-term chemical control with fluridone.

Many criteria or questions 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: Herbicide Guides found in the General Review of Best Management Practices section found in this handbook.

The labels from which this handbook were summarized are constantly changing. The most current herbicide label should be reviewed for the most recent 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 hydrilla management[1]

<table>
<tr><th>Herbicide Name</th><th>Example Trade Name</th><th>Formulation</th><th>Quality of Control</th><th>Mode of Action</th></tr>
<tr><td rowspan="3">Complexed copper</td><td>Cutrine-plus</td><td rowspan="3">Liquid</td><td rowspan="3">Good</td><td rowspan="3">Plant cell toxicant</td></tr>
<tr><td>Komeen</td></tr>
<tr><td>K-Tea</td></tr>
<tr><td>Diquat</td><td>Reward</td><td>Liquid</td><td>Good</td><td>Nonselective, contact</td></tr>
<tr><td>Endothall
Dipotassium salt</td><td>Aquathol K
Aquathol Super K</td><td>Liquid
Granular</td><td rowspan="2">Good</td><td rowspan="2">Nonselective, contact</td></tr>
<tr><td>Endothall
Dimethylalkylamine salts</td><td>Hydrothol 191</td><td>Liquid or Granular</td></tr>
<tr><td rowspan="2">Fluridone</td><td>Sonar A.S.
Avast!</td><td>Liquid emulsion</td><td>Good</td><td rowspan="2">Selective (based on application rate), systemic</td></tr>
<tr><td>Sonar PR
Sonar SRP
Avast! SRP</td><td>Slow release pellets</td><td>Good</td></tr>
</table>

[1]Only pesticides specifically labeled and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under the 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 is essential.

Inclusion of pesticides on this list does not imply any endorsement by the AERF, any of the authors, or Spectrum Research, Inc.

Mechanical & Physical Control: Mechanical control of hydrilla is a short-term method used to initially control small to moderate infestations (See Table 2 and Table 4). The disadvantage for some mechanical control options is the potential shredding of shoots. This vegetation can potentially further spread vegetative propagules. Physical control options provide medium to longer term control of this invasive aquatic weed (See Table 3 and Table 4). Used in combination with cultural, chemical, and biological control options provide longer term control and management of hydrilla can be achieved. The following is a brief description of the more successful mechanical and physical control practices.

Harvesting of hydrilla is effective for short-term clearance of the 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 in a manner that does not contaminate other water bodies. Selection of a good upland disposal site, with no possibility of the plant fragments washing back into a lake, creek, or river is essential.

Diver dredging can be effective against hydrilla 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 or other noxious aquatic weeds. With careful planning and implementation, diver dredging has minimal impact on the native plants. This treatment has been successful against well-established communities, but the high cost of the operation for extensive infestations limits the application of this technology.

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 uses 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 drawdown 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, but the 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 the spread, this technique has been suggested for hydrilla control. They have been used in a maintenance role, opening water around docks or swimming areas for use.

Biological Control:

Insects offer promise as biological suppressants for hydrilla, but as of yet none have been shown to consistently and effectively fit management programs. Several insects that feed on hydrilla are being evaluated as potential hydrilla biosuppressants in the United States. *Bagous affinis* Hustache is a weevil that was discovered in Pakistan and India. This is not truly an aquatic insect, but the adult lays its eggs on rotting wood and other organic matter and after hatching the larvae burrow though the sediment until they encounter the hydrilla tuber. The tuber is then destroyed as the insect feeds on it while it completes its life cycle. Another un-named *Bagous* spp. has been released in the United States but has not become established. *Hydrellia pakistanae* Deonier is a leaf mining fly that is very promising as a hydrilla biosuppressant. *H. pakistanae* is established in Florida but its impact in hydrilla is undetermined.

The native fungus *Mycoleptodiscus* terrestris also is being investigated as an inundative bio-herbicide. The fungus infects the plant resulting in destruction of leaf and vascular tissue. Earlier work showed difficulties in obtaining consistent infection and control with field trials. However, recent work with improved formulations of this bio-herbicide appears promising.

The manatee or sea cow (*Trichechus manatus*) have been considered for biological control of hydrilla in the past but is not presently considered for use as a potential biological control 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 shown a preference for hydrilla as a food source. This fish has been effective in managing hydrilla in controlled waterways. Grass carp are, however, a non-specific herbivore, although hydrilla is highly preferred. It is important to use the appropriate stocking rate to control and minimize damage to native plant species. Of all invasive aquatic weed species, hydrilla is most appropriate for control by grass carp.

Some states require permits for use in small ponds, lakes, and streams. Some states do not allow the use of this herbivore 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 hydrilla is so difficult to control once it has become established, prevention of infestation and early detection of hydrilla 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, 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 waterbody. 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. 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 8). 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
  - Published web sites
  - Workshops and lectures
  - Develop 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, which grows up to three feet in height. The plant has very prominent black, stringy roots. This species sometimes grows stranded in mud and may appear rooted. Until only a few years ago, this floating plant was a major problem in Florida until a statewide maintenance program brought this aquatic weed under control. Its growth rate is among the highest of any plant known. Water hyacinth populations can double in as little as 12 days. These weeds are notorious for clogging canals and waterways in the southern United States. By forming new plantlets, a population can completely dominate and obstruct a body of water in a short period of time.

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 over a wide variety of wetland types from lakes, streams, ponds, waterways, ditches, and backwater areas. Water hyacinth obtains nutrients directly from the water and has been used in wastewater treatment facilities. It prefers and grows most prolifically in nutrient-enriched waters. New plant populations often form from rooted parent plants. Wind movements and currents help 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.

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 native animals and waterfowl. Mats of floating plants prevent oxygen from entering the water while decaying vegetation drops to the bottom. This process consumes dissolved oxygen needed by fish and other aquatic organisms. Excessive oxygen depletion can result in fish kills. As light becomes limiting, it affects the growth and survival of phytoplankton and vascular plants. Oxygen may be so severely reduced beneath a mat that it influences fish habitat and survival. Extensive mats may exacerbate a situation because they prevent water circulation and mixing. Thus, water hyacinth infestations reduce fisheries, shades out submersed plants, crowd out native aquatic plants, and reduce biological diversity in aquatic ecosystems.

Wildlife habitat is altered by the obliteration of open water by the dense rafts of water hyacinth. Migrating birds may not recognize or stop at water bodies covered with water hyacinth. The floating mats provide excellent habitat for disease carrying mosquitoes. The fibrous root system of water hyacinth does provide good habitat for invertebrates and insects. Coots occasionally use leaf blades and petioles. However, the benefits this aquatic weed provides to wildlife are greatly overshadowed by the environmental invasiveness of this noxious species.

Control Options: As an internationally pervasive and detrimental invasive aquatic weed that infests rapidly, water hyacinth has become impossible to eradicate and difficult to control. Chemical and mechanical control methods have provided short- to medium-term control of this aquatic weed. In Florida long-term control of water hyacinth has been achieved using a combination of mechanical and chemical methods. These methods must be used at least annually to provide nuisance control. The mats have been reported to be up to three feet thick which hinders management by chemical or mechanical control. Biological control is still in the research stage to determine which native and naturalized insect species will provide long-term control. Prevention of infestation is the most straightforward management technique. Cultural control of nutrients in runoff from rural and urban watersheds can help control the suitability of freshwater for infestation by water hyacinth. In Florida as an example, even a single year of not controlling water hyacinth could result in millions of dollars in additional control costs to return to the current maintenance levels. Additional research on water hyacinth levels in lakes, streams, and ponds in relation to other aquatic vegetation and fish and wildlife habitat is necessary to establish threshold levels that trigger different control options.

Chemical Control: Herbicides currently used and labeled for the management of water hyacinth as well as information on various commercial formulations and the degree of control to be expected are shown in Table 13. The use of herbicides to control water hyacinth is common. The U.S. Army Corp of Engineers has reported excellent control of water hyacinth by the use of the aquatic herbicides 2,4-D, triclopyr, diquat, glyphosate, and a combination of diquat and complexed copper. Many criteria or questions 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: Herbicide Guides found in the General Review of Best Management Practices section found in this handbook.

The labels from which this handbook were summarized are constantly changing. The most current herbicide label should be reviewed for the most recent 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 water hyacinth management[1]

Herbicide Name	Example Trade Name	Formulation	Quality of Control	Mode of Action
2,4-D Dimethylamine (DMA)	Riverside	Liquid	Excellent	Selective, systemic growth regulator
	Weedar 64			
Diquat	Reward	Liquid	Excellent	Nonselective, contact
Glyphosate	Rodeo	Liquid	Excellent	Nonselective, systemic
Triclopyr	Renovate	Liquid	Excellent	Selective, systemic

[1]Only pesticides specifically labeled and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under the 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 is essential.

Inclusion of pesticides on this list does not imply any endorsement by the AERF, any of the authors, or Spectrum Research, Inc.

Mechanical & Physical Control:

Mechanical control of water hyacinth is a short-term method used to initially control small to moderate infestations (See Table 2 and Table 4). The disadvantage for some mechanical control options is the potential shredding of mats that can potentially further spread vegetative daughter plants. Physical control options, such as drawdowns of the water column, provide medium to longer term control of this invasive aquatic weed (See Table 3 and Table 4). Mechanical control options alone, such as harvesting have been used for nearly 100 years in Florida. When used alone, this technique is ineffective for large scale control, very expensive, and cannot keep pace with the rapid plant growth in large water systems. When used in combination with cultural, chemical, and biological control options, physical and mechanical control provides longer and 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. 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 in a manner that does not contaminate other water bodies. Selection of a good upland disposal site, with no possibility of the clonal fragments washing back into a lake, creek, or river is essential.

Mechanical cutting devises have been proposed control of floating and emergent aquatic weeds such as water hyacinth. The cookie cutter is a barge/cutting system developed in

Florida to deal with emergent aquatic vegetation, floating islands of vegetation and sediment, and to cut openings in shoreline and wetland areas through emergent wetland plants. This technology has some potential for control of the clonal mats of water hyacinth. The cookie cutter probably has application against some invasive species, including water hyacinth, when there are extensive infestations that need to be reduced very rapidly in an aquatic or wetland area. It is often selected to open areas in heavily infested wetlands and shoreline to improve nesting habitat and waterfowl 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 birds.

Drawdown of the water column has been suggested for control of water hyacinth. The use of drawdown for aquatic plant management is limited to those lakes or ponds that have sufficient water control structures and hydrologic characteristics to adequately control water level, and where drawdown will not interfere with other primary water uses such as domestic or irrigation supplies, navigation, or hydrologic power.

Biological Control:

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

Neochetina spp. (*Neochetina bruchi* Hustache – Chevroned water hyacinth weevil; *Neochetina eichhorniae* Warner – Mottled water hyacinth weevil). The chevroned water hyacinth weevil 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 was first introduced in Florida in 1972 and was released in Alabama, California, Louisiana, and Texas in the following few 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. Both 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. However, the *Neochetina* spp. do not appear to rapidly control water hyacinth populations in a manner similar to the agents released for alligatorweed control. It takes at least 3 to 5 years to see any persistent control using these species. Their impact to water hyacinth 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 other adverse environmental condition, like freezing temperatures, reduces the plant to more realistic levels.

Frequent and long-term management of water hyacinth using chemical applications can adversely affect the ability of the two weevil species to impact the plant. Care should be taken in leaving 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. This species 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.

Water hyacinth moth, in some instances, can tremendously damage water hyacinth in the field. This is especially true for those plants growing in more open water. However, 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. However, 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 recreational 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 waterbody. 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. 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 waterbody.

Once 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 8). 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
    - Published web sites

- Workshops and lectures
- Develop 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 control the suitability of freshwater suitability 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 components of water quality protection.

Purple Loosestrife [*Lythrum salicaria* L.]

Description: Purple loosestrife is an erect, emergent perennial herb. This dicot has a square, woody stem and opposite or whorled leaves (Figure 8). Leaves are lance-shaped, stalkless, and heart-shaped or rounded at the base. 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 vegetatively from a single rootstock of the previous year. So called "guaranteed sterile" cultivars of purple loosestrife can be highly fertile and able to cross freely with purple loosestrife and with other native *Lythrum* species. Therefore, outside of its native range, purple loosestrife of any form should be avoided.

Habitat & Range: Purple loosestrife is a beautiful, but very aggressive invader of many wetland types, 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. 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 1800s, 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 now occurs in every state except Florida and all Canadian Provinces.

Effects on Fish & Wildlife:

Purple loosestrife is a very aggressive emergent, aquatic/wetland weed. Once purple loosestrife enters a wetland, it can completely dominate the ecosystem. Eventually purple loosestrife will suppress the native ecosystem and alter the structure and function of wetland. This also will occur in shallow aquatic systems and moist uplands. Wild rice areas in shallow lakes and bays also can be eliminated by invasions of purple loosestrife.

Native wetland and aquatic plants usually cannot compete with purple loosestrife in wetlands. Native plants are usually choked out by purple loosestrife. Waterfowl, fish, and other wetland and aquatic species lose an important source of food and shelter. Purple loosestrife has little value as food for waterfowl and animals. Monocultures of loosestrife can become so dense and thick, that fish and wildlife can no longer use the infected area for cover or reproduction. Purple loosestrife also invades the shallow waters of northern pike spawning areas, which ruins these areas as spawning grounds.

Control Options:

Considerable effort has been expended to develop control techniques for purple loosestrife. Except for control of low density and small invasions, integrated best management practices will control but not eliminate medium to high density 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 control provides 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 on long-term biological control of purple loosestrife is continuing in North America. Several biological control agents are being actively evaluated and 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. These plant-eating insects include a root-mining weevil (*Hylobius transversovittatus*), and two leaf-feeding beetles (*Galerucella calmariensis* and *Galerucella pusilla*). Two flower-feeding beetles (*Nanophyes*) that feed on various parts of purple loosestrife plants are still under investigation.

Chemical Control:

Until the 1980's, the resistance of purple loosestrife to available herbicides gave wetland managers a limited choice of compounds for controlling this hardy exotic. Recent research has shown that at low to medium density for isolated to medium acreage, herbicide control can be effective used in combination with mechanical and cultural control options. The U.S. Army Corp of Engineers has reported relatively good control of purple loosestrife using the aquatic herbicides 2,4-D, glyphosate, triclopyr, and imazapyr. For older plants, spot treating with a 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. However, 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 14. Many criteria or questions 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: Herbicide Guides found in the General Review of Best Management Practices section found in this handbook.

The labels from which this handbook were summarized are constantly changing. The most current herbicide label should be reviewed for the most recent 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 purple loosestrife management[1]

Herbicide Name	Example Trade Name	Formulation	Quality of Control	Mode of Action
2,4-D Dimethylamine (DMA)	Weedar 64	Liquid	Good	Selective, systemic growth regulator
Glyphosate	Rodeo	Liquid	Good	Nonselective, systemic
Triclopyr	Renovate	Liquid	Excellent	Selective, systemic
Imazapyr[2]	Arsenal	Liquid	Good	Nonselective, systemic
Land application only	Arsenal 0.5	Granular		

[1]Only pesticides specifically labeled and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under the 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 is essential.

[2]Currently under Experimental Use Permit (EUP) registration for aquatic sites.

Inclusion of pesticides on this list does not imply any endorsement by the AERF, any of the authors, or Spectrum Research, Inc.

Mechanical & Physical Control:

Mechanical control of purple loosestrife is a short-term method used to control low to medium density infestations. They are 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. 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 in sand. 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. Small infestations of young purple loosestrife plants may be pulled by hand, preferably before seed set.

Cutting flowering spikes 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. However, raising water levels may provide some control. It has been reported that submerged purple loosestrife can survive for many years. However, 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. disc) the topsoil to encourage the establishment of seedlings or propagules of desirable food or cover plants. The 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 control option for extensive and 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 Goeze is a root-boring weevil. Adult weevils feed on foliage and stem tissue. The larvae feed on root tissue for 1 to 2 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. Aside from this restriction, the species appears quite tolerant to a wide range of environmental conditions. Adult feeding has little control effect. However, feeding by larvae can be very destructive to purple loosestrife root stock. Currently this biological control organism is being mass produced by Bernrd Blossey at Cornell University.

Galerucella calmariensis L. and *Galerucella pusilla* Duft are leaf eating beetles which 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 spring soon after shoot growth of purple loosestrife. Adults feed on shoot tips. Young larvae feed on developing leaf buds; older larvae feed on all above ground plant parts. Both species occur throughout the native range of purple loosestrife in Europe and Asia. Both species have been released in over 27 states and 6 Canadian Provinces. *G. calmariensis* is more common since the species was easier to mass produce than *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: Purple Loosestrife).

Nanophyes marmoratus Goezec is a flowering eating beetle that severely reduces seed production of purple loosestrife. A similar flower eating beetle *Nanophyes brevis* also is being considered as a potential biological control agent for purple loosestrife, but has not been released. *Nanophyes marmoratus* is widespread in Eurasia and tolerates a wide range of environmental conditions. The species has been introduced into 7 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. The new generation beetles appear mainly in August and feed on the remaining green leaves of purple loosestrife. The beetles overwinter in the leaf litter. Development from egg to adult takes about 1 month and there is one generation per year. Adult and larval feeding causes flower-bud abortion, thus reducing the seed output of purple loosestrife.

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 in the spring (from the state agency or specific field site), rearing insects on loosestrife in kiddy 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 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 aquatic species, it is imperative that **all** plant fragments are removed from clothes, equipment, and boats before putting in or leaving a lake's access area. 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 or wetland.

Purple loosestrife is still available in some states as a garden plant. Education programs should be started to inform the public of the danger of this plant. 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 state 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 8). 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
  - Published web sites
  - Workshops and lectures
  - Develop full fledged public outreach program via university extension service or Sea Grant programs

{PRIVATE **}Brazilian Elodea** [*Egeria densa* Planch.]

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 leaves are 1 to 3 cm long, up to 5mm 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 a lakes and rivers by interfering with navigation, fishing, swimming, and water skiing.

Habitat & Range: It is found in both still and flowing waters, in lakes, ponds, pools, ditches, and quiet streams. It tends to form dense monospecific stands that can cover hundreds of acres and can persist until senescence in the fall.

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.

Effects on Fish & Wildlife: Problems associated with this species include: displacement of native vegetation and interference with normal development of fish and wildlife habitat by the formation of impenetrable mats and decreased water flow. The rapid growth rate of this species allows it to cover water surfaces and displace native vegetation. It can form thick underwater stands of tangled stems. Dense stands of Brazilian elodea provide habitat for mosquitoes and may increase populations of some species of mosquitoes.

Brazilian elodea competes aggressively to displace and reduce the diversity of native aquatic plants and fish and wildlife habitat. Two major growth flushes occur in the spring and fall. Each of these flushes is followed by periods of senescence, with a loss of biomass through sloughing and decay of tips and branches. When Brazilian elodea invades a body of water, formation of a dense canopy and light reduction are the two significant factors in the decline of native plant abundance and diversity. This change in habitat quality quickly affects fish, wildlife, and other aquatic organisms. Over time, Brazilian elodea will out-compete or eliminate the 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. Brazilian elodea also has lower value as a food source for waterfowl than the native plants it displaces.

Fish populations may initially experience a favorable edge-effect increase in abundance with the establishment of this invasive weed. However, 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, which serve as fish food. Dense cover does allow high survival rates of young fish. However, 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.

Control Options: As a potentially detrimental invasive aquatic weed, regional effort has been expended to develop control techniques for Brazilian elodea. Typically, prevention of invasion of lakes, streams, and rivers is the best method of avoiding the development of uncontrolled monocultures of Brazilian elodea. Chemical and mechanical control provides 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 as a potential biocontrol agent. This fungal pathogen is being actively evaluated. However, at this time the only known available biological agent is 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 are necessary to establish threshold levels that trigger different control options.

Chemical Control: Control of Brazilian elodea with diquat and complexed copper, endothall dipotassium salt, and endothall and complexed copper has been reported. However, the endothall dipotassium salt is considered by aquatic plant managers to be less than effective against Brazilian elodea. Good control has been obtained with fluridone. California reports good control achieved using complexed copper alone. However, endothall, fluridone, and copper are permitted for aquatic use in Washington waters, but copper is generally permitted only as an algaecide.

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 15. Many criteria or questions 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: Herbicide Guides found in the General Review of Best Management Practices section found in this handbook.

The labels from which this handbook were summarized are constantly changing. The most current herbicide label should be reviewed for the most recent 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 15. Herbicides used for Brazilian elodea management[1]

Herbicide Name	Example Trade Name	Formulation	Quality of Control	Mode of Action
Diquat	Reward	Liquid	Good	Nonselective, contact
	Weedtrine-D	Liquid	Good	
Fluridone	Sonar A.S. Avast!	Liquid emulsion	Good	Selective (based on application rate), systemic
	Sonar PR Sonar SRP Avast!	Slow release pellets	Good	

[1]Only pesticides specifically labeled and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under the 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 is essential.

Inclusion of pesticides on this list does not imply any endorsement by the AERF, any of the authors, or Spectrum Research, Inc.

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 extent of the infestation is such that all available niches have been filled. Using mechanical controls while the plant is still invading, will tend to enhance its rate of spread. Mechanical control of Brazilian elodea is a short-term method used to initially control small to moderate infestations (See Table 2 and Table 4). Physical control options provide medium to longer term control of this invasive aquatic weed (See Table 3 and Table 4). When used in combination with cultural, chemical, and biological control options, physical and mechanical control provides longer and sustained control of Brazilian elodea. The following is a brief description of the more successful mechanical and physical control practices.

Hand cutting tools have been used to control all submersed aquatic weeds, including Brazilian elodea. Harvesting Brazilian elodea is a very effective option for short-term clearance of the vegetation from the upper portions of the water column. Harvesting 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 in a manner that does not contaminate other water bodies. Select good upland disposal site, with no possibility of the plant fragments washing back into the water body.

Rotovation of Brazilian elodea may be an effective technique when used properly. Brazilian elodea reproduces primarily by fragmentation. When a shoot fragment that contains a double node sinks it has great potential to form a new plant. Rotovation targets the roots by tilling the sediment resulting in the release of the roots.

Diver dredging has been used against Brazilian elodea. Diver dredging systems are best utilized against pioneering infestations of Brazilian elodea. Where pioneering colonies of the plant are discovered interspersed with native plants this technology can selectively remove the Brazilian elodea. 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 which blocks light from the plants. Managers of reservoirs and some lake systems may have the ability to lower the water level as a method of managing aquatic plants. It has been found that consecutive drawdowns maybe more effective that an individual drawdown. The success of a drawdown is dependent on several 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:

Insects or pathogens with field biocontrol potential for Brazilian elodea are currently unknown. However, recent research in Brazil has identified a fungus (*Fusarium* spp.), which damaged Brazilian elodea in laboratory tests. This may have potential as a biocontrol agent for Brazilian elodea.

Fortunately triploid grass carp (when older than fingerlings) find Brazilian elodea highly palatable. Grass carp have been successfully employed as a management tool. Brazilian elodea is highly preferred over most native species and theoretically, it should be possible to remove Brazilian elodea while favoring the growth of native species. However, 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 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 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. 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.

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 8). 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
  - Published web sites
  - Workshops and lectures
  - Develop full fledged public outreach program via university extension service or Sea Grant programs

Algae

Description: Understanding differences among the three major groups of algae is important when considering solutions to algae problems. The three different groups (based on growth form) are: microscopic algae (primarily phytoplanktonic), 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 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 1960s and 70s. 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. The trapped bubbles 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 *Chara* and *Nitella* 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, but some species also are 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. They can be found in swimming pools, water supply reservoirs, and aquaculture and fish hatchery facilities. Some species are considered to be invasive. For example, *Cylindrospermopsis*, a microscopic blue-green alga that is toxic, appeared in Florida lakes in the early 1990s. This species has now spread to other parts of the country.

Effects on Fish and 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, however, may cause detrimental effects on aquatic systems, endangering the organisms that live and depend on these systems. Excessive algal growths also hamper or prevent human uses of infested waterways. Population crashes (death) and the microbial decomposition of the dead algal cells result in the depletion of dissolved oxygen. 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 (at least 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 than 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 algal 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 control of algae is accomplished with copper and endothall dimethylalkylamine salt. Algicides currently used and labeled for the management of algae in aquatic systems as well as information on various commercial formulations and the degree of control to be expected are shown in Table 16.

Many criteria or questions 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: Herbicide Guides found in the General Review of Best Management Practices section found in this handbook.

The labels from which this handbook were summarized are constantly changing. The most current herbicide label should be reviewed for the most recent 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 16. Algicides used for algae management[1]

Herbicide Name	Example Trade Name	Formulation	Quality of Control	Mode of Action
Complexed copper	Cutrine-plus	Liquid or Granular	Good	Plant cell toxicant
	Clearigate			
	K-Tea			
Copper	Triangle Copper sulfate crystal	Granular	Good	
Growth Retardant Dye	Aquashade	Liquid	Fair to Good	Inhibits photosynthethesis
Endothall Dimethylalkyl-amine salts	Hydrothol 191	Liquid or Granular	Good	Nonselective, contact

[1]Only pesticides specifically labeled and approved by the US Environmental Protection Agency for application should be applied. Pesticides should be applied only by or under the 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 is essential.

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Mechanical And Physical Control:

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

Physical control methods mostly involve in-water reductions of nutrients, particularly phosphorus, 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. However, 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 blue-green 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 2-3 feet. However, 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, 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. However, some lakes are nitrogen (N) limited, particularly in the western part of the U.S. Both N and P limitation have been implicated in the regulation of mat-forming algal growth.

Although both N and P are required to support algal growth, most reduction efforts concentrate on P because it is easier to reduce from a technical standpoint than is N. Clearly where N fixation by planktonic blue-green algae is a response to N reduction, P should be the more reliable means to lower algal biomass. There are three general approaches to achieving phosphorus reduction: (1) decrease external P loading, (2) suppress internal P loading, and (3) increase P output from the system. Decreasing external inputs of P 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 P 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 reduce or controlled. The approach of releasing P-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 as additional reading for water, fisheries, and resource managers. This list certainly does not attempt to be an exhaustive literature database. References in bold typeface are particularly good sources of additional information.

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Figure 3. Eurasian watermilfoil.

Figure 4. Water chestnut.

Figure 5. Giant Salvinia

Figure 6. Hydrilla

Figure 7. Water hyacinth

Figure 8. Purple loosestrife

Figure 9. Brazilian elodea