Aquatic Vegetation Management in Texas: A Guidance Document

Texas Parks & Wildlife Department

INLAND FISHERIES

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Aquatic Vegetation Management in Texas

I. Background

This is the guidance document described in §57.932 of Texas Parks and Wildlife Department (TPWD) rules. Rules pertaining to the management of aquatic and riparian plants are found in Appendix B (return to index to see Appendix B) of this document. State law directs TPWD to develop a statewide management plan to guide decision making regarding nuisance aquatic vegetation in public water**.** This document describes the best available strategies and alternative treatment methods for prevention and management of nuisance aquatic vegetation problems, Guidance provided in this document is consistent with the principles of Integrated Pest Management (IPM). TPWD rules define IPM as:

> The coordinated use of pest and environmental information and pest control methods to prevent unacceptable levels of pest damage by the most economical means and in a manner that will cause the least possible hazard to persons, property, and the environment. Integrated pest management includes consideration of ecological, biological, chemical, and mechanical strategies for control of nuisance aquatic vegetation.

This document is also intended to assist individuals and organizations in meeting the procedural requirements of state law and rules. The document contains explanatory information, step-by-step procedures, and sample forms.

Aquatic vegetation is an extremely important component of most freshwater systems, providing habitat, refuge, and food for a wide variety of organisms including fish, invertebrates, and waterfowl. It is well documented that aquatic vascular plants serve as habitat for numerous invertebrate species (Muttkowski 1918; Soszka 1975; Biltgen 1981). Habitat complexity increases with plant biomass and is well correlated with increased abundance and diversity of aquatic invertebrates (Heck and Wetstone 1977; Stoner 1980; Wiley et al. 1984; Bell and Westoby 1986). As a result, plant communities often support a large percentage of the total invertebrate biomass in a system. For example, Watkins et al. (1983) found the number of benthic organisms associated with vegetation in one Florida lake was triple that in unvegetated areas, and Wiley et al. (1984) found that macrophytes increased invertebrate abundance by as much as 90% in Illinois ponds. Similarly, Iversen et al. (1985) reported 95% of invertebrates in the River Susa, Denmark, were found in vegetation. Obviously, increased production of invertebrates can have strong implications for fishery productivity since most freshwater fish species consume invertebrates during some portion of their life cycles.

There are also instances when excessive aquatic vegetation growth may detrimentally affect fishery and wildlife resources, or limit access for fishing, hunting, and other recreational activities. Maceina and Reeves (1996) found the lowest average weight of fish caught during largemouth bass fishing tournaments occurred during peak macrophyte coverage. Similarly, Hoyer and Canfield (1996) found a direct relation between macrophytes and young of the year largemouth bass abundance, however, there was an inverse relation between plant abundance and bass growth. A number of researchers have found that dense plant communities may inhibit the feeding efficiency of invertivorous fishes (Crowder and Cooper 1982; Minello and Zimmerman 1983; Heck and Wilson 1987; Russo 1987). In some cases plant species, as well as abundance, can have a strong influence on fish populations. For instance, Dibble and Harrel (1997) found significant differences between largemouth bass feeding in common pondweed *Potamogeton nodosus*, versus those feeding in Eurasian watermilfoil *Myriophyllum spicatum*, despite similar plant densities. Those feeding in pondweed fed heavily on macroinvertebrates, whereas those feeding in watermilfoil fed much more heavily on fish.

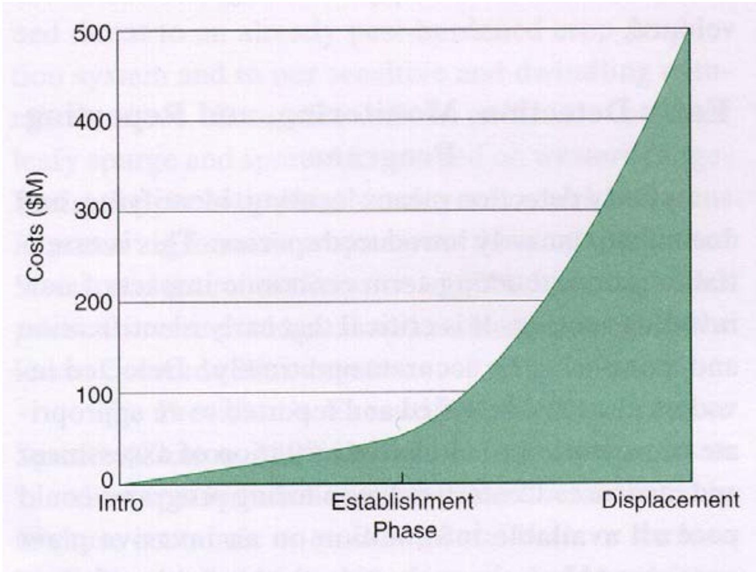
Overabundant aquatic vegetation is typically the result of introduction of exotic species which out-compete native plants and grow unchecked by natural herbivores or parasites. For example, two of Texas' most problematic aquatic plant species, hydrilla *Hydrilla verticillata* and water hyacinth *Eichhornia crassipes,* are not native to North America.

Other reasons for aquatic vegetation reaching nuisance proportions may include disturbed habitat and nutrient loading. Construction of reservoirs in Texas dramatically changed the aquatic and terrestrial landscape of the state. These reservoirs have provided flood control, water for agriculture and municipalities, power plant cooling, areas for recreational use, and fish and wildlife habitat that did not exist in Texas. However, like most disturbed habitats, many reservoir ecosystems have not developed stable aquatic plant communities. The fluctuating water levels of many reservoirs make the establishment and spread of native vegetation difficult. Exotic plant species succeed in Texas reservoirs because these species are adapted to rapidly fill ecological niches created by disturbed or unstable habitats, and because native herbivores may not readily feed on exotic plants. When exotic species are introduced into these systems, growth and spread of these aquatic plants can be quite dramatic. Nutrient-rich water speeds growth and spread of vegetation, including nuisance vegetation. Elevated nutrient input may come from a variety of sources including farm runoff, runoff from fertilized lawns, sewage treatment facilities, septic tanks, etc. Exotic plant species have been introduced and spread through Texas by a variety of mechanisms. Well-meaning aquarists and water gardeners are often unaware the plants they are buying are illegal in Texas (and sometimes the United States), and one flood is all it takes to carry unwanted plants from the backyard to the river. Once plants have been introduced they are often spread by waterfowl and wildlife. Boaters may also unknowingly carry plants from one water body to another via trailers, live wells, and motor lower units.

II. Prevention

The backbone of every effective program to control nuisance aquatic weeds is prevention. If possible, nuisance exotic aquatic weeds should be prevented from colonizing new waters, and if colonization does occur they should be prevented from spreading. Prevention is the least costly method of controlling aquatic weeds. Figure 1. illustrates the exponential rise in management costs as exotic plants are introduced, become established, and finally may displace native species. In general, prevention strategies fall into five categories, which are discussed below.

Figure 1. Comparing invasion phase with management costs shows that prevention is the least costly phase, with costs rising exponentially once the invading weed has become established and increasing further if it is displacing native species and/or disrupting native habitats (From Mullin et al. 2000). Costs are shown in millions of dollars.



Root causes

The root causes of nuisance aquatic vegetation - habitat disturbance, nutrient loading, lack of efficient herbivores, transportation and introduction of exotic plant species into previously uncolonized areas via boats, trailers, wildlife, and intentional releases- must be addressed if aquatic plant management in Texas is to succeed on a sustainable basis. Although aquatic herbicides, biological controls and mechanical controls can be effective in controlling or managing aquatic vegetation, these are all short-term solutions. Strategies for **preventing** nuisance aquatic vegetation will produce better and longer-lasting results than those directed at managing problematic vegetation. In that regard, managers should seek solutions to the root causes of nuisance aquatic vegetation.

One of the chief causes of nuisance vegetation growth is nutrient enrichment. Nutrient loading (eutrophication) is the process of adding surplus nutrients required for plant photosynthesis and growth (primarily nitrogen and phosphorus) to an ecosystem. The nutrients can either come from point sources (e.g., sewage treatment plants or agri-industrial effluent) or non-point sources (e.g., septic tank field lines or fertilizer runoff from lawns, fields, golf courses, etc.). Although some increase in nutrient inflow can be beneficial by increasing plankton production and native plant growth, an overabundance of nutrients may cause water quality problems and increase the likelihood that hydrilla and other nuisance plants will grow beyond control.

Steps to follow for reduction of nutrient loading include:

a. Contact the Texas Commission on Environmental Quality (TCEQ) to ensure that all point sources for nutrient inflow within the watershed are within permitted limits.

b. Educate property owners in the reservoir's watershed urging that septic systems be checked for proper operation, that turf and field fertilizer be limited to the amount necessary, and that vegetated buffer zones be established between activities that cause nutrient loading (livestock production operations, golf courses, etc.) and the reservoir or its tributaries.

Monitoring and rapid response

If the spread of nuisance aquatic vegetation is to be controlled, the help of all Texans who enjoy fishing, boating and contact recreation on our rivers, streams and reservoirs must be enlisted. Citizens' organizations and advisory groups may be used to aid in early detection of nuisance species infestations, as well as to provide input relative to the most appropriate management techniques for specific water bodies. When new infestations are discovered and management is deemed appropriate, water managers must be able to respond immediately. TPWD's experience predicts that the short-term costs associated with immediate response are often less than the costs related to "no management" or delayed management. Therefore, programs that enlist the aid of anglers, boaters, and other recreational enthusiasts should be encouraged, since they are often aware of new infestations before biologists. Exotic aquatic plants are here for the foreseeable future and everyone must get involved.

Research

TPWD is committed to ongoing research regarding ecology and management of aquatic vegetation. Over the next few years, TPWD will team with its partners to:

- Evaluate mechanical means of aquatic vegetation management.
- Evaluate the efficacy of reduced concentrations of aquatic herbicides in aquatic vegetation management.
- Continue research regarding native aquatic vegetation planting and restoration. The advantages of native plant species are understood, but much remains to be learned about the most appropriate species for a body of water, how to produce plants in quantities necessary for replanting, and the best way of maintaining re-vegetated habitats.
- Research the safety, efficacy and ecological benefits of biological controls. Biological control has significant potential, particularly when appropriately applied as part of an IPM approach to plant management. While grass carp biology and efficacy have been extensively researched, the use of this biological tool in an IPM plan that stresses establishing or re-establishing native vegetation remains to be carefully researched. Therefore, research into use of other types of biological controls, particularly insects and fungi, will continue.
- Better understand the best management practices necessary for preventing introduction and spread of nuisance aquatic vegetation.

Education

In Texas, where exotic plant distribution is becoming widespread, it is difficult to completely eliminate inadvertent spread of exotic plant species among public waters. However, an aggressive educational program could slow or prevent the distribution of these plants into new areas of the state. The solution may lie in developing and implementing programs to educate water managers, water resource users, and merchants (such as fishing clubs, boaters, aquaculturists, water gardeners, and aquarium hobbyists) about the problems that can arise from the transportation and consequent introduction of exotic aquatic plants. Programs will focus on best management practices necessary to prevent the spread of exotic aquatic plants. Citizens' organizations and advisory groups can play an important role in disseminating valuable information to the public.

Law enforcement

Current statutes and regulations provide penalties for possession, transport and placement of prohibited plant species in public water. Active law enforcement in other states has proved to be a very powerful means of preventing spread of nuisance species and of educating the public about the hazards of transporting and transplanting exotic plants. TPWD will team with its partners to strengthen and coordinate law enforcement activities.

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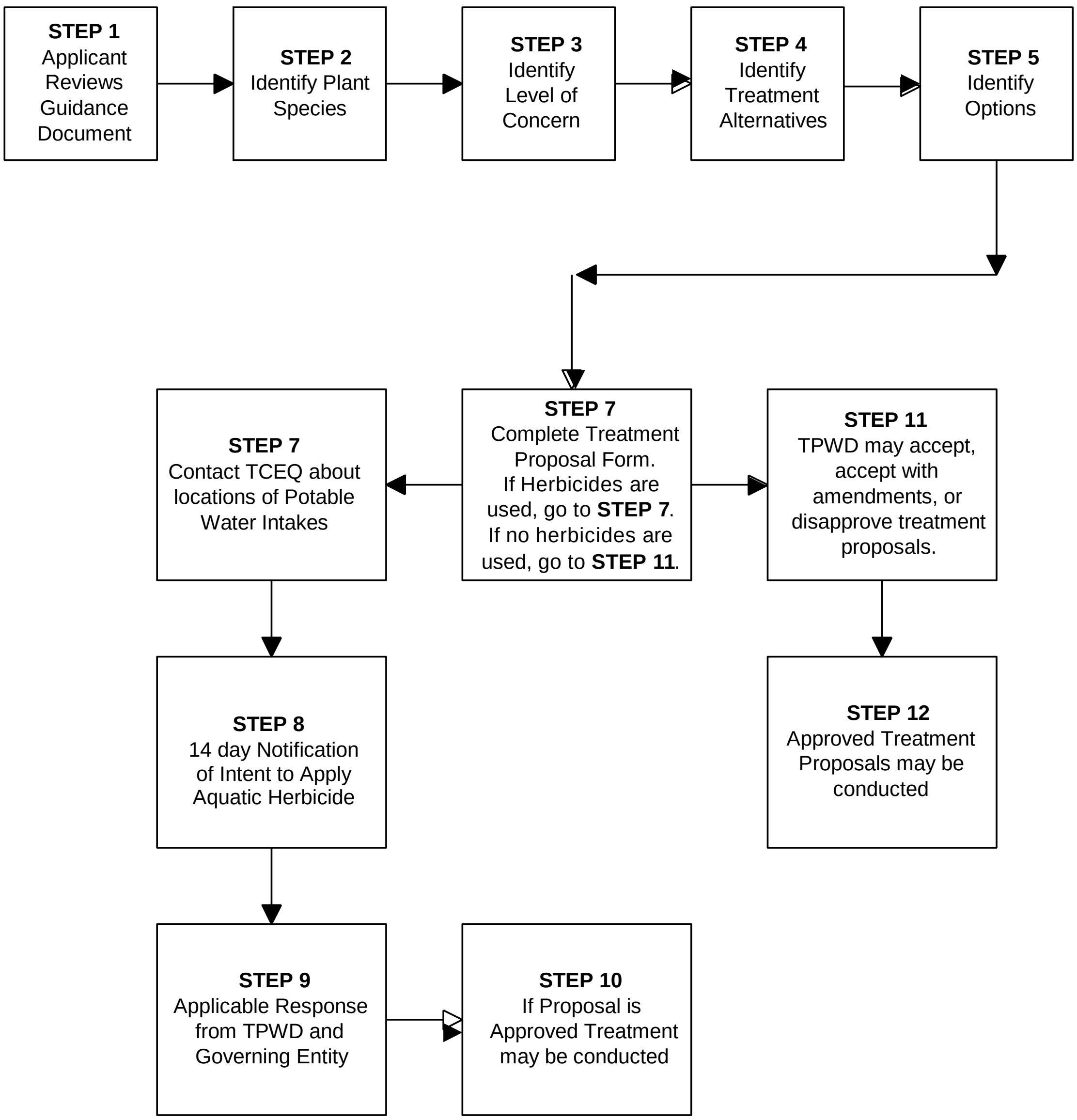
III. How to Develop an Aquatic Vegetation Treatment Proposal

Figure 2. Texas Vegetation Management Plan Process



Note: Pages 46 - 47 describe the steps above in detail.

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A. Identifying Vegetation Species

Correctly identifying aquatic vegetation species is critical for understanding what management options are available, and which are most efficacious. Often, vegetation species that are similar in appearance have entirely different management options. Published keys (e.g., Fassett 1957) are useful for identification. Unfortunately, many keys use only line drawings to aid in identification. The University of Florida Center for Aquatic and Invasive Plants maintains an internet site (http://plants.ifas.ufl.edu/) that provides color pictures and descriptions of many aquatic vegetation species. If you are not sure what type of vegetation you have please request assistance from a TPWD biologist (return to index to see Appendix D). Information is provided below for selected problematic aquatic and riparian exotic invasive plants in Texas. All are regulated by either the Texas Department of Agriculture (TDA) or TPWD.

Alligatorweed

Alligatorweed (*Alternanthera philoxeroides*) has been described as an amphibious plant because it grows in a wide range of habitat types including both terrestrial and aquatic (Vogt et al. 1979). It may be found as either a floating plant or a rooted plant. The aquatic form usually has hollow stems, whereas the terrestrial form does not. The plant originated in the Parana River region of South America (Maddox 1968, Vogt et al. 1979), but has since spread to other areas of South America, as well as North America, Asia, and Australia (Julien et. al. 1995). Flowering stems are upright. Leaves are usually elliptic and may be up to 4 inches long. Flowers bloom from April through October if conditions are favorable. Similar to water hycacinth and water lettuce, alligatorweed can clog waterways and limit boating, fishing, hunting, and swimming access. Low oxygen problems may also result where water bodies are completely covered.

Photo to the left by Robert H. Mohlenbrock, USDA-NRCS PLANTS Database / USDA SCS. 1991.

Eurasian watermilfoil

Eurasian watermilfoil (*Myriophyllum spicatum*) is an aquatic plant native to Europe and Asia which was first introduced into North America in the late 19th century (Reed 1977). In recent years it has gained a reputation as a nuisance plant species (Nichols and Shaw 1986). Although it is quite similar to the

North American native watermilfoil (*M. exalbescens*), the species can usually be distinguished on the basis of leaf morphology. In general, Eurasian watermilfoil produces 5-24 pairs of leaflets per leaf, whereas the North American native watermilfoil produces 4-14 (Aiken and McNeill 1980). About 70% accuracy can be obtained by characterizing everything with 14 or more pairs of leaflets as Eurasian watermilfoil (Nichols 1975).

Eurasian watermilfoil flowers in mid-June through late summer. In addition to flowering, the plant may reproduce asexually by producing vegetative buds and by fragmentation (Nichols 1975*).* Eurasian watermilfoil may survive winter seasons as a whole plant, as a root mass, or by producing turions or winter buds (Stuckey et al. 1978; Titus and Adams 1979).

Eurasian watermilfoil is a very good competitor capable of displacing native submerged plant species, reducing both habitat diversity and plant species diversity. When overabundant this species can create many of the same problems as hydrilla, including reduced boat access, reduced access to other recreational opportunities such as swimming and skiing, and low dissolved oxygen levels.

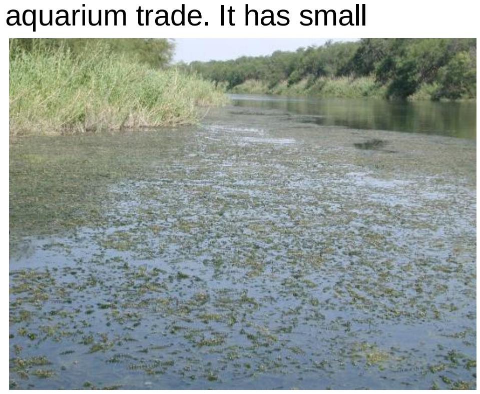
Giant Reed

Giant reed (*Arundo donax*) is a large, bamboo-like grass that can grow 20-30 feet tall. It is a hydrophyte that grows along the shores/banks of lakes, streams, drains and other wet areas, using prodigious amounts of water, Giant reed is native to fresh waters of eastern Asia (Polunin and Huxley 1987);, however it has been widely cultivated throughout Asia, southern Europe, north Africa, and the Middle East for thousands of years. In the 1820's it was intentionally introduced to California for erosion control in drainage canals, and was also used to thatch rooftops (Hoshovsky 1987)*.*

Giant reed grows very well in the Mediterranean-like climate of the lower Rio Grande valley and has invaded thousands of acres of riparian habitat along the river. Additionally, it can now be found growing along hundreds of miles of Texas highways and train tracks. Under optimal conditions it can grow more than 2 inches per day and produce more than 20 tons per hectare of above-ground dry mass (Purdue 1958).

Hydrilla

Hydrilla (*Hydrilla verticillata*), one of Texas' most problematic aquatic plant species, was introduced into Florida in the early 1950's through the aquarium trade. It has small (0.5-1.0 inches) leaves arranged in whorls around the stem and was initially marketed as Indian star-vine (Schmitz 1990). Since then the plant has spread throughout Florida, also becoming established widely throughout eastern seaboard states as well as California and Washington (Netherland 1997). As a result of its rapid growth and competitive ability, hydrilla populations often exceed beneficial



levels. Bowes et al. (1979) reported dense surface mats of hydrilla may cause wide fluctuations in dissolved oxygen levels, pH, and temperature. Overabundant hydrilla may also reduce plant and animal diversity (Barnett and Schneider 1974) and stunt sport-fish populations (Colle and Shireman 1980). Flow rates in canals and rivers may be restricted (TPWD staff observations), and access may become limited, precluding water recreation, as well as the economic benefits of recreational activities (Colle et al. 1987).

Two characteristics that are most problematic include its rapid growth rate under a wide range of environmental conditions, and its ability to reproduce in a variety of ways. Hydrilla can grow up to one inch per day until it nears the surface of the water. Once near the surface it forms a thick mat of branches and leaves that intercept sunlight, often preventing native plants from growing underneath. Hydrilla commonly occurs in reservoirs ranging from oligotrophic (low in nutrients) to eutrophic (high in nutrients) conditions. Although hydrilla does best at pH of 6-8 (Langeland 1990) it can grow under a wide range of pH conditions. Hydrilla can also tolerate relatively high salinity, but perhaps its greatest advantage is the ability to grow and photosynthesize in less than 1% of full sunlight (Haller 1978). This allows hydrilla to colonize deeper water, frequently growing in water 3 yds deep with instances of establishment in very clear water up to 15 yds deep. It is this ability to grow at greater depths that allows hydrilla to cover such a large portion of relatively shallow Texas reservoirs.

Hydrilla can reproduce in a variety of ways including fragmentation, tubers, turions, and seeds (Langeland 1990). The ability of hydrilla to reproduce from fragments aids its rapid spread within reservoirs and from one reservoir to another. Nearly 50% of fragments with a single leaf whorl can sprout a new plant (and subsequently a new population). For fragments with three or more leaf whorls, the success rate is over 50%. It is easy to see why hydrilla is spread easily by boats, boat trailers, wildlife, and discarded aquarium water.

Tubers are actually subterranean (underground) turions that can remain dry for several days and still remain viable. Tubers can be buried in undisturbed wet sediment for over four years and survive. They can also survive herbicide treatment and ingestion and regurgitation by waterfowl. It is largely the tubers that allow hydrilla to remain established even during an aggressive treatment program. A single tuber can potentially produce 6,000 new tubers per yd^2.

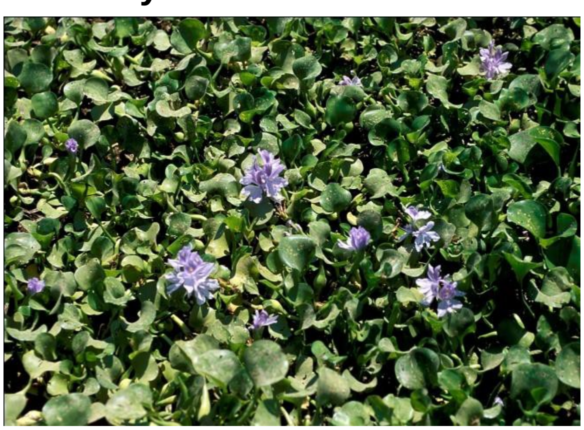
Turions that form in leaf axils are another potential means of hydrilla expansion. A single turion can potentially produce over 2,800 additional turions per yd^2.

Although hydrilla can reproduce sexually, seed viability is low and the overall importance of seed production is unknown. So far in Texas only dioecious populations of female plants have been found, so seed production in Texas is unknown.

Salvinia

Two species of aquatic fern, genus *Salvinia*, have been identified in Texas. Both are small floating plants with oval shaped leaves (fronds) that have tiny hairs on the upper surface. Common salvinia (*S. minima* was first identified in Jefferson County (Port Arthur area) in 1992 while the more ecologically threatening giant salvinia (*S. molesta*) was first identified in the Houston area in Spring 1998. Common salvinia is smaller and is readily distinguished from giant salvinia by the morphology of its leaf hairs. In common salvinia the hairs are split four ways near the tip. In giant salvinia the hairs are also split, but they come together at the tip forming an egg-beater type structure. Typically, mature leaves of giant salvinia are quarter to half-dollar sized, about twice the size of common salvinia. All salvinia species are on the state's "Harmful or Potentially Harmful Exotic Fish, Shellfish, and Aquatic Plants" list, which means they are prohibited in the State of Texas. Giant salvinia, also known as Kariba Weed, has spread from its native habitat in southern Brazil to many other countries around the world including Australia, New Guinea, New Zealand, Zambia, Zimbabwe, and now to the United States (Mitchell 1976). It ranks second behind water hyacinth on the nuisance aquatic weed list where it was placed in 1984 (Barrett 1989). Giant salvinia damages aquatic ecosystems by outgrowing and replacing native plants that provide food and habitat for native animals and waterfowl. Additionally, salvinia blocks out sunlight and decreases oxygen concentration to the detriment of fish and other aquatic species. When plant masses die, decomposition lowers dissolved oxygen still further. Blockage of waterways to traffic is common. Giant salvinia infestations often expand very rapidly. Doubling times as low as two days have been observed in the laboratory, and under field conditions doubling times of approximately a week

Water hyacinth



Water hyacinth (*Eichhornia crassipes*) is a large floating plant, native to South America, which has been called the world's worst aquatic weed (Cook 1990). It is believed to have been introduced into the United States at the World's Industrial and Cotton Centennial Exposition of 1884-1885 in New Orleans, Louisiana, and may have been cultivated in the U.S. as early as the 1860's (Tabita and Woods 1962). By the late 1890's, water hyacinth had become such a problem for navigation that Congress was prompted to pass The Rivers and Harbors Act of 1899 which authorized the U.S. Army Corps of Engineers (ACOE) to begin major aquatic plant control programs (North American Lake Management Society and Aquatic Plant Management Society 1997). Water hyacinth reproduces by budding daughter plants, or by producing seeds when its distinctive purple flower is in bloom. Populations may double in size every 6-18 days (Mitchell 1976). Perhaps due to its rapid growth rate, efforts by the ACOE were unable to control water hyacinth, and populations expanded to over 125,000 acres in Florida by the late 1950s (United States Congress 1965). Light and oxygen diffusion

(Gopal 1987), as well as water movement (Bogart 1949) can be severely reduced by the presence of overabundant water hyacinth. Water hyacinth can smother beds of submersed vegetation and eliminate plants that are important to waterfowl (Tabita and Woods 1962; Chesnut and Barman 1974). Similarly, low oxygen concentrations underneath water hyacinth mats can cause fish kills (Timmer and Weldon 1967). Water hyacinth has completely eliminated resident fish populations in some small Louisiana lakes (Gowanloch 1945). The combination of large leaves and hanging roots can produce evapotranspiration rates in excess of twice normal evaporation. Water hyacinth induced water loss can be significant in West Texas water supply systems where drought conditions often occur. Water hyacinth infestations are often associated with reduced boating, fishing, hunting, and swimming access.

Water lettuce

Water lettuce (*Pistia stratiotes*) is one of the most cosmopolitan aquatic plants in the world. It is a floating plant (although capable of rooting in wet soil for prolonged periods of time), and is easily recognizable by its lettuce-like leaves, which are broadly rounded at the upper end and covered by tiny hairs. This plant is found on every continent except Europe and Antarctica (Gillett et al. 1968, Stoddard 1989). Origins of the plant are unclear, but based on the abundance of associated insects it is believed water lettuce may have come from South America (Cordo et al. 1981).

As a large floating plant, water lettuce may cause many of the same problems associated with water hyacinth, including reduced boating, fishing, hunting, and swimming access.

Other Harmful or Potentially Harmful Exotic Plants

For a complete list of plant species currently illegal in Texas Visit the following website:

http://www.tpwd.state.tx.us/huntwild/wild/species/exotic/prohibited_aquatic.phtml

B. Identifying Your Level of Concern

Each body of water in Texas is unique. The native flora and fauna, primary and secondary uses, water quality parameters and recreational use of reservoirs (in particular) underscore the need for aquatic plant management that is tailored to each water body. As shown on the treatment proposal form (return to index to see Appendix C), the person submitting the treatment proposal should try to classify each aquatic vegetation problem on each body of water into one of three "management response categories." Which response category should be chosen depends on several factors, including (but not limited to) primary use of the water body, recreational uses, drinking water uses, agricultural uses, species of plant, surface coverage, ecological significance, history of infestation, and possibility of expansion. A multi-tier system provides a sound method of classifying reservoirs with nuisance aquatic vegetation to allow a consistent and reasonable approach to meeting the challenges brought about by invasive aquatic plants. This system is set up with general guidelines; placement of a particular reservoir situation into a specific tier will be based on all the attributes and uses of the reservoir, not strictly on the amount of nuisance vegetation present.

It is possible that a water body will face nuisance aquatic vegetation problems from more than one species of plant. For example, a reservoir could have both giant salvinia and hydrilla. In that case, each nuisance plant species should be classified into a response category. The giant salvinia infestation will probably be Tier I, while the hydrilla might be Tier I, II or III. Each nuisance plant species on each water body should be addressed on a different treatment proposal form. If the choice of category is not easily ascertained, consultation with TPWD is readily available and encouraged (return to index to see Appendix D).

Immediate Response - Tier I

Tier I response is a management option for bodies of water experiencing limited, controllable stands of nuisance aquatic vegetation, or areas of special ecological concern. Tier I situations will be addressed by executing as quickly as possible an appropriate management strategy designed to eliminate the nuisance vegetation and reduce or preclude chances of spread or reoccurrence.

Presence of nuisance aquatic plant species, primary water use requirements and the water body's physical and biological attributes (e.g., submerged contour, hydrology, and nutrient loading) should determine Tier I response. For example, if the uses of the reservoir are not affected and there is little potential for expansion over 30% surface coverage, the decision may be to implement a different tier response. Conversely, in bodies of water with characteristics conducive to establishing stands of nuisance plant species (for example, stable water levels, shoreline development and an absence of native vegetation), an immediate Tier I response could be the most effective and least harmful long-term solution. The goals of any Tier I response will include the continuation or improvement of fishery and/or other recreational benefits.

Maintenance - Tier II

Tier II response situations are those that have substantial occurrences of nuisance aquatic vegetation such that complete control is virtually impossible or at least impractical. Tier II situations are to be monitored closely and managed, in conjunction with the governing entity, to provide fishing and boating access or to meet ecological needs. Mechanical, biological and chemical plant control methods may be used, consistent with IPM, to help limit adverse impacts of vegetation on fishing and boating access.

Watch Status - Tier III

Tier III response situations are those where control of nuisance aquatic plants could be achieved given adequate resources; however, the plants are stable or declining, and there is little chance of the infestation being spread to a nearby water body. These reservoirs should be monitored for expansion of the exotic plant populations with a plan in place to control plants if such control becomes necessary. Since native species rarely become overabundant to the extent that they harm native ecosystems, they will nearly always be classified in the Tier III response category.

C. Identifying Possible Prevention and Treatment Techniques

The tools commonly available to control nuisance vegetation can be grouped into three major categories: **Biological controls** use living organisms capable of controlling particular plant species; **Mechanical/physical controls** incorporate a wide variety of techniques, usually shredding or cutting and removing nuisance vegetation directly or exposing plants to unfavorable environmental conditions; and **Chemical controls** eliminate vegetation by utilizing herbicides toxic to specific plants, or in some cases making use of plant hormones. Using an IPM approach, any one of a variety of techniques, or combinations thereof, may be used to effectively manage nuisance aquatic vegetation in the most economic and environmentally sound way possible.

1. Mechanical/Physical Control

i. **Mechanical harvesters** (Includes traditional barge type harvesters with both vertical and horizontal cutting blades and a conveyor belt that gathers cut material for later offloading or for shredding.)

Target Species: All aquatic vegetation found in water greater than 2.0 feet in depth.

Pros:

- No chemicals introduced into the water, and no effect on drinking water.
- Plant biomass/nutrients can be removed from the system.
- No new organisms are introduced.

- High level of treatment precision; targeted plants can be removed within a well-defined area.

Cons:
- Very slow removal (typically 1-2 acres/day under ideal conditions).
- Fragmentation may accelerate spread of aquatic plant species.
- Small fish and other wildlife mortality may occur during the process of vegetation removal, but may not affect overall fish community health.
- Short-term control method, repeated cutting during the growing season typically required.
- Only cuts to a maximum depth of 5-5.5 feet.
- Requires 2-3 feet of water (depending on harvester size) with no submerged obstacles (stumps, rocks, etc.).

Applicability: May be used in areas greater than 2.0 feet deep, where there are few submerged obstacles, and where fragmentation and re-growth will not significantly increase a plant's ability to spread.

ii. **Mechanical shredders** (Includes floating barge type machines that shred vegetation near the water surface rather than cutting and harvesting it.)

Target Species: All aquatic vegetation found in the upper 1-2 feet of water greater than 2.0 feet in depth that does not reproduce by fragmentation.

Pros:
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- No new organisms are introduced.
- 80% or more of the plants that are shredded usually die.
- Up to 32 times faster than traditional harvesters.
- Potentially much lower cost per acre than traditional harvesters.

Cons:
- Fragmentation may accelerate spread of aquatic plant species.
- Requires a minimum of 2-3 feet of water with no submerged obstacles (stumps, rocks, etc.).
- May require multiple use during each growing season.
- May temporarily depress dissolved oxygen levels.
- May be dangerous to fish and other wildlife associated with plants.

Applicability: Areas greater than 2.0 feet deep with few submerged obstacles, and where fragmentation will not significantly increase a plant's ability to spread.

iii. **Water level manipulations -** The purpose of drawdowns is to strand plants on the shoreline for a sufficient period to cause mortality by desiccation or freezing. Water level is usually manipulated by the reservoir's governing entity. Specific strategies vary depending on the reservoir situation, but generally, holding the water level at several feet above normal pool in the spring can reduce light transmission to established vegetation, thereby reducing its growth. Dropping the water level several feet through the fall and winter dries vegetation, killing some of the plants outright. Drawdowns are quite effective on most submerged plants such as Eurasian watermilfoil. However, although hydrilla on dry ground is more likely to be damaged by cold weather than hydrilla insulated by water, in general, water level manipulations seem to be somewhat less effective on hydrilla than on many other plants. Because of hydrilla's adaptability, water level manipulation could give hydrilla a survival advantage over desirable native plants. Raising the water level in the spring may cut light penetration enough to limit native plant growth while hydrilla continues to grow unabated, especially in relatively clear water. Lowering water level in the fall may kill both hydrilla and native plants, but the hydrilla, because of its ability to produce numerous tubers, may return more quickly than many native plants when the water level rises. Further, some drying seems to act as a trigger to cause increased hydrilla tuber sprouting. For these reasons, specific circumstances have to be examined carefully before water level manipulation is used as a hydrilla control strategy. For example, if hydrilla already maintains a monospecific plant community, water level manipulations may be a viable means of controlling its growth, especially if two drawdowns are used as suggested in some literature; one to germinate tubers, and a second to kill germinated tubers.

Target Species: All floating or submergent near-shore aquatic vegetation

Pros:

- Can provide substantial control if water levels can be adjusted.
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Can provide selective control if level manipulations are properly timed with the life history of target species.
- No new organisms are introduced.
- Depending on the size of the water body, time of year, and controlling authority water level manipulations can be a low cost management tool.

Cons:

- May have significant detrimental impacts to ecosystem, particularly fisheries, if drawdowns are not appropriately timed.
- Drawdowns may be restricted by water rights and/or reservoir obligations.
- May impact various uses of the water body (e.g. boat access, sale of water, power plant cooling, etc.).
- Individual floating plants (species such as salvinia or water hyacinth) may remain viable.

Applicability: Use of drawdowns is limited to water bodies with water control structures.

iv. **Booms -** The use of floating booms can be useful in a floating plant control program. They can be deployed to prevent floating plants from clogging water intakes, marinas, swimming areas, or other susceptible sites. Booms can also be used to collect or contain plants in an otherwise open setting. Booms placed around a boat launch may prevent plants from interfering with ingress or egress of boats, and prevent plants that have been accidentally introduced at a boat launch from escaping into the open water body. Floating booms can also be used to collect floating plants being moved by currents within a water body, or prevent plants from entering the main course of the reservoir from feeder embayments. Plants collected in such manner can be more efficiently removed with other control methods.

Target Species: All floating plant species

Pros:

- After deployment, operation of booms is fairly passive.
- No new organisms are introduced.
- Can achieve high level of site-specific control.
- Simple technology.
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Few off-target impacts.
- No water use restrictions.
- Can help prevent spread of floating nuisance plant species.

Cons:

- Does not provide "active" control of existing infestations.
- Effectiveness limited spatially, except when considered as a preventative measure.
- May restrict navigation, or become a navigation hazard.
- Requires a high level of maintenance; booms must be cleaned regularly.
- Built up material may be carried over or under a boom by current.
- Easily vandalized.
- Short-term solution.

Applicability: Mainly for protection of fixed structures and facilities. Also for containing infestations for control by other methods and for helping prevent new introductions.

v. **Bottom Barriers -** Physical barriers have been used with varying degrees of success to prevent weed growth in specific applications. Usually these consist of various types of dark polyethelene plastic which are spread across the bottom of the area to be kept weed-free and then staked in place. Barriers are fairly expensive and labor-intensive to install. These systems are generally used only around boat docks, swimming areas, etc. due to their expense. Barriers are susceptible to damage by propellers, storm damage, and dredging. Problems have also been encountered in the past with gases (i.e. oxygen and CO_2) building up under the film and buoying the barrier up from the bottom; however, more modern gas permeable fabrics are designed to avoid this.

Target Species: All submerged plant species.

Pros:
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- No new organisms are introduced.
- Growth of submerged plant species is inhibited.
- No fragmentation problems.
- No water use restrictions.

Cons:
- Not plant specific, all submerged plants are affected.
- Expensive and labor intensive.
- Not effective on floating species.
- Difficulties keeping the barrier submerged.
- Sediment may accumulate on top of the barrier.
- Plants may grow in sediment on top of the barrier.
- Limited to small areas.

Applicability: Primarily useful in small pond and still water situations.

vi. **Shading -** Shading is an artificial means of controlling unwanted submersed aquatic vegetation. Chemicals are employed to inhibit light penetration and thus shade out the problem plant species. Shading is best employed in small lakes or ponds. Commercially available chemical dyes are sometimes used to color the water (usually a deep blue) to inhibit light penetration and thus shade out existing or potential weeds. These products are generally used in maintaining immaculate landscape ponds.

Target Species: All submerged plant species.

Pros:
- No use restrictions in drinking water sources.
- Growth of submerged plant species as well as phytoplankton is inhibited.
- No new organisms are introduced.
- No fragmentation problems.
- No water use restrictions.

Cons:
- Not plant specific, all submerged plants are affected.
- Not effective on floating species.

- Inhibition of phytoplankton may affect fish production.
- Not effective in flowing water situations.
- Artificial-looking water color.

Applicability: Primarily useful in small pond and still water situations.

vii. **Weed Rollers** – Microchip controlled cylinders roll in an arc (up to 270°) continually, disturbing vegetation and inhibiting growth.

Target Species: Submerged plant species

Pros:
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- No new organisms introduced.
- Can be used on any submerged plant species.
- Site specific.
- No water use restrictions.
- May be effective in 2 days to 2 weeks.

Cons:
- Limited to a radius of 7-21 feet.
- May disturb benthic (bottom dwelling) organisms.
- May cause fragmentation.

Applicability: Useful on small areas with no stumps or other underwater obstructions.

viii. **Removal by hand**

Target Species: All plant species.

Pros:
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- No new organisms are introduced.
- Can be used on any plant species.
- Can be highly species and site specific.
- No water use restrictions.

Cons:
- Very labor intensive.
- May significantly alter substrate and disturb resident organisms.
- Very time consuming.
- Only effective on small infestations.
- Re-growth may occur in as little as 30 days unless roots and tubers are removed.
- Fragmentation can be a significant problem with submerged species.

Applicability: Primarily useful with new or small infestations.

2. Biological Control

The following list includes non-experimental control methods considered acceptable under the statewide plan. For procedures relative to the use of triploid grass carp in public water see Appendix F (return to index to see Appendix F).

i. Triploid grass carp (*Ctenopharyngodon idella*)

Grass carp, or white amur, are plant-eating fish native to Asia. They are capable of surviving at temperatures ranging from below freezing to over 100ºF. Grass carp grow rapidly. In their native habitat they may typically grow to 80-100 pounds. Fingerlings, juveniles and adults feed almost exclusively on plant material. Depending on temperature, water quality, and plant quality they may eat up to three times their body weight per day. Typically, submerged plants such as hydrilla are preferred food items, whereas floating plants (with the exception of duckweed) are among the last species consumed. Triploid grass carp are sterile. In Texas, only triploid grass carp may be stocked, and only by TPWD permit. In general, recommended stocking rates are 5-10 fish per acre of water body.

Target Species: Hydrilla and other species

Pros:
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Usually long-term control
- Plant biomass can be removed from the system.
- Triploid grass carp will not reproduce.

Cons:
- If not confined, grass carp will typically leave target treatment area. In some cases they have been found over 200 miles away from target treatment areas.
- Grass carp may consume non-target plant species when available.
- Grass carp may consume vegetation in non-target areas.
- It is difficult to achieve partial control.
- Grass carp are not readily susceptible to conventional capture techniques and are not easily removed from water bodies if overstocked.
- Grass carp have been captured in brackish water up to 17 ppt (~50% sea water) and can even survive for short periods of time in hypersaline water. Escapees may be capable of feeding in some estuary situations.

Applicability: Water bodies where confinement is possible and potential elimination of all aquatic vegetation is preferable to the nuisance plant infestation.

ii. Alligatorweed flea beetles (*Agasicles hygrophila*)

Alligatorweed flea beetles are native to Argentina. Adults are 0.2-0.3 inches long. Their head and thorax are black, while their wing covers have yellow and black stripes. Larvae burrow into the hollow stem of the aquatic form of alligator weed. Larvae often feed on the plant stem, but both larvae and adults feed primarily on the leaves. Since they were first used in the U.S. in the early 60's alligatorweed flea beetles have proven to be very effective at controlling alligatorweed. Rarely are other control measures now necessary. However, they are only effective on the aquatic form of the plant.

Target Species: Alligatorweed

Pros:

- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Insects may reduce plant biomass significantly.
- Alligatorweed flea beetles are plant specific (feeding only on alligatorweed).

Cons:

- Significant amounts of alligatorweed may remain in the system because the beetles are more effective on the aquatic rather than the terrestrial growth form of the plant.
- Insect populations should be monitored to ensure continued stability.
- Severe winter conditions may negatively impact insect populations.
- Limited commercial availability

Applicability: Any waterway with alligatorweed. Herbicide use may inhibit effectiveness of insects.

iii. Water hyacinth weevils (*Neochetina eichhorniae, N. bruchii)*

Water hyacinth weevils are native to Central and South America. The chevroned water hyacinth weevil *N. bruchii* and the mottled water hyacinth weevil *N. eichhorniae* were introduced into the U.S. in the 1970's to help control water hyacinth. The two species are very similar in

appearance; both are usually gray to dark brownish red. However, grooves on the wing covers are coarse on the mottled weevil and fine on the chevroned weevil. Larvae may grow up to about 0.3 inches. Adults and larvae of both species feed exclusively on water hyacinth. Circular to rectangular scars are often evident on the leaves as a result of water hyacinth weevil feeding activity. However, rather than quickly killing water hyacinth plants, weevil herbivory often results in stunted plant growth, less flowering (and hence less seed production), and reduced competitive ability against native plants.

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Target Species: Water hyacinth

Pros:

- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Insects may reduce plant biomass significantly.
- Insects may reduce the number of flowers present and the number of seeds produced.
- No problems with low oxygen levels.
- Weevils are species specific (feeding only on water hyacinth).

Cons:

- Weevils will not eliminate water hyacinth.
- Weevils will probably not reduce the area covered to below nuisance levels.
- In some cases efficiency may be reduced if chemical treatments are conducted.
- Severe winter conditions may negatively impact insect populations.
- Limited commercial availability.

Applicability: Any waterway with water hyacinth.

iv. Water lettuce weevils (*Neohydronomous affinis*)

Water lettuce weevils are native to Central and South America. They were first introduced into the U.S. in the 1980's to help control water lettuce in Florida. Adult weevils are very small ranging in size from 0.06 to 0.09 inches. They vary in color from nearly white to blue-gray to brown. Larvae cause extensive damage to water lettuce by tunneling through leaves, whereas adults cut circular holes on both the underside and the top (primarily) of leaves. Water lettuce weevils have proven to be very effective at water lettuce control. Where they have become established, nearly-complete control is usually achieved in 18-24 months.

Target Species: Water lettuce

Pros:

- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Insects significantly reduce plant biomass.
- No problems with low oxygen levels.
- Weevils are species specific (feeding only on water lettuce).

Cons:

- Efficiency may be reduced if chemical treatments are conducted.
- Severe winter conditions may negatively impact insect populations.
- Limited commercial availability.

Applicability: Any waterway with water lettuce.

v. Salvinia weevils (*Cyrtobagous salviniae*)

Target Species: Salvinia, Giant salvinia

Pros:

- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Has been highly effective in other countries. This is the most frequently used biological control for salvinia in the world.
- Could be fairly fast acting for insect controls.
- In the tropics results are obtained in months rather than years.
- Well documented host specificity.
- Highly cost effective if experience in the U.S. proves to be similar to that in other areas of the world.
- Effects have been observed in Texas.

Cons:

- Effectiveness may vary depending on a number of abiotic, as well as biotic, factors including temperature, nutritional status of the plants, predators, etc.
- Conditions for effectiveness are not totally understood.
- Does not totally eradicate salvinia.
- Severe winter conditions may negatively impact insect populations.
- Efficacy of the weevil is not proven in Texas or in other parts of the U.S.
- Limited commercial availability.

Applicability: Biological control techniques can be used in areas where long-term suppression can be tolerated and where plant populations are large and require reduction before other management techniques can be employed economically and effectively.

3. Chemical Control

Many herbicides are quick acting and show results within a matter of days. Others are systemic and kill plants over longer periods of time. Appendix G lists commonly used herbicides available today (return to index to see Appendix G). Use of federally approved chemicals for the purposes of nuisance aquatic plant removal is acceptable under the plan within the limitations of the rules (return to index to see Appendix B).

Because human health and safety are always a concern when aquatic herbicides are applied to vegetation in water supplies (particularly drinking water) and areas of contact recreation, TPWD staff conducted a review of the scientific literature relative to three of the most commonly used aquatic herbicides in Texas (Luedke and Cantu 2000). Before labeling herbicides for use in aquatic systems, the United States Environmental Protection Agency (EPA) evaluates appropriate data and determines that at the approved rate, these chemicals should not adversely affect human or ecosystem health.

In many instances surfactants may have to be used with herbicides to help increase their effectiveness. Depending on the morphology of the plant species in question both a wetting agent and a penetrant may be used. Surfactants can increase costs by as much as 10-15 percent.

TPWD rules (57.932(b)(2)(D)) prohibit aquatic herbicide use unless the individual proposing to apply the herbicide use includes, with the notice of proposed herbicide use, "information demonstrating that the proposed application will not result in exceeding: (i) the maximum contaminant level of the herbicide in finished drinking water as set by the TCEQ and the EPA; or ii) if the aquatic herbicide does not have an MCL established by the TCEQ and the EPA, the maximum label rate."

Regarding all of the herbicides discussed below, MCL's either have not been set, or have been waived by TCEQ as long as instructions on each specimen label are followed correctly. In order to demonstrate compliance with the specimen label, the notice should provide water depth, area treated, and amount of herbicide proposed for use. This information will be sufficient to make the demonstration required in this provision of the rules. Below is detailed information about the herbicides listed in Appendix G (return to index to see Appendix G). However, always consult the most current specimen label for the product that will be used.

For large treatments in excess of 100 acres or 200 shoreline miles, consult with Texas Commission on Environmental Quality about compliance the new Texas Pesticide Discharge Elimination System (TPDES) General Permit that was developed under the federal Clean Water Act.

i. 2,4-D

Active ingredient: 2,4-D (2,4-dichlorophenoxy acetic acid, dimethylamine salt) (Due to lower volatility n-alkylamine salts are recommended over ester formulations).

2,4-D is a systemic herbicide. Although systemic herbicides tend to act more slowly than contact herbicides, 2,4-D is known to act quickly and very effectively on water hyacinth.

In Texas 2,4-D compounds have a restricted use and are regulated by TDA. Applicators must be certified by TDA and must follow strict use restrictions based on the county of a proposed application. In areas where 2,4-D use is limited, and at times of the year where its use is restricted, other herbicides can be used depending on the plant species.

Target Species: Water hyacinth is the most common target species. For a more complete list of target species consult the specimen label for the 2,4-D product that will be used. (2,4-D can also be used on Eurasian watermilfoil, but it is rarely done in Texas.)

Pros:

- Requires short contact time with target plant.
- Very quick acting, results evident in a few days.
- When sprayed on floating plants very little enters water column.
- No new organisms are introduced.
- Low cost relative to other herbicides.

Cons:
- Low oxygen can be a problem if large areas are controlled at once.
- Treated water cannot be used for livestock, irrigation, or as municipal water source for 21 days after application or until tests indicate concentration levels are below 0.1 ppm.
- Surviving plants may re-establish population levels within 1-2 months; therefore, maintenance spraying may be required later in the growing season.
- Not species specific.
- Volatility may be a problem, particularly in hot weather or where an atmospheric inversion may develop.
- Cannot be used on submerged plants within ½ mile of a potable water intake.
- Can only be purchased and applied by an applicator licensed by TDA.

Applicability: Can be used on water hyacinth growing in both lotic (river-like) and lentic (lake-like) habitats.

ii. Bispyribac

Active ingredient: Bispyribac-sodium (sodium 2,6-bis[(4,6-dimethoxypyrimidin-2-yl)oxy]benzoate)

Bispyribac is a systemic herbicide that inhibits acetolactate synthase (ALS) which is essential for the synthesis of branched-chain amino acids. It is relatively slow acting and may take eight weeks or more before results are achieved.

Target Species: Alligatorweed, duckweed, Eurasian watermilfoil, hydrilla, parrotfeather, sago pondweed, salvinia spp., water hyacinth, water lettuce, water pennywort

Pros:
- Minimal impacts on desirable species such as cattail, maidencane, southern naiad, spatterdock, and wild celery.
- Kills fluridone-resistant hydrilla.
- Activity on both submerged and free floating plants.
- No drinking, swimming, or fishing restrictions.
- No new organisms are introduced.

Cons:
- Not for use in flowing water, intertidal, or estuarine areas.
- Treated water may not be used to irrigate food or ornamental crops until concentrations fall below 1 ppb.
- Water cannot be used for crayfish farming.
- Treated water may not be used for livestock until concentrations fall below 1 ppb.
- Drift may kill broadleaf plants.
- A drop in dissolved oxygen may result from decaying plants, coupled with decreased plant oxygen production.

- May require relatively long contact times of 8 weeks or more depending on the plant species.

Applicability: May be used in still water.

iii. Chelated Copper

Active ingredient: Copper chelates

Copper is typically used as either copper sulfate or as a chelated copper compound. These are quick acting contact herbicides.

(Copper sulfate is sometimes used instead. However, chelated copper is generally recommended because it typically remains in suspension longer and provides similar or better results with less copper.)

Target Species: Hydrilla, chara, nitella, filamentous algae

Pros:
- Requires a short contact time on the order of hours with target plant species.
- Quick acting, results evident in a few days.
- No water use restrictions after application.
- No new organisms are introduced.
- May be used to treat planktonic, filamentous, and macrophytic algae, as well as hydrilla.

Cons:
- Low dissolved oxygen can be a problem if large areas are controlled at once.
- Surviving plants may re-establish population levels within 1-2 months.
- May have to be used more than once per growing season.
- Does not affect hydrilla tubers buried in the soil, which may remain dormant for 4-5 years or more before germinating.
- In flowing water, special slow-release herbicide delivery equipment is required.
- Copper concentrations may not exceed 1 ppm in potable water.

Applicability: May be used in still water. May also be used on plants in flowing water, however, a special delivery system may be required in high flow situations.

iv. Diquat

Active ingredient: Diquat (6,7-dihyrodipyrido (1,2-α:2’,1’-c) pyrazinediium bromide)

Diquat is a fast acting contact herbicide. It is most effective for spot treatments and when there is moving water. Surfactants are spray additives used to enhance adherence to and penetration through the dense covering of hairs on the plant leaf surface. These additives are especially critical to achieving desirable efficacy levels when using diquat for salvinia control. A combination of two surfactants, one silicone-based and the other petroleum-based, is used.

Target Species: Bladderwort, Brazilian elodea, bushy pondweed, cattail, coontail, duckweed, filamentous algae, frog's-bit, pennywort, pondweeds, salvinia species, southern naiad, water hyacinth, water lettuce, watermilfoil species (including parrot feather and water stargrass).

Pros:

- Requires short contact time with target plant (minutes).
- Quick acting, results evident in a few days (in some cases the same day).
- When sprayed on floating plants, very little enters the water column (although it can be injected into the water for use on submerged vegetation).
- No new organisms are introduced.
- No swimming or fishing restrictions when using diquat at labeled rates.
- Controls floating, marginal, and submerged weeds.

Cons:

- Low dissolved oxygen can be a problem if large areas are controlled at once. Only 1/3 to 1/2 of the target area should be treated at one time, and there should be a 14-day interval between treatments.
- Depending on the application rate, treated water cannot be used by livestock for at least one day, and may not be used for drinking for 1-3 days following application.
- Surviving plants may re-establish population levels within weeks.
- May have to be used more than once per growing season to control surviving plants (depending on plant species).
- Does not affect hydrilla tubers buried in the soil that may remain dormant for 4-5 years before germinating.
- Safety clothing must be worn by applicators during treatments.

Applicability: May be used on floating and marginal plants in either still or flowing water. Submerged plants in still or slow flowing waters may also be treated.

v. Endothall

Active ingredient: Dipotassium salt of endothall (7-oxabicyclo [2,2,1]heptane-2,3-dicarboxylic acid)

Studies have indicated that endothall can affect a variety of diverse biochemical reactions in plants. When used on hydrilla it appears to act as a contact herbicide and severe cellular disruption occurs within 72 hours of treatment. Endothall has a relatively short half-life in aquatic environments. The dipotassium salt formulation has a half-life of only 3 days.

Target Species: Bur reed, coontail, horned pondweed, hydrilla, hygrophila, watermilfoil species (Myriophyllum spp.), Naiad species (*Najas* spp.), Pondweed species (*Potamogeton* spp.), water stargrass.

Pros:

- Requires very short contact time (~2 hrs in some cases) with target plant to be effective.
- Quick acting. Results may be seen in 7-10 days.
- Remains in the water column only a matter of minutes.
- No new organisms are introduced.

Cons:

- Low dissolved oxygen can be a problem if large areas are controlled at once.
- Surviving plants may re-establish population levels within 30 days.
- May have to be used more than once per growing season.
- Does not affect hydrilla tubers buried in the soil that may remain dormant for 4-5 years before germinating.
- In flowing water, special slow release herbicide delivery equipment would be required.
- Concentration may not exceed 1 ppm in potable water.
- There is a 600 foot setback distance from operating potable water intakes.

Applicability: Can be used in moderate flow situations where immediate use of the water for drinking or livestock is unnecessary. As with fluridone, experimental drip delivery systems which expose target plants to low concentrations over extended periods of time have shown promise.

vi. Flumioxazin

Active ingredient: 2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2*H*-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1*H*-isoindole-1,3(2*H*)-dione

Flumioxazin is a fast acting contact herbicide that inhibits the production of chlorophyll in plants. It degrades rapidly and is practically non-toxic to a variety of species such as bees and birds. A surfactant should be used for greatest effectiveness. Flumioxazin should be applied when plants are actively growing. Field tests indicate water should have a pH of 10.0 or less, otherwise it may degrade and lose its effectiveness.

Target Species: Alligatorweed, cladophora, coontail, curly-leaf pondweed, duckweed, Eurasian watermilfoil, fanwort, frog's-bit, hydrilla, Illinois pondweed, pithophora, sago pondweed, salvinia spp., southern naiad, variable-leaf pondweed, watermeal, variable-leaf watermilfoil, water lettuce, water pennywort,

Pros:

- Fast control of invasive plants in 14 days or less.
- Dissipates quickly from the water column and does not accumulate in sediment.
- Activity on both submerged and free floating plants.
- No drinking, swimming, or fishing restrictions.
- No new organisms are introduced.

Cons:

- Not for use in flowing water, intertidal, or estuarine areas.
- Treated water may not be used for irrigation for at least five days after application.
- Water cannot be used for crayfish farming.
- The same section of water may not be re-treated more than 6 times per year.

Applicability: May be used in still water.

vii. Fluridone

Active ingredient: Fluridone (1-methyl-3-phenyl-5-[3-(trifluoromethyl) phenyl]-4(1H)-pyridinone)

Fluridone is a slow acting systemic herbicide that inhibits the biosynthesis of carotenoid pigments. These pigments protect chlorophyll from photo-degradation. Therefore, in the presence of fluridone chlorophyll is left unprotected, it breaks down over time, and plants are unable to adequately photosynthesize. It is best used in still water. Fluridone may be the most effective in small pond applications where the entire water body is treated. It requires a long contact time and desired results may take 90 days or more.

Target S*pecies:* *Duckweed, coontail, egeria, fanwort, hydrilla, Naiad species (Najas* spp.), Pondweed species (partial control on Illinois pondweed), salvinia species *(Salvinia* spp.), spatterdock, water-lily species (*Nymphaea* spp.), and watermilfoil species (partial control on variable-leaf milfoil). For a more complete list consult the specimen label for the fluridone product that will be used.

Pros:

- Fluridone is a systemic herbicide and hydrilla populations are slow to recover after treatment. All parts of the plant are affected, with the exception of dormant tubers which have become separated from parent plants. In some reservoirs 2-4 years of control are achieved.
- Low dissolved oxygen typically not a problem because plants die slowly.
- May kill newly germinated hydrilla tubers.
- No new organisms are introduced.

- May be used in the presence of functioning potable water intakes at application rates of 20 ppb or less.
- There are a number of different formulations of fluridone that are tailored for use in different conditions.

Cons:

- Requires very long contact time. In some cases the treatment may be spread out over several weeks to provide the necessary contact time (under normal treatment conditions in still water).
- May take 90 days or more for full results.
- Cannot be used within ¼ mile of a potable water intake at concentrations greater than 20 ppb.
- For most crops treated water should not be used for irrigation for 7-30 days, depending on the crop.
- For tobacco, tomatoes, peppers or other plants within the Solanaceae Family and newly seeded crops or newly seeded grasses such as overseeded golf course greens, Sonar A.S. treated water may not be used if measured fluridone concentrations are greater than 5 ppb.
- Does not affect dormant hydrilla tubers buried in the soil and separated from parent plants. Tubers may remain dormant for 4-5 years or more before germinating.

Applicability: Fluridone is most applicable in water with little flow, and where the treatment area is greater than 10 acres in size. There is little applicability in flowing water such as main channels using conventional delivery systems. However, experimental drip delivery, which exposes target plants to low herbicide concentrations over an extended period of time, has shown promise. The use of pelleted formulations allows treatment in areas with some flow. Pellets are also often used on submerged plants. Liquid fluridone is usually used on floating vegetation such as salvinia.

viii. Glyphosate

Active ingredient: Glyphosate (N-(phosphonomethyl) glycine)

Glyphosate is a systemic herbicide. It is one of the most widely used in the world. It is used as a topical spray on salvinia, and as with diquat it requires a combination of two surfactants to properly penetrate the dense covering of hairs on the leaf surface of plants like giant salvinia and waterlettuce.

Target Species: Alligatorweed, American lotus, bulrush, cattail, Chinese tallow, giant reed, phragmites, purple loosestrife, salvinia species, smartweed, spatterdock, water hyacinth, waterlettuce, water-lily, water primrose, willow, and torpedograss. For a more complete list of target species consult the specimen label for the glyphosate product that will be used.

Pros:

- Requires short contact time with target plant (4-6 hours).
- Very quick acting, results evident in 1-2 weeks.
- No need to post signs prior to application.
- When sprayed on floating plants very little enters water column.
- No new organisms are introduced.

Cons:

- Low dissolved oxygen can be a problem if large areas are controlled at once.
- Clean water needed for mixing if large mats are treated.
- Plant populations may recover and grow back quickly; therefore periodic re-treatment is often necessary.
- May have to be used more than once per growing season.
- Floating and marginal plants only.

Applicability: Can be used as a topical spray on plants in still or in flowing water.

ix. Imazamox

Active ingredient: ammonium salt of imazamox 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid

Imazamox is a broad spectrum systemic herbicide. Although imazamox is an ALS inhibitor it requires a much shorter contact time (3-7 days) than other ALS inhibitors (sometimes 60 days or more).

Target Species: Alligatorweed, American lotus, arrowhead, bladderwort, cattail, Chinese tallowtree, common reed, common salvinia, elephant ear, Eurasian watermilfoil, northern watermilfoil, variable-leaf watermilfoil, floating pennywort, four-leaf clover, frog's-bit, giant reed, Mexican lily, parrotfeather, pickerelweed, pondweeds, smartweed, spatterdock, water hyacinth , water lily (*Nymphaea* spp.), water primrose, water stargrass, watershield, wideon grass

Pros:

- Fast control of invasive plants in 14 days or less.
- Dissipates quickly from the water column and does not accumulate in sediment.
- Activity on both submerged and free floating plants.
- No drinking, swimming, or fishing restrictions.
- No new organisms are introduced.

Cons:

- Not for use in flowing water, intertidal, or estuarine areas.
- Treated water may not be used for irrigation for at least five days after application.
- Water cannot be used for crayfish farming.

- The same section of water may not be re-treated with *Clipper* Herbicide more than 6 times per year.

Applicability: May be used in still water.

x. Imazapyr

Active ingredient: Isopropylamine salt of Imazapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-imiazol-2-ly]-3-pyridinecarboxylic acid)

Imazapyr is an amino acid synthesis inhibitor and kills plants by inhibiting production of amino acids which are required for DNA synthesis and growth. Treated plants usually die slowly, in some cases plants may take six to nine months to die. Imazapyr can be persistent and mobile in soil, depending on soil type.

Target Species: Water hyacinth, salvinia, Alligatorweed, smartweed, water lily, parrot feather, pickerelweed, water pennywort, water primrose, water-willow, yellow cow-lily, duckweed, black willow, bulrush, cattail, giant reed, torpedograss.

Pros:

- When sprayed on floating plants very little enters water column.
- No new organisms are introduced.
- No swimming or fishing restrictions on treated water.
- No restrictions on livestock consumption of treated water.

Cons:

- May not be used within one mile upstream of an active potable water intake in flowing water, or within one mile of an active potable water intake in a standing body of water (lake or pond).
- Treated water may not be used for irrigation for 120 days post treatment, or until the concentration is determined (by analysis) to be 1 ppb or less.
- May not be applied to dry irrigation canals/ditches.
- May not be used within one mile of an irrigation intake in a lake or reservoir unless the intake will be inactive for 120 days post application, or inactive until the concentration of imazapyr is determined by laboratory analysis to be less than 1 ppb.
- May not be used in flowing water within one half mile upstream of an active irrigation intake unless the intake is shut off for a period of time sufficient to allow imazapyr to completely flow past the intake.
- Applications may not be made within one half mile of a potable water intake unless the intake is turned off for a minimum of 48 hours.
- Does not control submerged species.

Applicability: Can be used in flowing or quiescent water. Typically used primarily on riparian plants.

xi. Penoxsulam

Active ingredient: penoxsulam: 2-(2,2-difluoroethoxy)-6-(trifluoromethyl)-N-(5,8-dimethoxy[1,2,4]triazolo-[1,5c]pyrimidin-2-yl)-benzenesulfonamide

Penoxsulam is a systemic sulfonamide herbicide that inhibits the plant enzyme (ALS). 60-120 days may be required to kill target plants.

Target Species: Baby's tears, cabomba, duckweed, egeria, Eurasian watermilfoil, frog's-bit, hydrilla, mosquito fern, water fern (salvinia), water hyacinth, water lettuce

Pros:

- Penoxsulam is a systemic herbicide and plant populations are slow to recover after treatment.
- Penoxsulam is effective on all three of Texas' most problematic aquatic plants giant salvinia, hydrilla, and water hyacinth. Therefore, they can be treated without the need for multiple herbicides.
- Low dissolved oxygen typically not a problem because plants die slowly.
- No new organisms are introduced.
- No restrictions on consumption of treated water for potable use or by livestock, pets or other animals.
- No restrictions on the use of treated water for recreational purposes, including swimming and fishing.

Cons:

- Requires very long contact time. In some cases the treatment may be spread out over several weeks to provide the necessary contact time (under normal treatment conditions in still water).
- May not be used through any type of irrigation system.
- Water from treated sites may not be used for food crop irrigation until residues are determined to be less than or equal to 1 ppb, except for rice (consult the specimen label for instructions relative to rice irrigation).

Applicability: Due to the requirement of a long contact time penoxsulam is best used on plants in still water.

xii. Triclopyr

Active ingredient: Triclopyr: 3,5,6-trichloro-2-pyridinyloxyacetic acid, triethylamine salt.

Triclopyr is absorbed by roots and leaves and then translocated throughout the plant, ultimately accumulating in root and stem shoot tissue. It mimics the plant hormone auxin and interferes with normal plant growth.

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Target Species: Water hyacinth, alligatorweed, American lotus, smartweed, waterlily, parrot's feather, pickerelweed, water pennywort, water primrose, waterwillow, yellow cow-lily, Eurasian watermilfoil, variable-leaf milfoil, frog's-bit, Chinese tallow, black willow, bulrush.

Pros:
- When sprayed on floating plants very little enters water column.
- No new organisms are introduced.

Cons:
- May not be used within one mile upstream of an active potable water intake in flowing water, or within one mile of an active potable water intake in a standing body of water (lake or pond).
- Personal protection equipment must be worn during application.
- May not be used through any type of irrigation system.
- Treated water may not be used for irrigation for 120 days post treatment, or until the concentration is determined (by analysis) to be 1 ppb or less.
- May not be used in irrigation ditches unless the 120-day restriction can be met.
- May not be applied to saltwater bays or estuaries.
- May not be applied directly to un-impounded rivers and streams.
- May not be applied where runoff can flow onto agricultural lands.
- Treated areas may not be grazed by lactating cows.
- Livestock may not graze treated areas for a period of three days before slaughter.

Applicability: Can be used in flowing or quiescent water.

4. Experimental Options and Procedures

Experimental procedures are not recommended for general use at this time. Consistent control of target species has not been fully demonstrated and further research and documentation is currently underway. Additionally, insects listed below are not generally available for sale. They are, however, used in conjunction with research activities and use may be approved.

a. Experimental Biological Controls

i. Hydrilla flies *Hydrellia pakistanae*

Target Species: Hydrilla

Pros:
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Preliminary evidence suggests insects may reduce plant biomass significantly in some instances.
- Flies are plant specific (feeding only on hydrilla).
- No problems with low oxygen levels.

- Effectiveness has been observed at certain locations in Texas.

Cons:
- Effectiveness is variable and difficult to document.
- Severe winter conditions may negatively impact insect populations.
- Significant amounts of hydrilla remain in the system.
- Hydrilla must be at the surface for insects to lay their eggs.
- Insect populations must be monitored to ensure continued stability.
- Herbicide use may inhibit effectiveness of insects.
- Limited commercial availability.

Applicability: Any waterway where hydrilla has grown to the surface.

b. Experimental Ecological Intervention

i. Native Vegetation Establishment

Reservoirs are disturbed ecosystems that often do not contain a propagule bank for native plants and therefore often remain un-vegetated until weedy species such as hydrilla are accidentally introduced. Most reservoirs capable of supporting hydrilla can also support some species of native aquatic vegetation. Filling the empty niches in un-vegetated areas of reservoirs with native vegetation may act as a deterrent to hydrilla establishment or further spread. For information regarding current research efforts and possibility of partnerships in further research dealing with the establishment of native aquatic vegetation, contact TPWD representatives listed in Appendix D (return to index to see Appendix D).

Pros:
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Some native species, if established, may slow (but not eliminate) the spread of introduced exotics.
- Native vegetation adds needed habitat diversity for invertebrate and fish production.

Cons:
- Native plant establishment is long-term, and quick results are usually not seen.
- Native plants are sometimes susceptible to damage due to water level fluctuations and herbivory.
- Does not totally eradicate already established introduced exotic plants.
- Experimental results have been inconsistent and the controlling mechanisms are not well understood.

Applicability: Nearly all Central and East Texas reservoirs. West Texas reservoirs may experience drastic water level fluctuations, which reduce the effectiveness of many native littoral zone plant species that require a more stable environment.

D. Choosing the Appropriate Management Options

Following is a list of selected vegetation species that are included on Texas' "Harmful or Potentially Harmful Exotic Fish, Shellfish, and Aquatic Plants" list. It is illegal to "release into public waters, import, sell, purchase, transport, propagate, or possess any species, hybrid of a species, subspecies, eggs, seeds, or any part of any species" included on the list. Recommended general management options are provided for each plant species. General management options are the currently accepted procedures for controlling aquatic vegetation. If you cannot locate a species of interest, or have questions, contact a TPWD biologist (return to index to see Appendix D).

1. Giant Salvinia

Giant salvinia has previously been intercepted and eradicated at nurseries and botanical gardens in Florida, Virginia, Texas and Missouri and at a private pond in South Carolina (NPAG 1998). Its introduction to Toledo Bend Reservoir, a 186,000 acre body of water that forms a large portion of the boundary between Texas and Louisiana, poses a serious threat to interstate spread. The plant was found by the Sabine River Authority (SRA) of Louisiana on September 24, 1998, and identified by TPWD personnel, in the central portion of the reservoir, where it has become widespread (Hyde and Temple 1998). Since then it has been found in a number of water bodies, both public and private.

Because of its extreme growth rate and highly invasive tendencies, any infestation of giant salvinia warrants a **Tier I Management Response**. Infestations of giant salvinia should be reported immediately to the TPWD Inland Fisheries Division. TPWD personnel familiar with both common and giant salvinia should verify all identifications. The following management options will be applicable to both species; however, infestations of giant salvinia will have preference if resources are limited.

Recommendations:

Mechanical-Physical Control - Various physical methods may be used to control or restrict spread of salvinia. These include mechanical and manual removal, devices for blocking entrance to or exit from an area, and inducing changes in the environment.

Booms and other barriers - Booms and other barriers may be useful in confining infestations or restricting entry into sensitive areas. However, in areas with significant current or wind action their utility is limited without frequent clearing and maintenance since plants will accumulate against barriers until pressure forces them over or under the barrier.

Water Level Manipulation – Water level is usually controlled by the reservoir's controlling authority. Dropping the water level several feet has proven effective at helping control salvinia. Since salvinia is a small floating plant it is often blown into shallow water nearshore areas, and is therefore susceptible to being stranded on dry ground under falling water conditions. In 1999, a rise and subsequent drop in water level on Toledo Bend Reservoir significantly reduced the salvinia population on the lake. However, in order to be effective, water levels must remain low long enough to allow for the desiccation or freezing of stranded plants.

Biological Control - No biological control agents are currently available for sale and general use on salvinia in Texas. However, there are currently two operating giant salvinia weevil *Cyrtobagous salviniae* rearing facilities in the state. The weevil has proven to be very effective parts of Texas as well as other parts of the world.

Chemical Control – Although *Cyrtobagous salviniae* shows great promise, herbicide treatment is currently the most efficient method of salvinia control in Tier I situations. However, small floating plants such as salvinia can be difficult to eradicate with herbicides. Due to the extremely large number of individual plants present, applying herbicide to each plant is difficult. In addition, the dense hair or pubescence on the leaf surface, characteristic of all salvinia species, can negatively impact the effectiveness of certain types of herbicide applications. These thick hairs can impede herbicide penetration when using any type of foliar spray application. This is especially true when attempting to control giant salvinia.

Because application techniques and herbicides of choice are subject to change, contact TPWD Inland Fisheries Division before attempting a herbicide application for the control of either species of salvinia. With the introduction and expansion of giant salvinia into the U.S., renewed effort and research into the available herbicides, surfactants, and their combinations are ongoing.

Currently, there are six primary options for herbicide use. The effectiveness of all six is generally inhibited when salvinia has formed a thick mat before application.

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Recommended Salvinia Treatment Options

Treatment Methods	Tier I
Booms	Yes[1]
Herbicide	Bispyribac, Diquat, Flumioxazin Fluridone, Glyphosate Penoxsulam
Water level manipulation	Yes

[1]Booms may be used to help prevent the spread of salvinia while other methods are used for actual eradication.

2. Hydrilla

Hydrilla is considered a nuisance aquatic plant because of its 1) rapid growth, 2) ability to colonize deeper water, 3) ability to spread easily, 4) ability to form dense surface mats that block sunlight, inhibit surface oxygen exchange, and increase biological oxygen demand in the mat area, 5) ability to inhibit navigation and other water uses, 6) resistance to control methods, and 7) its ability to outcompete native plants and form a monoculture (single species community) and thereby decrease plant community diversity.

Recommendations:

Mechanical-Physical Control – Because hydrilla can spread by fragments, the only appropriate mechanical control in a Tier I situation is complete removal with shovels or other implements designed to carefully avoid fragmentation and remove the entire plant including the root system below ground. If this type of mechanical removal is attempted, it should be accomplished as soon after discovery of the infestation as possible to lessen the chance of fragmentation or tuber or turion production. Infested area(s) should be frequently monitored and plant re-growth removed or treated appropriately. Since the spread of hydrilla is not usually a concern in Tier II situations, both mechanical harvesters and shredders may be used effectively. Small cutters such as those mounted on a jon boat may be useful around individual docks but most areas will require large boats equipped to cut and move through dense hydrilla mats. Cutting should begin in early spring. Since hydrilla can grow an inch a day, areas cut to a depth of five feet will need to be re-cut at least every 60 days during the growing season. Other physical control techniques are listed below. Because of the potential for hydrilla spread from fragmentation, the only appropriate use of mechanical control in a Tier III situation would be to open areas within a large mat to allow angler/boater access, greater oxygen exchange, and increased edge effect. Great care should be taken to insure fragments stay bound within the mat and do not float free in open water.

Water level manipulation - In general, the effectiveness of drawdowns to control hydrilla is unclear. Survival of plant material found at the bottom of drying hydrilla mats, as well as germination of tubers, may facilitate rapid population recovery.

Biological Control - Because of the lack of proven effectiveness of hydrilla flies and the lack of feeding selectivity by grass carp, biological control is problematic in Tier I situations for hydrilla. However, triploid grass carp are quite cost effective on large infestations where herbicide use is cost prohibitive, and where substantial overall vegetation removal is not considered a problem. Steps to follow for using grass carp as a biological control in public water are found in Appendix F (return to index to see Appendix F).

Chemical Control - Chemical control is likely the most effective means of hydrilla control in a Tier I situation where complete removal of all vegetation species is not desired. For continuous areas of less than 10 acres, or in moderately flowing water, copper, diquat, or endothall products are appropriate. For continuous infestations of 10 acres or more, and with little to no water flow, Bispyribac, fluridone, or penoxsulam products are probably most appropriate. Chemical treatments should be conducted as soon as possible after the infestation is discovered to decrease fragmentation and tuber or turion production. Systemic herbicides should only be used when water temperatures are warm enough for active growth and photosynthesis (usually 60-65°F). Treated areas should be surveyed often to determine effectiveness of treatment and possible plant re-growth. Chelated copper compounds are also acceptable, and early studies suggest efficacy of chelated copper may be enhanced when used in combination with other herbicides such as diquat. Programs using both contact and systemic herbicides have been demonstrated to be highly effective.

Recommended Hydrilla Treatment Options

Treatment Methods	Tier I	Tier II
Harvesters	No	Yes
Shredders	No	Yes
Shading	Yes	Yes
Herbicide	Bispyribac Copper Diquat Endothall Fluridone Imazamox Penoxsulam	Bispyribac Copper Diquat Endothall Fluridone Imazamox Penoxsulam
Triploid Grass Carp	Yes	Yes[1]
Water level manipulation	Yes	Yes

[1]Grass carp may be used at low stocking rates in Tier II situations to help put added stress on hydrilla populations.

3. Water hyacinth

Like a number of other exotic floating plants, water hyacinth is considered a nuisance aquatic plant because of its 1) rapid growth, 2) ability to spread easily by floating into previously uncolonized areas, 3) ability to form dense surface mats that block sunlight and inhibit surface oxygen exchange, 4) ability to inhibit navigation and other water uses, and 5) its ability to outcompete native plants and decrease plant community diversity.

Recommendations:

Mechanical/Physical Control – Mechanical removal may be a viable and economically feasible method of water hyacinth control. For moderately large infestations (on the order of approximately 100 acres or less) in water more than 2 feet deep with few stumps or other obstructions, shredding may be used effectively. For larger infestations, shredding quickly becomes logistically difficult with current technology. Harvesting may be used on small infestations in water greater than 2 feet deep with few stumps and other obstructions.

<u>Water Level Manipulation</u> – Specific strategies vary depending on the reservoir situation, but dropping the water level several feet through the fall and winter can

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strand plants on the bank. Water hyacinth can survive for long periods on moist damp soil so stranding plants during cold weather when there is a chance of freezing is most effective.

Biological Control – Water hyacinth weevils may be used to slow the growth of water hyacinth populations and reduce their ability to flower and produce seeds. In some cases, water hyacinth populations have also been significantly reduced by weevil introductions. In general, triploid grass carp are not a viable biological control option for water hyacinth since they rarely eat the plant unless all other vegetation is removed.

Chemical Control – In Tier I situations, herbicide use may be the most efficacious means of water hyacinth control in areas with many stumps or other obstructions, or in areas with water depths less than two feet. Similarly, in Tier II situations herbicides are probably the most efficient control method in areas with extremely large infestations where aerial application is required. In general, the cheapest and most efficacious herbicide for water hyacinth is 2,4-D. However, a wide variety of herbicides are now available for use on water hyacinth (see below). Which one is most appropriate often depends on factors such as temperature, hydrology, flow rate, etc.

Recommended Water hyacinth Treatment Options

Treatment Methods	Tier I	Tier II
Harvesters	Yes	Yes
Shredders	Yes	Yes
Booms	Yes[1]	Yes
Herbicide	2,4-D Bispyribac Diquat Glyphosate Imazamox Imazapyr Penoxsulam Triclopyr	2,4-D Bispyribac Diquat Glyphosate Imazamox Imazapyr Penoxsulam Triclopyr
Water hyacinth Weevils	Yes	Yes
Water level manipulation	Yes	Yes

[1]Booms may be used to help prevent the spread of water hyacinth while other methods are used for actual eradication.

4. Eurasian watermilfoil

Eurasian watermilfoil can out-compete native plant species and create a mono-specific plant community. Because it can grow to be very dense at the surface, Eurasian watermilfoil stands can inhibit angling, boating, swimming, and other forms of aquatic recreation if not controlled.

Recommendations:

Typically, Eurasian watermilfoil causes few problems in Texas waters. TPWD has conducted no herbicide treatments for Eurasian watermilfoil for at least 10 years. Therefore, **Eurasian watermilfoil infestations usually will be considered Tier III situations.**

Mechanical/Physical Control – Due to the likelihood of Eurasian watermilfoil spread due to fragmentation, the only appropriate mechanical control in a Tier I situation is complete removal of small patches with shovels or other implements designed to carefully avoid fragmentation. If mechanical removal is attempted in this manner it should be accomplished as soon after discovery of the infestation as possible to lessen the chance of fragmentation or turion production. Infested area(s) should be frequently monitored and plant re-growth removed or treated appropriately. In Tier II situations mechanical harvesters may be effectively used to remove Eurasian watermilfoil in areas where water depth is greater than 2.0 ft.

Water Level Manipulation – Specific strategies vary depending on the reservoir situation, but dropping the water level several feet through the fall and winter dries the vegetation, killing much of the plant outright. This strategy has proven effective for Eurasian watermilfoil control. However, care should be exercised if hydrilla or some other extremely invasive species is also present. Since drawdowns have very limited efficacy on hydrilla, removal of Eurasian watermilfoil by this method may simply open new areas for colonization by hydrilla.

Biological Control – Triploid grass carp are the only effective biological control agent currently available for Eurasian watermilfoil. However, since Eurasian watermilfoil is typically low on their dietary preference list, they are rarely recommended for its control in Texas. Grass carp should only be considered if watermilfoil populations grow beyond the point at which they can be controlled with herbicides or drawdowns, and complete eradication of all vegetation becomes preferable to the milfoil infestation.

Chemical Control – In Tier I situations herbicide use may be the most efficient means of Eurasian watermilfoil control in nonpotable water lakes and in water bodies that also have hydrilla. In general, the cheapest and most efficient herbicide is 2,4-D. In areas where 2,4-D use is limited and at times of the year where its use is restricted, diquat, endothall, and fluridone products can be used effectively.

Recommended Eurasian watermilfoil Treatment Options

Treatment Methods	Tier I	Tier II
Harvesters	No	Yes
Herbicide	2,4-D Bispyribac Diquat Endothall Fluridone Imazamox Penoxsulam Triclopyr	2,4-D Bispyribac Diquat Endothall Fluridone Imazamox Penoxsulam Triclopyr
Water level manipulation	Yes	Yes

5. Water lettuce

The floating growth characteristic and fast reproductive rate of water lettuce can cause environmental problems similar to those encountered with water hyacinth. Waterways can be clogged and access to fishing, swimming, and boating may be reduced or eliminated. Dense mats of water lettuce may cause oxygen depletion (Attionu 1976) and increase siltation, which effectively reduce the suitability of the underlying substrate for nesting fish (Beumer 1980) and invertebrates (Roback 1974). The seeds, which may remain dormant for months, are resistant to both drought and freezing.

Recommendations:

New infestations of water lettuce or recurrence in areas where it has previously been problematic should be considered a Tier I situation. Because of the extreme nature of the problems encountered with overabundant water lettuce most occurrences of water lettuce will be considered Tier I situations.

Mechanical/Physical Control – Mechanical removal may be a viable method of water lettuce control. Shredding may be used effectively for removal of moderately large infestations (100 acres or less), in water more than 2 feet deep, in areas with few stumps or other obstructions, and where biological control has proven ineffective.

Water Level Manipulation – Specific strategies vary depending on the reservoir situation, but generally, lowering the water level several feet through the fall and winter can strand plants on the bank. Water lettuce can survive for long periods on moist damp soil so stranding plants during cold weather when there is a chance of freezing is most effective.

Biological Control – Water lettuce weevils are currently the only viable option, although research into other biological controls is now underway.

Water lettuce weevils – Water lettuce weevils have proven effective so far at every location they have been tried in Texas. Within a year or two water lettuce populations have usually been eliminated.

Water lettuce infestations should be surveyed by a qualified person(s) to determine if water lettuce weevils are already present, and if so at what density. Water lettuce weevils are stocked at densities of 500 – 1,000 per site. Stocking sites should be surveyed to determine if either or both species of water lettuce weevils is established, and additional weevils should be stocked as necessary to insure the population remains at optimum density.

Chemical Control – Herbicide use is a viable means of water lettuce control in areas with many stumps or other obstructions, in areas with water depths less than two feet, in the case of extremely large infestations where aerial application is required, and in areas where biological control may prove ineffective. Currently, there are six primary options for herbicide use.

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Recommended Water lettuce Treatment Options

Treatment Methods	Tier I
Harvesters	Yes
Shredders	Yes
Booms	Yes[1]
Herbicide	Bispyribac Diquat, Flumioxazin Glyphosate Imazapyr Penoxsulam
Water lettuce Weevils	Water lettuce Weevils
Water level manipulation	Yes

[1]Booms may be used to help prevent the spread of water lettuce while other methods are used for actual eradication.

6. Alligatorweed

Alligatorweed can cause a variety of problems. Free floating plants can choke waterways, and rooted plants can even invade moist pastoral and agricultural land (Coulson 1977, Julien and Bourne 1988, Julien and Broadbent 1980).

Recommendations:

In general, alligatorweed causes very little problem in Texas. Since the release of the alligatorweed flea beetle, very few areas have required active control efforts. Therefore, alligatorweed infestations will usually be considered Tier III "wait and see" situations.

Mechanical/Physical Control – Mechanical removal may be a viable method of alligatorweed control. Costs for shredding floating alligatorweed plants are equivalent to herbicide treatments. However, in order to use machinery, infestations must occur in water more than 2 feet deep, and in areas with few stumps or other obstructions.

Biological Control – Alligatorweed flea beetles have effectively controlled alligatorweed in a number of areas of Texas. Alligatorweed infestations should be surveyed by qualified person(s) to determine if alligatorweed flea beetles are already present and if so at what density. Flea beetles should be stocked at densities of 500-1000 per stocking site. Stocking sites should be surveyed to determine if the flea beetles are established and additional flea beetles should be stocked as necessary to insure optimum densities.

Chemical Control - Herbicides are an effective means of alligatorweed control for rooted infestations that are apparently less susceptible to control by the flea beetle. Fluridone, glyphosate, imazapyr, and triclopyr products may be used when the flea beetle is ineffective.

Recommended Alligatorweed Treatment Options

Treatment Methods	Tier II
Harvesters	Yes
Shredders	Yes
Booms[1]	Yes
Herbicide	Fluridone, Glyphosate, Imazapyr, Triclopyr
Alligatorweed Flea beetle	Yes
Water level manipulation	Yes

[1]Booms may be used to help prevent the spread of alligatorweed while other methods are used for actual eradication.

7. Other exotic species

Responses to infestations of other exotic species will depend on which species are involved and information regarding potential threat. New infestations by species for which there is evidence of environmental or economic damage or for which no information is available will generally be considered Tier I situations. However, if evidence suggests the species will not grow to overabundance and become problematic it will be treated as Tier III.

8. Native plant species

Since native species rarely become overabundant and create environmental difficulties they will nearly always be classified in the Tier III response category. See the Pond Manager Diagnostics Tool or Fassett (1957) for descriptions of native species.

E. Develop and Submit Your Treatment Proposal

A Treatment Proposal details what will be done to manage nuisance vegetation in Texas' public water. Although there is latitude in how vegetation can be managed, the Treatment Proposal formalizes those actions and provides a basis for future efforts. A Treatment Proposal, accompanied by a map of the proposed treatment site, must be submitted to the TPWD 14 days before anticipated implementation. Failure to provide a map may slow the review process. A blank Treatment Proposal Form is found in Appendix C (return to index to see Appendix C). A separate treatment proposal should be filled out for each plant species treated. Below is a step-by-step guide to development and submittal of a Treatment Proposal. Individuals who are planning to conduct vegetation control activities on a public body of water should follow these steps:

STEP 1 - Review this guidance document and/or other materials (e.g., Pond Manager Diagnostics Tool).

STEP 2 - Using this Guidance Document and/or other materials, identify the plant species that are causing a problem (see pages 7 – 11). If necessary, contact an Extension agent, professional pond manager or aquaculturist, a botanist, the local river authority or other governing entity, or the local TPWD Inland Fisheries Management District (return to index to see Appendix D).

STEP 3 - Identify your level of concern for managing the species in question (see pages 12-13), and which management response tier seems most appropriate--Immediate Response (Tier I), Maintenance (Tier II), or Watch Status (Tier III).

STEP 4 - Familiarize yourself with possible prevention and treatment techniques, and identify those that may work best for your management needs (see pages 13 -34).

STEP 5 - Review management recommendations for the species in question (see pages 35 – 45) and determine which control technique or combination of techniques may be most effective. At this stage, you may want to contact the local TPWD Inland Fisheries Management District (return to index to see Appendix D) for guidance.

STEP 6 - **Complete the Treatment Proposal form** (return to index to see Appendix C; see also example on page 48). The treatment proposal is valid for the period shown on the form in Appendix C. If herbicide use is proposed, go to STEP 7. If herbicide use is not proposed, go to STEP 11.

STEP 7 - Contact TCEQ's Public Drinking Water Section (512-239-6020) to obtain a list of locations of public potable water intakes on the water body in question.

STEP 8 - Assure that **at least 14 calendar days prior to the proposed herbicide use**, the treatment proposal, map, and notice of intent to apply aquatic herbicide (see example on page 49) are provided to (1) the river authority or other governing entity, (2) the local TPWD Inland Fisheries Management District (return to index to see Appendix D), [STEP 8 continues on next page]

STEP 8 - (cont.) (3) any water providers that have an intake within two river miles of the site at which an application of aquatic herbicide is proposed to occur, and (4) all persons who have requested to be notified in advance of herbicide applications (https://tpwd.texas.gov/landwater/water/environconcerns/nuisance_plants/notification_list.phtml). A sample "Proposed Herbicide Use Notice" is provided with this guidance document (see page 49).

The notice of intent must include:

- all label information for the aquatic herbicide to be applied (this requirement may be fulfilled by providing the URL of an internet site with the specimen label, and may be waived if the same herbicide has been used under an approved proposal for that water body within the previous year);
- a statement that the guidance document has been reviewed and the proposed herbicide application is consistent with the principles of integrated pest management, §57.932(a)(2) of TPW rules, and the guidance document;
- information demonstrating that the proposed application will not result in exceeding the maximum contaminant level of the herbicide in finished drinking water as set by the TCEQ and the EPA, or if the aquatic herbicide does not have an MCL established by the TCEQ and the EPA, the maximum label rate; and the TDA applicator license number, if any.

STEP 9 - The governing entity must also notify the individual in writing that it is a violation of state law to apply aquatic herbicides in a public body of water in a manner inconsistent with the state plan. A sample "Notice from Governing Entity in Response to Proposed Herbicide Use" is provided with this guidance document (see page 50).

STEP 10 - TPWD and the governing entity will respond to the treatment proposal, map and notice no later than the day before the herbicide application is to occur. Both TPWD and the governing entity must approve herbicide applications.

Note that if the individual proposing to apply the herbicides is *not* a licensed applicator, the herbicide application may not proceed in the absence of an affirmative finding by the governing entity and TPWD that the application will be consistent with the state plan (or an approved local plan if one has been adopted for the particular public body of surface water in question).

In a case where the herbicide application would be done by a licensed applicator, however, the application may proceed if the governing entity or TPWD do not disapprove the application by the day before it is scheduled.

STEP 11 - If approved, the herbicide use called for in the treatment proposal may be conducted.

STEP 12 - In a case where the treatment proposal does not include herbicide use, TPWD will review and may disapprove or amend the treatment proposal no later than the day before the proposed control measures are to begin.

STEP 13 - If approved, the measures called for in the treatment proposal may be conducted.

Aquatic Vegetation Management in Texas: A Guidance Document
Appendix C. Aquatic Vegetation Treatment Proposal Form

Form Instructions: Please fill in all of the following information completely and write legibly. **A map of the waterbody with marked or delineated proposed treatment sites must be attached to the treatment proposal or processing may be delayed.** The permit application on the next page must be completed if prohibited exotic vegetation will be mechanically removed.

Water Body Name: Lake Neck of the Woods **Water Body Type(s):** ☑ Lake/Reservoir ☐ River/Creek

Submitted By: John Doe **Submission Date:** 05/15/2018

Property Owner: Jane & John Doe **Contact Person:** Jimmy Doe (Property Manager)

Contact Phone: (123) 456-7890 **Contact Email:** jimmydoe@email.com

Treatment Site Physical Address (attach map): 555 Bythelake Rd., Somewhere, TX 98765

Date Surveyed: 5/1/18 **Proposed Treatment Start & End Dates:*** 6/15/18 **TO** 9/1/18

Aquatic Vegetation Type(s) - Please Check ALL That Apply: ☑ Floating ☑ Emergent ☐ Submerged

Concern Tier – Please Check ONE: ☐ Immediate Response (Tier I) ☐ Maintenance (Tier II) ☑ Watch Status (Tier III)

Estimated Vegetation Coverage (Acres OR Shoreline Distance) To Be Treated: 0.5 acres **Average Water Depth:** 2 **ft.**

Proposed Treatment Type(s) - Please check ALL that apply: ☑ Mechanical ☐ Biological ☑ Chemical

Herbicide Applicator Name: Mary Smith **Applicator License Number:** 123456

Enter Each Target Aquatic Vegetation Species Name On A Separate Row In Table Below. ** Also Enter All Surfactants In Table.

Aquatic Vegetation Species Enter one species per row.	**Chemical Treatment Brand Name(s) / Active Ingredient(s)** Enter one per row; use separate row for each surfactant.	**Method/ Form of Treatment** Chemical spray, granular chemical, mechanical/cutting, biological control, etc.	**Treatment Site Description** Shoreline, cove, river/creek, etc.	**Treatment Area** Enter as acres, acre-feet, or shoreline distance for river/creek; give unit of measure).	**Percent Coverage** Enter as percent of treatment area.***	**Chemical Treatment Rate** Rate per acre or acre-foot (or per gallon***); give unit of measure	**Total Treatment Used** Multiply rate X area***
Cattails	Not applicable	Mechanical - backhoe	Shoreline	0.5	25 %	Not applicable	Not applicabl
Water hyacinth	Rodeo / Glyphosate	Chemical spray	Shoreline	0.5	25 %	1.3 oz / gal	8.125 oz
Water hyacinth	Agri-dex oil surfactant	Chemical spray	Shoreline	0.5	25 %	3 oz / gal	18.75
					%		
					%		
					%		
					%		

Comments: Herbicide and surfactant labels can be found online at http://www.cdms.net/Label-Database

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***Approved proposals authorize treatments (up to the maximum acreage proposed) until December 31st of the year the proposal was approved, provided compliance with requirements for notices of intent to apply aquatic herbicide and all applicable local or other regulations/requirements.**

**Use Additional Copies Of This Form If Needed.

***Chemical Treatment Of Individual Patches of *Riparian* Nuisance Vegetation Intermittently Distributed Along a River or Creek Enter "Spot Treatment."

(Example)

PROPOSED HERBICIDE USE NOTICE

TO:
TPWD; Governing Entity; Public Drinking Water Providers With an Intake Within Two River Miles of the Proposed Herbicide Application; All Persons Who Have Requested Notice

This is a notice of proposed herbicide use on [water body], as described in the enclosed treatment proposal. Following is the label information for [the herbicide to be applied] [a copy of the label is adequate]. [Name of person proposing herbicide use] has reviewed TPWD's guidance document and determined that the proposed herbicide application is consistent with the principles of integrated pest management, § 57.932(a)(2) of TPWD rules, and the guidance document.

The information demonstrating that the proposed application will not result in exceeding the maximum contaminant level of the herbicide in finished drinking water as set by TCEQ and EPA, or if there is no MCL, the maximum label rate, is [see section III.B.3 of guidance document for discussion of how this information is developed]:

The TDA license number for the herbicide applicator is:

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(Example)

NOTICE FROM [GOVERNING ENTITY] IN RESPONSE TO PROPOSED HERBICIDE USE

TO: [Person(s) proposing herbicide use]

[Name of Governing Entity] has received your Proposed Herbicide Use Notice, Treatment Proposal, and map. As state law requires, [governing entity] is providing you, as an attachment to this letter, a copy of the state aquatic vegetation plan. It is a violation of state law to apply aquatic herbicides in a public body of water in a manner inconsistent with the state plan.

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LITERATURE CITED

Aiken, S.G., and J. McNeill. 1980. The discovery of *Myriophyllum exalbescens* Fernald (Haloragacea) in Europe and the typification of *M. spicatum* and *M. verticillatum* L Botanical Journal of the Linnean Society 8:213-222.

Attionu, R. H. 1976. Some effects of water lettuce (*Pistia stratiotes*, L.) on its habitat. Hydrobiologia 50:245-254.

Barnett, B. S., and R. W. Schneider. 1974. Fish populations in dense, submersed plant communities. Hyacinth Control Journal 12:12-14.

Barrett, S.C.H. 1989. Waterweed invasions. Scientific American 261:90-97.

Bell, J.D. and M. Westoby. 1986. Abundance of macrofauna in dense seagrass is due to habitat preference, not predation. Oecologia 68:205-209.

Biltgen, B.A. 1981. Aufwuchs and benthic macroinvertebrate community Structure associated with three species of rooted aquatic macrophytes in Lake Onalaska, 1976-1977. M.S. Thesis. University of Wisconsin, LaCrosse, Wisconsin. 112 pp.

Bogart, D. B. 1949. The effects of aquatic weeds on flow in Everglades canals. Proceedings of the Soil Science Society of Florida 9:32-52.

Bowes, G., A. S. Holaday, and W. T. Haller. 1979. Seasonal variation in the biomass, tuber density and photosynthetic metabolism of hydrilla in three Florida lakes. Journal of Aquatic Plant Management 15:32-35.

Beumer, J. P. 1980. Hydrology and fish diversity of a North Queensland tropical stream. Australian Journal of Ecology 5:159-186.

Chesnut, T. L., and E. H. Barman, Jr. 1974. Aquatic vascular plants of Lake Apopka, Florida. Florida Science 37:60-64.

Colle, D. E., and J. V. Shireman. 1980. Coefficients of condition for largemouth bass, bluegill, and redear sunfish in hydrilla infested lakes. Transactions of the American Fisheries Society 109:521-531.

Colle, D. E., J. V. Shireman, W. T. Haller, J. C. Joyce, and D. E. Canfield, Jr. 1987. Influence of hydrilla on harvestable sport-fish populations, angler expenditures at Orange Lake, Florida. North American Journal of Fisheries Management 7:410-417.

Cook, C. D. K. 1990. Origin, autecology, and spread of some of the world's most troublesome aquatic weeds. Pages 31-73 in A. H. Pieterse and K. J. Murphy, editors. Aquatic weeds. Oxford University Press. Cary, North Carolina.

Cordo, H. A., J. C. DeLoach, and R. Ferrer. 1981. Biological studies on two weevils, *Ochatina bruchi* and *Onychylis cretatus*, collected from *Pistia* and other aquatic plants in Argentina. Annals of the Entomology Society of America 74:363-369.

Coulson, J.R. 1977. Biological control of alligatorweed, 1959-1972. A review and evaluation. USDA Technical Bulletin 1547, 98 p.

Crowder, L.B. and W.E. Cooper. 1982. Habitat structural complexity and the interaction between bluegills and their prey. Ecology 63:1802-1813.

Dibble, E.D. and S.L. Harrel. 1997. Largemouth bass diets in two aquatic plant communities. Journal of Aquatic Plant Management 35:74-78.

Fassett, N.C. 1957. A manual of aquatic plants. The University of Wisconsin Press. Madison, Wisconsin.

Gillett, J. D., C. R. Dunlop, and I. L. Miller. 1968. Occurrence, origin, weed status and control of waterlettuce (*Pistia stratiotes* L.) in the northern territory. Plant Protection Quarterly 3(4):144-148.

Gopal, B. 1987. Water hyacinth. Elsevier Science Publishers, Amsterdam.

Gowanloch, J. N. 1945. Economic importance of the waterhyacinth, *Eichhornia crassipes*, in management of water areas. Transactions of the 10th North American Wildlife Conference 10:339-345.

Haller, W.T. 1978. Hydrilla: a new and rapidly spreading aquatic weed problem. University of Florida Circular S-245.

Heck, K.L., Jr., and G.S. Wetstone. 1977. Habitat complexity and invertebrate species richness and abundance in tropical seagrass meadows. Journal of Biogeography 4:135-142.

Heck, K.L. and K.A. Wilson. 1987. Predation rates on decapod crustaceans in latitudinally separated seagrass communities: a study of spacial and temporal variation using tethering techniques. Journal of Experimental Marine Biology and Ecology 107:87-100.

Hoshovsky, M. 1987. *Arundo donax*. Element Stewardship Abstract. The Nature Conservancy, San Francisco, CA, 10 pp.

Hoyer, M.V. and D.E. Canfield Jr. 1996. Largemouth bass abundance and aquatic vegetation in Florida lakes: an empirical analysis. Journal of Aquatic Plant Management 34:33-38.

Iversen, T.M., J. Thorup, T. Hansen, J. Lodal, and J. Olsen. 1985. Quantitative estimates and community structure on invertebrates in a macrophytes rich stream. Archives fur Hydrobiologie 102:291-301.

Julien, M.H. and A.S. Borne. 1988. Alligatorweed is spreading in Australia. Plant Protection Quarterly 3:91-96.

Julien, M.H. and J.E. Broadbent. 1980. The biology of Australian weeds 3. Alternanthera philoxeroides(Mart.) Griseb. The Journal for the Australian Institute of Agricultural Science 46:150-155.

Julien, M.H., B. Skarratt, and G.F. Maywald. 1995. Potential geographical distribution of alligator weed and its biological control by *Agasicles hygrophila*. Journal of the Aquatic Plant Management Society 33:55-60.

Langeland, K.A. 1990. Hydrilla (Hydrilla verticillata (L.F.) Royle): a continuing problem in Florida waters. University of Florida Circular No. 884.

Luedke, M. and R. Cantu. 2000. The environmental fate and effects of diquat, fluridone, and 2,4-D. Texas Parks and Wildlife Department FCTS-2000-001.

Maceina, M. J. and W.C. Reeves. 1996. Relations between submerged macrophyte abundance and largemouth bass tournament success on two Tennessee River impoundments. Journal of Aquatic Plant Management 34:33-38.

Maddox, D.M. 1968. Bionomics of an alligator weed flea beetle, *Agasicles* sp. In Argentina. Annals of the Entomological Society of America 61:1300-1305.

Minello, T.J. and R.J. Zimmerman. 1983. Fish predation on juvenile brown shrimp, *Penaeus aztecus* Ives: the effects on simulated Spartina structure on predation rates. Journal of experimental Marine Biology and Ecology 72:211-231.

Mitchell, D. S. 1976. The growth and management of *Eichhornia crassipes* and Salvinia spp. In their native environment and in alien situations. Pages 167-175 in C. K. Varshney and J. Rzoska, editors. Aquatic weeds in southeast Asia. Dr. W. Junk Publisher. The Haque, Netherlands.

Mullin, B.H., L.W.J Anderson, J.M. DiTomaso, R.E. Eplee, and K.D. Getsinger. 2000. Invasive plant species. Council for Agricultural Science and Technology, Issue Paper Number 13.

Muttkowski, R.A. 1918. The fauna of Lake Mendota: A qualitative and quantitative survey with special reference to the insects. Transactions of the Wisconsin Academy of Sciences, Arts, and Letters 19:374-482.

Netherland, M.D. 1997. Turion ecology of hydrilla. Journal of Aquatic Plant Management 35:1-10.

Nichols, S.A. 1975. Identification and management of Eurasian watermilfoil in Wisconsin. Wisconsin Academy of Science, Arts, and Letters 63:116-128.

Nichols, S.A. and B.H. Shaw. 1986. Ecological life histories of the three aquatic nuisance plants, *Myriophyllum spicatum*, *Potamogeton crispus*, and *Elodea canadensis*. Hydrobiologia 131:3-21.

North American Lake Management Society and Aquatic Plant Management Society. 1997. Aquatic plant management in lakes and reservoirs. M.V. Hoyer and D.E. Canfield, editors. University of Florida, Center for Aquatic Plants.

Perdue, R.E. 1958. *Arundo donax* - source of musical reeds and industrial cellulose. Economic Bot. 12: 368-404.

Polunin, O. & A. Huxley. 1987. Flowers of the Mediterranean. Hogarth Press, London.

Reed, C.F. 1977. History and distribution of Eurasian water-milfoil in the United States and Canada. Phytologia 36:417-436.

Roback, S. S. 1974. Insects (Arthropoda: Insecta). Pages 313-376 in C. W. Hart, Jr. and S. L. H. Fuller, editors. Pollution ecology of freshwater invertebrates. Academic Press, New York.

Russo, A.R. 1987. Role of complexity and mediating predation by the gray damselfish Abudeduf sordidus on epiphytal amphipods. Marine Ecology-Progress Series 36:101-105.

Schmitz, D. C. 1990. The invasion of exotic aquatic and wetland plants into Florida: history and efforts to prevent new introductions. Aquatics 12(2):6-24.

Soszka, G.J. 1975. The invertebrates on submerged macrophytes in three Masurian Lakes. Ekologia Polska 23:371-391.

Stoddard, A. A. 1989. The phytogeography and paleofloistics of *Pistia stratiotes* L. Aquatics 11:21-24.

Stoner, A.W. 1980. The role of seagrass biomass in the organization of benthic macrofaunal assemblages. Bulletin of Marine Science 30:537-551.

Stuckey, R.L, J.R. Wehrmeister, and R.J. Bartolotta. 1978. Submersed aquatic vascular plants in ice covered ponds of Central Ohio. Rhodora 80:575-580.

Tabita, A., and J. W. Woods. 1962. History of waterhyacinth control in Florida. Hyacinth Control Journal 1:19-23.

Timmer, C. E., and L. W. Weldon. 1967. Evapotranspiration and pollution of water by water hyacinth. Hyacinth Control Journal 6:34-37.

Titus, J.E., and M.S. Adams. 1979. Comparative carbohydrate storage and utilization patterns in the submersed macrophytes, Myriophyllum spicatum and Vallisneria americana. American Midland Naturalist 102:263-272.

U.S. Congress. 1965. Expanded project for aquatic plant control: letter from the Secretary of the Army. Unpublished report, House document 251(89-1).

Vogt, G.B., J.U. McGurie, Jr., and A.D. Cushman. 1979. Probable evolution and morphological variation in South American Disonychine flea beetles (Coleoptera: Chrysomelidae) and their Amaranthaceous hosts. USDA Technical Bulletin 1593, 148 p.

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Watkins, C.E., II, J.V. Shireman, and W.T. Haller. 1983. The influence of aquatic vegetation upon zooplankton and benthic macroinvertebrates in Orange Lake, Florida. Journal of Aquatic Plant Management 21:78-83,

Wiley, M.J., R.W. Gorden, S.W. Waite, T. Powless. 1984. The relationship between aquatic macrophytes and sport fish production in Illinois ponds: a simple model. North American Journal of Fisheries Management 4:111-119.

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