A Beginner's Guide to Water Management

Aquatic Plants in Florida Lakes

Information Circular 111

Mark Hoyer

Littoral zone of Lake Newnan, Florida, July 2007

Florida LAKEWATCH

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The following is a list of all ***Beginner's Guides to Water Management***. We encourage you to read those that pertain to your individual lake management needs:

The ABCs: Descriptions of commonly used terms. Information Circular 101. 1999.
Nutrients. Information Circular 102. 2000.
Water clarity. Information Circular 103. 2000.
Lake Morphology. Information Circular 104. 2001.
Symbols, Abbreviations & Conversion Factors. Information Circular 105. 2001.
Bacteria. Information Circular 106. 2003.
Fish Kills. Information Circular 107. 2003.
Color. Information Circular 108. 2004
Oxygen and Temperature. Information Circular 109. 2004
Fish Communities and Trophic State in Florida Lakes. Information Circular 110. 2007.

As always, we welcome your questions and comments.

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Acknowledgements

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Preface

This circular has been prepared by Florida LAKEWATCH, the Department of Fisheries and Aquatic Sciences, and the Center for Aquatic and Invasive Plants of the University of Florida. Much of the material for this circular has been taken and modified from the Aquatic Plant Management in Lakes and Reservoirs manual, which was produced by the North American Lake Management Society (P.O. Box 5443, Madison, WI 53705-5443) and the Aquatic Plant Management Society (P.O. Box 1477, Lehigh, FL 33970).

Information Circular #111 represents a summary of existing knowledge on aquatic plants and aquatic plant management strategies, highlighting the Florida situation. The major focus of this circular is the management of aquatic plants as opposed to dealing with nutrients, algae, or water clarity. Readers will find practical information on those subjects and general water management information for Florida lakes in Florida LAKEWATCH Circulars #101, #102, and #103. The science of aquatic plant management, like that of lake management, continues to evolve. New information will emerge over time. Readers are therefore urged to consult knowledgeable professionals for information on recent advances in the field of aquatic plant management.

Finally, the North American Lake Management Society (NALMS) and the Aquatic Plant Management Society (APMS) recognize that citizens often hesitate to tread on the territory staked out and vigorously (even viciously) defended by "experts." NALMS and APMS, however, encourage private citizens to take an active part in developing comprehensive lake management plans that include aquatic plant management. NALMS and APMS also urge professionals to work with citizens. Although working with a diverse group of nonprofessionals may be frustrating, experts by themselves cannot manage lakes. Florida LAKEWATCH, the Department of Fisheries and Aquatic Sciences, and the Center for Aquatic and Invasive Plants agree wholeheartedly. We must all be part of the solution!

Fragrant water-lily (Nymphaea odorata)

Introduction to Sections 1 through 3

Control the weeds! Once these simple words are uttered at a Florida lake, controversy often soon follows. Why? Quarrels typically break out between and among user-groups, scientists, and management/regulatory agencies over whether there is a "weed problem" and whether the problem needs to be managed. If agreement is reached that management is necessary, quarrels then tend to erupt over how much aquatic vegetation should be controlled. If the desirable level of vegetation management can be established, additional quarrels then develop over how to achieve those levels. Should nutrient control be instituted? Should aquatic herbicides be used or should mechanical harvesting be used? Should biological controls like grass carp be used? Should a combination of management techniques be used?

Faced with what seem to be unending questions and controversies, many Floridians and some government agencies often choose the "Do Nothing" or "Delay" option. Doing nothing or delaying a decision are viable options when it comes to managing aquatic weed problems, but the history of aquatic plant management in Florida has shown that these options should not be chosen at the wrong time or for the wrong reason. When nothing is done or delay occurs beyond a reasonable time because of fear of the unknown, the abundance of aquatic plants in Florida's waters can reach truly problematic levels. Powerful political forces may then be unleashed. Soon "something" shall be done to solve the "problem" even if the political solution will create more problems at a later date!

Aquatic plant management is an important aspect of lake management. As with other lake management issues, controversies come with the territory. Quarreling among ourselves, however, cannot solve problems nor improve the chances that a serious aquatic weed problem will improve if left alone. A well-evaluated and carefully designed management plan must be developed for each water body. With reasonable care in the decision making process, aquatic plants can be managed successfully without destroying the desirable attributes of lakes that attract us to these water bodies.

Many of the conflicts that arise over the management of aquatic plants in lakes are rooted in differences in educational background, philosophy, experience, and even differing perspectives based on what region of the country our citizens may have come from. This circular is written to provide the citizens of Florida and visitors to our State a better understanding of why aquatic plants are managed as they are. Besides providing information on the concepts and techniques of aquatic plant management, the role of aquatic plants in Florida's lakes is also discussed.

The focus of this circular is the management of aquatic macrophytes. Aquatic macrophytes, by definition, are the macroscopic (large enough to be observed by the naked eye) forms of aquatic plants found in water bodies. The term aquatic macrophytes refers to a diverse group of aquatic and wetland plants and encompasses flowering vascular plants, mosses, ferns, and macroalgae. Emphasis is placed on the management of aquatic plants in lakes, but much of the information contained herein should also be useful to individuals concerned with the management of aquatic plants in reservoirs, ponds, and flowing-water systems such as canals and rivers. This circular provided information on the majority of aquatic plant management options that are currently available for large-scale use, and mention is also made of experimental techniques that may be used in the future. Most importantly, the pros and cons of using different techniques are discussed along with the potential trade-offs among alternative options given different lake uses. The following sections/topics represent the best available information on aquatic plant management as the professionals of Florida LAKEWATCH, the Department of Fisheries and Aquatic Sciences, and the Center for Aquatic and Invasive Plants have come to know:

Section 1 describes how aquatic plants fit into the ecology of Florida lakes. Understanding the role of aquatic macrophytes in water bodies, especially with regard to water quality and fisheries, is critical to the development of sound management plans. All readers are strongly urged to read Section 1 completely because this section reveals many relationships between aquatic plants and lake ecology that should be understood before developing an aquatic plant management plan.

Section 2 addresses the question of whether there is a weed problem at a lake. This section focuses on how to define the problem and identify possible causes for the problem.

Section 3 discusses the various aquatic plant management techniques that are currently available for managing nuisance growth of aquatic weeds. Specific attention is given to mechanical, chemical, and biological controls with discussion of the pros and cons of using these techniques.

Section 1: Aquatic Plant Biology

Introduction

Much aquatic plant research has been stimulated by the need to control nuisance species such as hydrilla (*Hydrilla verticillata*), water hyacinth (*Eichhornia crassipes*), Eurasian watermilfoil (*Myriophyllum spicatum*), elodea (*Elodea canadensis*), coontail (*Ceratophyllum demersum*), curly-leaf pondweed (*Potamogeton crispus*), and alligator-weed (*Alternanthera philoxeroides*). Understanding aquatic plant biology is important to the immediate problems of managing aquatic plants and aquatic ecosystems, and it makes the development of new management techniques, the application of present techniques, and the assessment of environmental impacts more efficient. Interest in restoring and restructuring macrophyte communities and an appreciation for the littoral zone (the littoral zone is that portion of a water body extending from the shoreline lakeward to the greatest depth occupied by rooted plants) are growing. There is also a need to make management results more predictable, especially when considered in a long-term ecosystem context.

The development of effective and environmentally acceptable aquatic plant management programs also requires some knowledge of lake limnology. Limnology is the scientific study of the physical, chemical, geological, and biological factors that affect aquatic productivity and water chemistry in freshwater ecosystems-lakes, reservoirs, rivers, and streams. Many limnological processes affect the species, distribution, and/or abundance of aquatic plants that will be present in a water body. Making things more complicated, aquatic plants can also impact limnological processes like nutrient, chemical and temperature regimes and other biota in a lake or reservoir, especially in the littoral zone.

A single written section cannot review all the aquatic plant biology and limnology that might be relevant to aquatic plant ecology and it is not our intent to do so. There are several good technical textbooks that go into great detail on the ecology of aquatic plants (Hutchinson 1975; Wetzel 1983; Cole 1983). However, we will provide information that is most applicable to aquatic plant management efforts including information about:

- Types of aquatic plants
- Littoral zone
- The limnological and physical factors that determine plant distribution and abundance
- The influence that aquatic plants have on the limnology of the littoral zone
- The biotic component: relationships between aquatic plants and other organisms including epiphytes, macroinvertebrates, fish, and wildlife.

Types of Aquatic Plants

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Emergent plant: Cattail (*Typha sp.*)

The types of aquatic and wetland plants (macrophytes) of interest to most aquatic plant management programs can be classified into four groups: Emergent, Floating-leaved, Submersed, and Free floating. Aquatic macrophytes, by definition, are the macroscopic (large enough to be observed by the naked eye) forms of aquatic and wetland plants found in water bodies. The term aquatic macrophytes refers to a diverse group of aquatic plants and encompasses flowering vascular plants, mosses, ferns, and macroalgae.

Emergent macrophytes (plants that are rooted in the substrate, with the tops of the plant extending into the air) grow on periodically inundated or submersed soils. Most emergent macrophytes are perennials (plants or plant parts living for longer than one year). They are typically rooted in the lake bottom, have their base portions submersed in water, and have their tops elevated into the air. This is ideal for plant growth. Nutrients are available from the sediment, water is available from the sediment and overlying water, carbon dioxide and sunlight are available to the emergent portions of the plant.

Emergent plants have to be strongly rooted and much energy is put into producing a strong structure to withstand the wind and waves in the shallow water zone. Many plant species need mud flats for their seeds to germinate, but they can spread into deeper water by sprouting from rhizomes, which are expanding roots or underground stem systems. In northern climates, the dry dead stems often supply oxygen for root respiration during the winter when the lakes are covered with ice. Cutting off dead stems below the water surface before the lake freezes limits oxygen supplies and sometime kills the rhizomes – a potentially useful management technique in northern cold climates, but not in Florida.

Vic Ramey © 1999 Univ. Florida

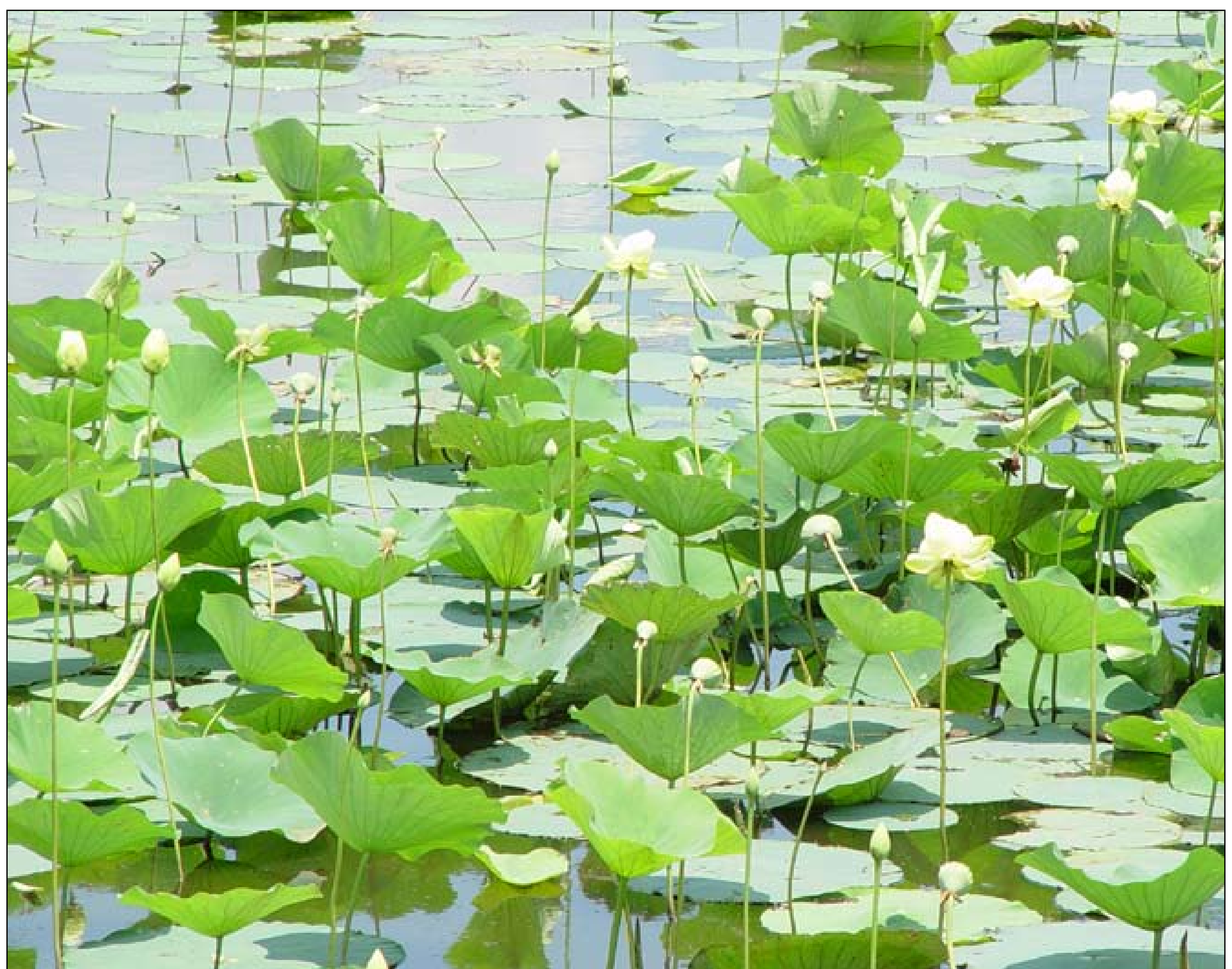
Free floating plant: Water hyacinth (*Eichhornia crassipes*)

Common emergent macrophytes include plants such as bulrushes (*Scirpus spp*.), cattails (*Typha spp*.), reeds (*Phragmites spp*.), spikerushes (*Eleocharis spp.*) maidencane (*Panicum hemitomon*), pickerelweed (*Pontederia cordata*), and duck potato (*Sagittaria lancifolia*). Some emergents, wild rice (*Zizania spp.*) for example, develop submersed or floating leaves before mature aerial leaves form.

Floating-leaved macrophytes (plants that are rooted to the lake bottom, with leaves that float on the surface of the water) generally occur in areas of a lake that do not occasionally dry out. Common representatives include waterlilies (*Nymphaea spp.*), spatterdock (*Nuphar spp.*), and watershield (*Brasenia spp.*). Floating leaves are attached to roots or rhizomes with a flexible, tough stem (actually in many cases a leaf stalk). Some floating-leaved macrophytes, like *Nuphar spp.*, can exist in a submersed form for a considerable time. Many floating-leaved species form large colonies from spreading underground rhizomes. In northern climates, under winter drawdown conditions, frost will often "heave" the rhizomes up out of the lake bottom, which helps thin dense stands.

Floating-leaved plants live in two extremely different habitats, water adjacent to the bottom of the plant and air adjacent to the top of the plant. A thick, waxy coating protects the top of the leaf from the aerial environment, which makes herbicidal control of this plant type difficult. The waxy coating repels herbicides unless it is mixed with special chemicals called adjuvants (wetting agents) to help the herbicide stick and penetrate the waxy surface. Adjuvants are also used on many kinds of emergent and free-floating species when treating with herbicides because these plants also have protective coatings. The waxy coating also tends to be present on most emergent aquatic plants and not specific to floating leaved species.

Submersed macrophytes (plants that grow completely under the water) are a diverse group that includes quillworts (*Isoetes spp*.), mosses (*Fontinalis spp.*), muskgrasses (*Chara spp.*), stoneworts (*Nitella spp.*) and numerous vascular plants. Many submersed plants, such as widgeon-grass (*Ruppia maritima*), various pondweeds (*Potamogeton spp.*), and tape-grass (*Vallisneria spp.*), are native to the United States. Others like hydrilla, Eurasian



Floating-leaved plant: American lotus (*Nelumbo lutea*)

watermilfoil, and curly-leaf pondweed are exotic and cause some of the worst aquatic weed problems. These invasive plants tend to grow rapidly to the water surface and they can form dense canopies in the upper water column that interfere with both the use and aesthetics of the water body.

Submersed species face special problems, including obtaining light for photosynthesis and carbon dioxide from the water where it is much less available than it is in the air. However, submersed species have to invest much less energy into structural support because they are supported by the water and water accounts for about 95% of the weight of this type of plant.

Submersed plant: Coontail (*Ceratophyllum demersum*)

Free-floating macrophytes (plants that typically float on or just under the water surface with their roots in the water and not in the sediment) are also a diverse group of aquatic plants. Small free-floating plants include duckweeds (*Lemna spp.*), mosquito fern (*Azolla caroliniana*), water meal (*Wolffia columbiana*), and water fern (*Salvinia spp.*). Larger free-floating plants include water hyacinth and water lettuce (*Pistia stratiotes*).

Free-floating species are entirely dependent on the water for their nutrient supply. In fact, some (e.g., water hyacinth) have been used in wastewater treatment to remove excess nutrients. If nutrient limitation will work for macrophyte management, this is the group for which it will most likely work. Free-floating plants are also the only aquatic plants not constrained by water depth. The location of these plants is at the whims of wind, waves, and current, so they will likely be found in quiet locations and embayments. The growth rate of these plants is also extremely high. For example, water hyacinth plants can double in ten days and 10 plants can become almost 41,000 plants in 120 days (Figure 1). For this reason, water hyacinths can cover nearly the entire surface of ponds, lakes and rivers (not just quiet locations and embayments).

The above are general descriptions of aquatic plant groups and some of the biology pertinent to their management. One excellent resource for this type of information is the Aquatic Plant Information Retrieval System at the University of Florida, Center for Aquatic and Invasive Plants Plants, 7922 N.W. 71st Street, Gainesville, Florida 32653 (http://plants.ifas.ufl.edu/). Control tactics are often species-specific and, as management plans are developed, you will need to know exactly what species are present, where they are located, and in what abundance that they occur. This takes some technical knowledge but help is usually readily available through natural resource agencies, universities, museums, natural history surveys, and private consultants.

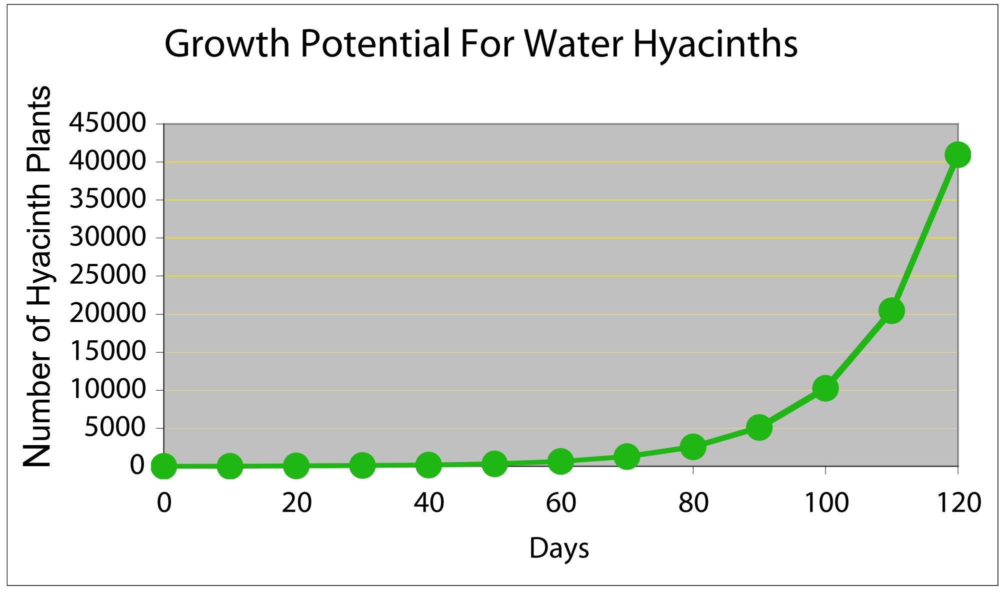


Figure 1. Growth potential of water hyacinths without any control, based on one plant doubling every ten days.

Littoral Zone

Rooted aquatic plants inhabit the littoral zone, the interface between dry land and open water of lakes and reservoirs. The littoral zone is defined by where rooted plants will grow (Figure 2). It is the area from the lake's edge to the maximum water depth where rooted plant growth occurs. Because most lakes and reservoirs in the United States are relatively small and shallow, the littoral zone often contributes significantly to a water body's productivity and it can be a major factor regulating lake or reservoir ecosystems. The littoral zone has traditionally been divided into four rather distinct transitional zones: the eulittoral, upper littoral, middle littoral, and lower littoral.

The eulittoral zone constitutes that part of the shoreline that lies between the highest and lowest seasonal water levels and often contains many wetland plants. The upper littoral zone is commonly called the emergent plant zone and is generally dominated by emergent plants. This zone extends from the waters edge to depths of about 3 to 6 feet (1 to 2 m). The middle littoral zone is deeper and is generally dominated by floating-leaved plants like fragrant waterlily (*Nymphaea odorata*), yellow waterlily (*Nymphaea mexicana*) and American lotus (*Nelumbo lutea*). The middle littoral zone extends lakeward from the upper littoral zone to water depths of 3 to 9 feet (1 to 3 meters). Finally, the lower littoral zone is the deepest zone where most submersed plants are found and typically extends from the floating-leaved plant zone down to the limits of the photic zone (photic zone is the area of a lake where photosynthesis can occur and is defined by the depth to which at least 1 percent of the surface light intensity penetrates). The depth of the photic zone is dependent on water clarity, which is primarily determined by the amount of algae in the water (see Florida LAKEWATCH Circular #103, *A Beginner's Guide to Water Management – Water Clarity*).

Limnological and Physical Factors that Determine Plant Distribution and/or Abundance

Different species of aquatic plants live in different "worlds," with sediment, water, and air in different combinations. Most aquatic plants are secondarily adapted to life in the water having once lived on land and gradually evolving mechanisms to deal with a watery world.

The most important environmental factors affecting the abundance and distribution of aquatic macrophytes in lakes include: light availability, lake trophic state characteristics as they relate to water chemistry, sediment characteristics, wind energy, lake morphology (e.g., surface area, shape, depth, etc.), and watershed characteristics. All of these factors can work independently and/or in combination to determine the distribution and abundance of aquatic plants in lakes.

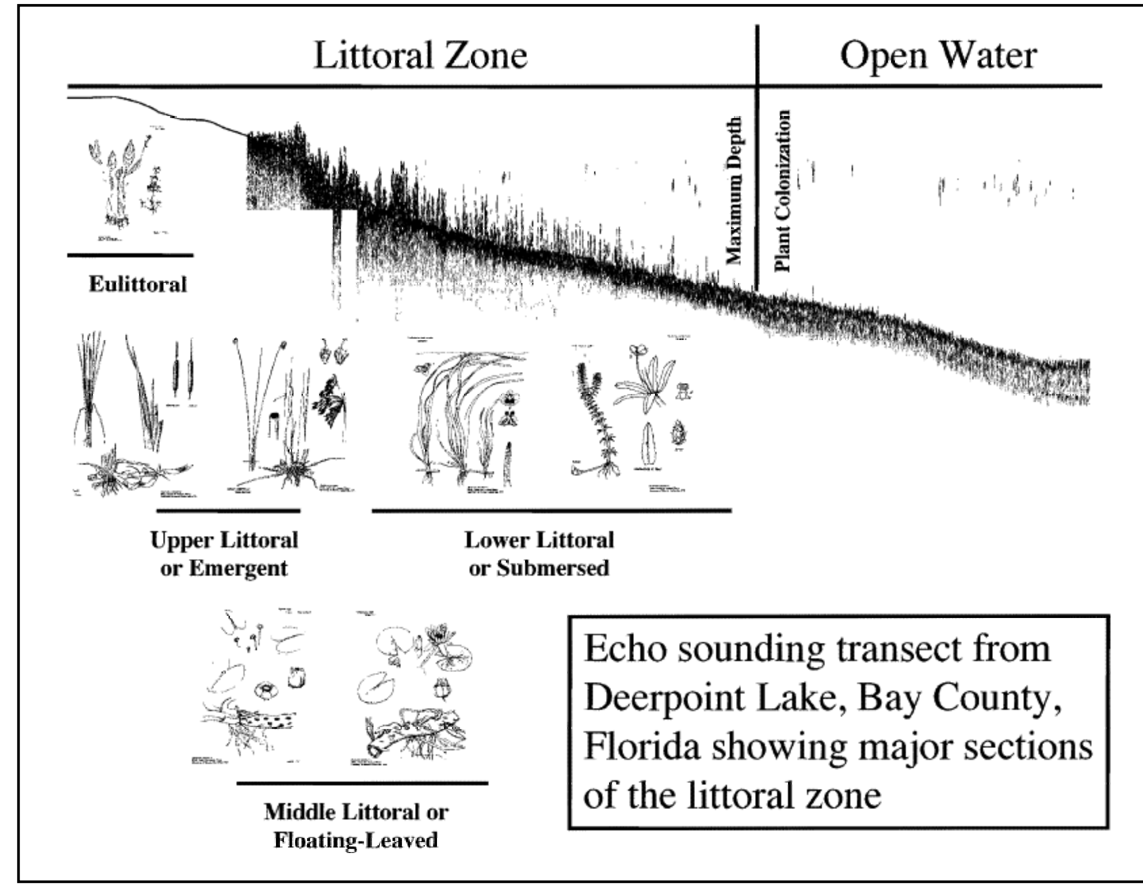


Figure 2. Diagram of a lake's littoral zone.

Light Availability

Aquatic plants require light for growth, thus light availability is often considered the single most crucial environmental factor regulating the distribution and abundance of aquatic plants. Light availability is directly linked to water clarity and as water depth increases or water clarity decreases both the amount and the spectral quality of light for photosynthesis at the lake bottom diminishes. Generally, submersed macrophytes will grow to a depth where at least 10% of the ambient surface light is available. This depth can roughly be estimated by multiplying the Secchi depth (depth at which a black and white disk lowered into a lake disappears) by 1.7. Thus, lakes with the majority of their bottom exceeding 1.7 times the Secchi depth will have fewer aquatic macrophytes. Even shallow lakes, if they are turbid enough, will have sparse aquatic plant growth on the bottom.

Recent work by Florida LAKEWATCH graduate students and staff has defined the relationship between maximum depth of aquatic plant colonization and Secchi depth for 279 Florida lakes (Figure 3), (Caffrey et al. 2007). This relationship was shown to be similar to those that have been published using data from other parts of the country and world, suggesting that this relationship is extremely robust and can be use to help determine aquatic plant management strategies for lakes. In fact, Florida LAKEWATCH staff (Hoyer et al. 2005) successfully used published relationships between maximum depth of aquatic plant colonization and Secchi depth to estimate changes in the potential aquatic plant coverage of some Florida lakes that have large fluctuations in water level.

Florida LAKEWATCH Circular #103 (*A Beginner's Guide to Water Management – Water Clarity*) does an excellent job describing factors that determine water clarity in lakes. In a nutshell, water clarity is determined by the abundance of phytoplankton, organic color, and both organic and inorganic suspended particles present in the water. Lakes with low phytoplankton concentrations and low color values have high water clarity. As phytoplankton and color levels increase, there is a rapid reduction in water clarity, aquatic macrophytes become light limited, and the size of the littoral zone decreases. Conversely, the size of the littoral zone can increase if phytoplankton or color levels decrease. Non-algal suspended particle (suspended solid) concentrations in lakes are determined by the continuous processes of surface runoff input, loss to sedimentation, and resuspension of the bottom. Shallow lakes, with substantial layers of soft sediments and open to the wind often have high suspended solid concentrations due to wind mixing of bottom sediments. Suspended solids limit light for plant growth and decrease littoral zone size. Boat traffic, shoreline erosion, and biotic factors such as fish (e.g., the common carp or catfish) feeding on the bottom can also increase suspended sediment.

Trophic State, Plant Nutrition, and Water Chemistry

All things being equal, nutrient-poor lakes are less productive than nutrient-rich lakes. The primary factor determining trophic state of a lake (i.e., nutrient richness) is the geologic region where the lake occurs. Some soils, which are determined by the surrounding geology, simply have more nutrients than other soils. Additionally, watershed management practices and human-caused nutrient additions can also be important in determining nutrient levels in lakes. These nutrients in turn generally result in more algal growth, which decreases water clarity and thus decreases available light for aquatic plants (see Florida LAKEWATCH Circular #102, *A Beginner's Guide to Water Management – Nutrients*).

Some lake managers believe that nutrients can limit the growth of aquatic plants. However, there are few substantiated reports of nutrient-related growth limitation for aquatic plants. Nutrients supplied from sediments, combined with those in solution, are generally adequate to meet nutritional demands of rooted aquatic plants, even in oligotrophic (nutrient-poor) systems. While this information suggests that nutrients do not limit growth of aquatic plants in oligotrophic lakes, a large survey of Florida lakes (Canfield and Hoyer 1992; Hoyer et al. 1996) indicated that these lakes generally do maintain less total biomass of aquatic plants and usually different species than eutrophic (nutrient-rich) lakes. Even though this is true for extremes on the nutrient continuum, nutrient control is probably not a viable tool for aquatic plant control in lakes.

Rooted macrophytes usually fulfill their phosphorus (P) and nitrogen (N) requirements by direct uptake from sediments. The role of sediments as a direct source of P and N for submersed macrophytes is ecologically quite significant, because available forms of these elements are normally in very low concentrations in the open water of most aquatic systems, especially during the growing season. Likewise, the availability of micronutrients in the open water is usually very low but they are relatively available in most lake sediments. However, the preferred source of some required nutrients such as potassium (K),

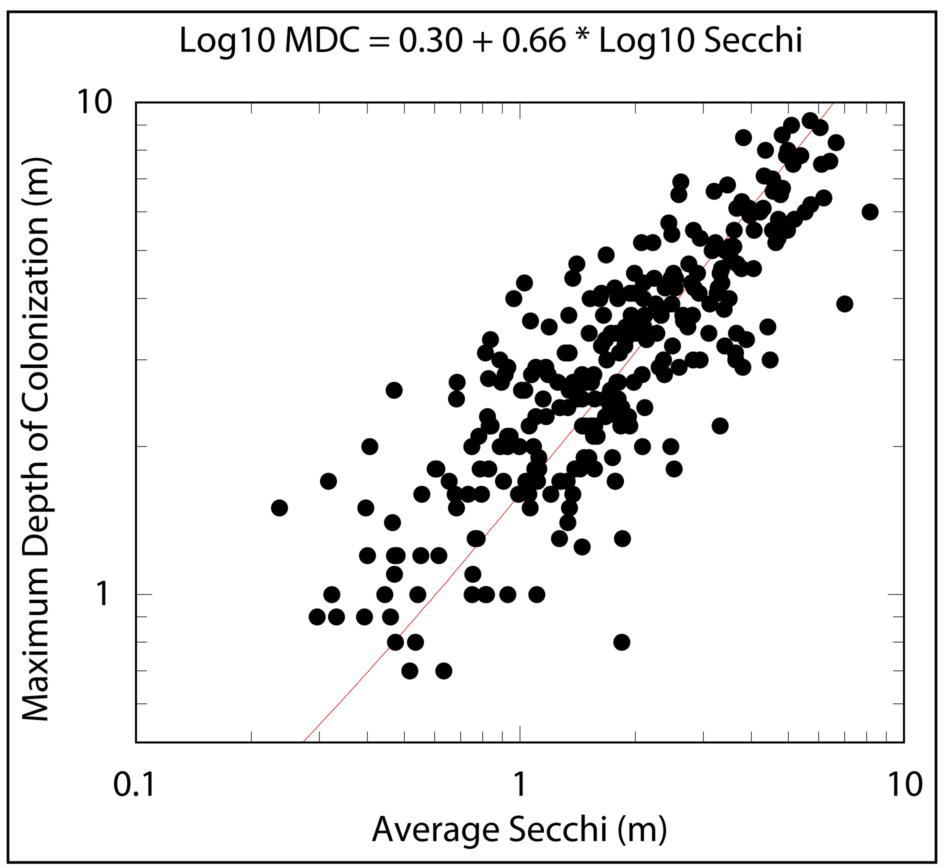


Figure 3. Relationship between maximum depth of aquatic plant colonization and Secchi Depth for 279 Florida lakes.

calcium (Ca), magnesium (Mg), sulfate (SO_4), sodium (Na), and (Cl) appears to be the open water. Submersed macrophytes make use of both aqueous and sedimentary nutrient sources, and sites (roots vs. shoots) of nutrient uptake are related, at least in part, to nutrient-specific differences in sediment compared to overlying water nutrient availability. In other words, submersed plants are operating like good opportunistic species should operate; they take nutrient supplies from the most easily available source.

Inorganic carbon is the nutrient most likely limiting photosynthesis and growth of submersed macrophytes. The difficulty plants have in capturing carbon dioxide (CO_2) and transporting it throughout the plant is known to limit photosynthesis in terrestrial plants. This aspect is even more critical in submersed aquatic plants because the diffusion of CO_2 into lake water is slow. The free CO_2 dissolved in water is the most readily used carbon form by freshwater submersed plants for photosynthesis. Some species of aquatic plants can utilize bicarbonate (HCO_3) as a carbon source, but do so much less efficiently. The ability to use bicarbonate has adaptive significance in many freshwater systems because the largest fraction of inorganic carbon exists as bicarbonate.

Besides influencing growth, general water chemistry (i.e., pH, alkalinity, specific conductance) influences the species composition in lakes and is an important factor determining plant distribution over broad geographic regions. For example, Hoyer et al. 1996 found water-moss (*Fontinalis spp.*) occurred in 32 of 322 lakes that had an average pH of 5.2, while bacopa (*Bacopa monnieri*) occurred in 57 of the 322 lakes that had an average pH of 7.4. Apparently, these two plant species need different water chemistries to survive. There are large water chemistry gradients in the waters of the world including; hardwater/softwater, acid/alkaline, oligotrophic/eutrophic —but usually there are some plant types than can live in any combination of chemistries.

Substrate Characteristics

Bottom sediments act as a nutrient source and anchoring point for aquatic plants. Some bottom types (e.g., rocks or cobble) are so hard that plant roots cannot penetrate them. Others are so soft, flocculent, and unstable (commonly called muck) that they will not anchor plants. Thus, substrate with characteristics between rock and flocculent organics, with sufficient nutrients and light, will generally support aquatic plants.

Another substrate factor that may limit the growth of aquatic plants is anaerobic (devoid of oxygen) conditions. Low dissolved oxygen concentrations in sediments can cause a host of chemical conditions that can be toxic to aquatic plants. High concentrations of soluble reduced iron, manganese and sulfides including S=, HS-, and H_2S are highly toxic to plants. High soluble iron concentrations interfere with sulfur metabolism and limit the availability of phosphorus. Sediments containing excessive organic matter often contain high concentrations of organic acids, methane, ethylene, phenols, and alcohols that can be toxic to vegetation. The above conditions are most frequently found in anaerobic sediments of eutrophic or hypereutrophic lakes. To some degree, aquatic plants can protect themselves from these toxins with oxygen released from roots, which eliminates the anaerobic conditions that create the toxic substances.

Lake Morphology – An Integrating Factor

Water clarity, trophic state, water chemistry, substrate type, wind and wave action are parameters identified as important factors determining aquatic plant distribution and abundance. These parameters are interrelated and interact with the lake's basin depth, bottom slope, surface area, and shape to determine littoral zone size (aka, lake morphology). For a good overall description of lake morphology see LAKEWATCH Circular #104 *A Beginner's Guide to Water Management – Lake Morphology*.

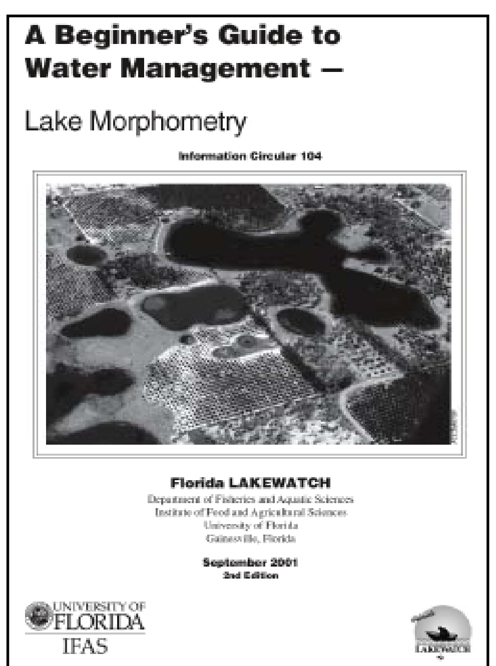
Lake basin forms are extremely variable and reflect the water body's mode of origin. Lake basins are continuously modified with water movements and sediment inputs from the basin's watershed. As basin form is modified, the size of the littoral zone in relation to a lake's open-water changes with most water bodies becoming shallower. Unless something or someone intervenes, littoral zone size increases as a water body gets older.

Water depth is one of the most critical environmental factors determining the lakeward extent of the littoral zone and the type of plants that grow in a water body. Where a lake's substrate exceeds approximately 1.7 times the Secchi depth, submersed aquatic plants will be light limited and generally unable to grow. With some exceptions, a depth range between 30 and 45 ft (9 and 14 m) is the limit for most aquatic plants, even if light is available. Emergent and floating-leaved plants seldom grow in water exceeding 10 ft (3 m), so deep lakes also have limited emergent communities.

The steepness of the littoral slope is inversely related to the maximum biomass of submersed macrophytes, which is probably due to the difference in sediment stability on gentle and steep slopes. A gently sloping littoral zone allows the deposition of fine sediments that promote plant growth. Steeply sloped littoral zones are areas of erosion and sediment transport not suitable for plant growth. The manipulation of lake depth and slope are both powerful tools when encouraging or discouraging the growth of aquatic plants in specific areas of a lake.

Wind Energy and Watershed Characteristics

All lakes have a shoreline-water interface that receives energy from wind and waves. Surface area and shape significantly influence the effect wind can have on wave size and current strength. Large lakes tend to have larger fetches (area open to the prevailing wind) and thus have greater wave and current energy than lakes with small surface areas. Wave action and currents erode a terrace along the shoreline, leaving coarse material in shallow water and depositing finer materials in deep water. The direction and strength of the wind, slope, and shape of the lake basin determine where the substrates will move. Generally, points and shallows where wind and wave energy are highest tend to be swept clean. Bays and deep spots in a lake tend to fill with sediment. In England, Pearsall (1920) demonstrated that the variation in the quantity and quality of silt largely controls the distribution of submersed vegetation. Large lakes with many bays or coves may develop an extensive littoral zone because these areas are protected from strong waves and currents. Thus, basin size, shape, and depth determine to a large degree the distribution of sediments in a lake and therefore the distribution of aquatic plants.



The Influence Aquatic Plants have on Limnology of the Littoral Zone

Up to this point, we discussed the effects of the environment on aquatic plants. Now, it is time to discuss the converse – the effects that aquatic plants have on their environment. Natural ecosystems can experience massive changes in aquatic plant biomass over time scales of decades to centuries. Management practices and the introduction of new species produce equally large changes over time scales of weeks or months. These changes in the species composition, distribution, and abundance of aquatic plants impact lake ecosystems by altering physical, chemical, and biological aspects of the littoral zone and potentially whole lake systems.

The following relationships are complicated and describing them in detail is beyond the scope of this circular. We offer the following general descriptions to let the reader know that managing or not managing aquatic plants in lakes can cause rippling effects throughout a lake system.

Physical and Chemical Components

Dense stands of aquatic plants form a heavy shading canopy that significantly alters the available light under the aquatic plants. This shading and reduced water circulation allows the formation of vertical temperature gradients as steep as 18°F (10°C) over 3 ft (1m) of water (Figure 4). Reduced water circulation throughout plant beds also enhances deposition of fine sediment that would otherwise be suspended in the water column. Aquatic plant beds also act as a sieve, retaining coarse particulate organic matter that enters the lake from storm water. Aquatic plants themselves produce tremendous amounts of organic matter through photosynthesis that falls to the bottom on a daily basis. All of these mechanisms tend to increase the accumulation of sediments, which is often considered undesirable for people who use these areas of a lake.

Over the short-term, organic matter accumulation creates a food source for benthic (bottom dwelling) organisms. However, over the long term, accumulation of organic sediments causes expansion of the littoral zone and filling in of the lake. In general, macrophyte stands are sinks for particulate matter and sources of dissolved phosphorus and inorganic carbon.

Photosynthesis and respiration (metabolism) in dense submersed aquatic plant stands can cause daily dissolved oxygen changes as large as 12 mg/L to occur in surrounding waters. During daylight hours, while photosynthesis occurs, water can become supersaturated with oxygen. Respiration at night can deplete dissolved oxygen in dense beds with little water circulation. Metabolism of submersed aquatic plants can also influence concentrations of dissolved inorganic carbon, which in turn impacts pH. Aquatic plants remove inorganic carbon from the water by assimilation and the production of marl (carbonate deposits that encrust some aquatic plants). By removing inorganic carbon, aquatic plants stands can change pH by 2 to 3 pH units during a 24-hour period. Additionally, aquatic plants release several dissolved organic compounds into the water that contribute to the metabolism of bacteria and epiphytic (living on the plant) microorganisms that can also impact oxygen, inorganic carbon, and pH.

Aquatic plants and associated periphyton (algae that attaches to plants) can influence nutrient cycles. Phosphorus, for example, is removed from the sediment via plant roots and incorporated into plant biomass. Phosphorus is also removed from the water by plants and associated periphyton. When plant tissue dies, phosphorus is released and circulated, at least briefly, back into the water column. The extent and timing of this cycling can greatly influence phytoplankton growth. If nutrients are "tied up" in aquatic plant and periphyton biomass during the growing season, little is available for phytoplankton growth and the water in the littoral zone may be clearer than in deeper open water zones. In northern lakes, if the nutrients are released in the fall, water temperatures are cool enough so phytoplankton blooms, at least noxious ones, do not occur. If macrophytes die during the spring or summer, as often happens with herbicide treatments, nutrients are released at an opportune time for phytoplankton growth.

Aquatic plant death and decay also adds organic matter to the sediments. When and how much organic matter is added to the sediment influences dissolved oxygen concentrations. If large amounts of dead organic matter are added to the lake under warm, still conditions, oxygen depletion and its associated negative impacts on aquatic organisms can occur, especially if summer herbicide treatments are not well planned. In northern climates, oxygen depletion occurs under ice and can be critical if decaying vegetation is extremely abundant, often times killing fish. These are referred to as "winter kills."

How important is the littoral zone to overall lake productivity and ecology? The importance of the littoral zone to whole lake primary productivity (the rate at which algae and macrophytes fix or convert light, water, and carbon to plant tissue in plant cells) varies with the surface area and volume of the lake and the size of the

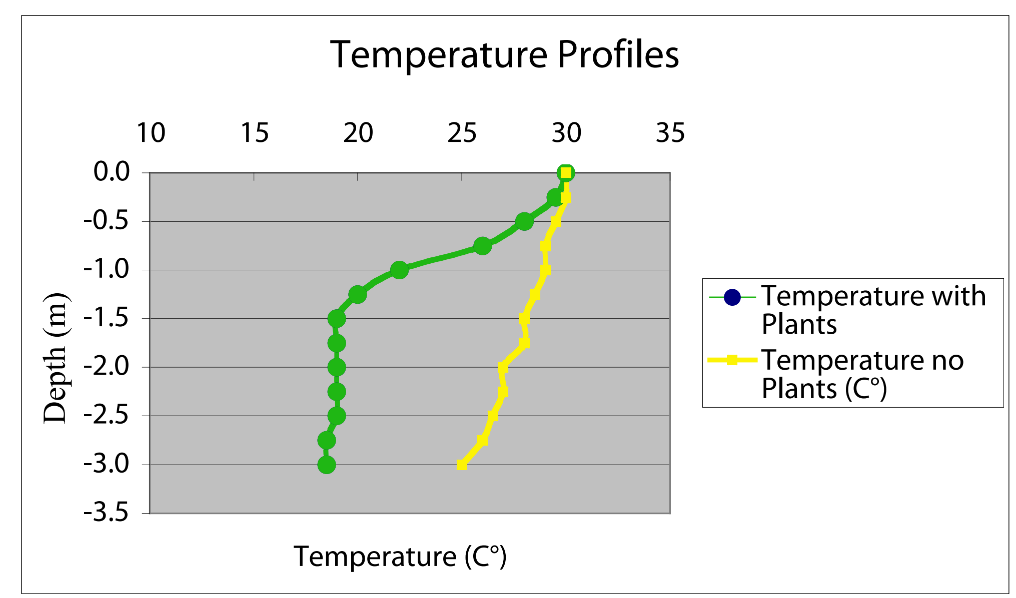


Figure 4. Profiles of temperature by depth for two stations in Orange Lake, Florida measured in July 2007. One profile was measured in matted hydrilla and one was measured in open water.

littoral zone in that lake. Small lakes generally have more shoreline length per lake surface area, so the percentage of productivity contributed by the littoral zone is higher when compared to open-water algal productivity. Thus, the importance of aquatic macrophytes and attached periphyton to the overall productivity of lakes decreases proportionately as lakes get larger and deeper. Shallow lakes, however, can also have a limited littoral zone with low submersed macrophyte abundance because of natural circumstances (low water clarity) or lake management activities (macrophyte control with herbicides, biocontrol, or mechanical harvesting). In these lakes, open-water algae would again dominate the total primary productivity of these systems.

Generally, the more productive the littoral zone, the more productive the whole lake is likely to be, if your definition of productive is carbon fixed (total photosynthesis). There are, however, few herbivores in North America (invertebrates or fish) that derive energy directly from aquatic macrophytes. Recently, stable carbon isotope analysis (an analysis that follows the flow of carbon through a food web from primary producers through top carnivores) in a shallow Florida lake showed the carbon source for 12 species of fish and five species of invertebrates was primarily epiphytes (algae that grow attached to aquatic plants) and not eel-grass (V*allisneria americana*), the rooted aquatic plant that covered 90% of the lake area. Thus, while eel-grass was fixing the majority of the carbon in the lake, the carbon fixed by the periphyton was the major source being transferred through the food web.

U.S. Army Corps of Engineers

It is easy to see from this 1939 photograph, taken in West Palm Beach, why water hyacinth became one of the first aquatic plant problems and why maintenance control is so important.

J. Butler

Hydrilla midge (*Criptopus lebetis*)

The Biotic Component

Aquatic plants and attached periphyton in the littoral zone are food and habitat for a wide variety of organisms. Because this is a rather large and understudied topic, we will discuss it separately from the other effects that macrophytes have on their environment. The physical and chemical changes that macrophytes produce in the littoral zone impact the organisms that live there. We separate the relationships only for ease of discussion and will emphasize the relationships with epiphytes and macroinvertebrates, fish, and wildlife species.

By now, you should understand that the influences that aquatic plants have on lake systems are tremendous and that this circular cannot fully explain all aspects of their impact. This circular is designed to highlight some of the more important characteristics of aquatic plants and their place in the ecosystem, so read on and enjoy.

Aquatic plants are colonized by a rich array of attached algae (periphyton) and microbes, particularly in hard-water lakes where carbonate deposits strengthen the matrix formed by the attached organisms. The total productivity of the attached organisms ranges from 4 to 93% of the host aquatic plant productivity. As mentioned above, open water algae are sparse in the presence of abundant aquatic plants and attached periphyton. One reason for this is the competition for nutrients between periphyton and open-water algae; periphyton appear to be much more active than their host plants in dissolved-nutrient exchange.

High invertebrate densities, typically associated with aquatic plants, result in part from the abundance of periphyton (prime invertebrate food) available on macrophyte surfaces. Many invertebrates associated with aquatic plants eat the periphyton complex on the surface of the macrophytes rather than the macrophytes themselves. A few invertebrates, however, feed directly on aquatic macrophytes. A classic case is the denuding of some macrophyte communities in northern Wisconsin lakes by the exotic (for this region) rusty crayfish (*Orconectes rusticus*). Also, mining insects like the hydrilla tip mining midge (*Cricotopus lebetis),* bore through plant tissue and some insects use plant tissue as habitat to lay eggs and nurture immature life stages (e.g., waterhyacinth weevils, *Neochetina spp.*). With these activities, insects destroy much more macrophyte tissue than they consume.

Invertebrates that live in sediments congregate beneath macrophytes as well because of the abundance of organic matter trapped or deposited by the aquatic plants. Some use aquatic plant remains as food and others eat algae that cover the sediments. The total abundance of invertebrates (primarily chironomid/midge larvae) varied up to 196,000/m^2 on and under Eurasian watermilfoil beds in a cove of the Hudson River, New York. In the Eau Galle Reservoir, Wisconsin, bottom dwelling organisms were more than ten fold greater in number associated in a coontail bed than in an adjacent barren area with the same substrate type. The inshore area, under macrophyte beds in Halverson Lake, Wisconsin, contained 60% of the midge larvae and over 90% each of snails, fingernail clams, and caddisfly, dragonfly, damselfly, and mayfly larvae that existed in the lake. These examples again point toward the importance of aquatic plants to aquatic ecosystems.

The importance of aquatic invertebrates may not be obvious to many lake users. However, aquatic invertebrates are a major food source for forage fish and young life stages of many game fish. Many waterfowl and other birds also depend heavily on invertebrates as a high protein food source needed for reproduction and rapid early growth of their young. Because aquatic invertebrates are linked to the production of aquatic plants, periphyton, open water phytoplankton and the energy (i.e., food) needs of recreationally important fish and wildlife species, you can again see the importance of aquatic plants to lake systems.

Fish

The interactions between fish and aquatic plants are highly variable, which makes generalities difficult. The interactions vary because of differences in aquatic systems related to lake morphology, trophic state, plant/fish species distribution and abundances, geographic area, and others. Generally, however, there are fish species that decrease in abundance (e.g., bluespotted sunfish, *Enneacanthus gloriosus*), increase in abundance (e.g., gizzard shad, *Dorosoma cepedianum*), and maintain the same abundance (largemouth bass, *Micropterus salmoides*) as aquatic macrophyte abundance decreases in lakes.

Will Strong

Mark Hoyer caught this largemouth bass in Lake Tohopekaliga, Florida, fishing the edge of hydrilla mats.

Each lake has a carrying capacity for the total amount of fish, which is primarily determined by lake trophic state. Within that carrying capacity, aquatic macrophytes can determine the fish species and size composition in a lake. High aquatic plant abundance favors fish species that are adapted to aquatic plants (mostly small size fish). Low aquatic plant abundance favors fish species that are adapted to open water. It is important to note here that the number of species in a lake generally remains the same and only the species composition changes as aquatic plants change in a lake. A good example of this is Lake Baldwin, Florida that went from 95% covered with hydrilla to <1% after the introduction of grass carp, while maintaining the same fish species richness (number of species).

A major factor determining the value of aquatic plants to fish is whether the fish is a prey species or a predator species. The presence of aquatic macrophytes increases the physical structural complexity of lake ecosystems. This structural complexity provides refuge for prey species and interferes with the feeding of some predator species. Exposure to predators strongly determines small fish feeding behavior and survival rates. If they are relatively safe from predators, they can forage more effectively. For large predators, the visual barrier of plant stems decreases their foraging efficiency; hence growth of large predators declines as habitats become more complex.

Sometimes small areas of littoral habitat, while not contributing significantly to the total production of the lake, are important for the reproduction or recruitment (i.e., spawning or nursery habitat) of some fish or other aquatic organisms. For example, although spawning on macrophytes is unusual for salmonids, at least a portion of the population of lake trout (*Salvelinus namaycush*) in Lake Tahoe spawns in deep water (40-60m deep) over beds of muskgrass (*Chara spp.*). No additional evidence for spawning was found over rocky formations that exist at various depths in the lake. Apparently, the muskgrass mounds, which represent a small portion of the primary productivity in Lake Tahoe, are favored as spawning habitat, as they provide the basic requirements for successful egg incubation.

These are only a few of the important relationships that exist between aquatic plants and fish populations. Unfortunately, these relationships give little insight to how aquatic macrophytes affect "fishing." Some anglers enjoy fishing in and around aquatic plants and some do not, but most anglers agree that there can be too many aquatic plants for good fishing. Thus, the question boils down to how many plants are "the right amount" to provide habitat for fish populations and structure for anglers. Too few plants generally do not provide enough cover; too many may lead to stunted fish populations, poor predator growth, and poor access for fishing. The common answer is a moderate amount of aquatic plants. Several studies have suggested the optimum aquatic plant coverage in lakes for healthy fish populations ranging from 15-85%. It is important to note, however, that lakes with no aquatic plants and those with 100% volume infested with aquatic plants will both support fish populations. The problem is that some of these populations do not occur in the desired abundances or species compositions.

Wildlife

Similar to fish, the interaction between wildlife and aquatic plants is highly variable, again making the discussion of generalities difficult. Herbivory of macrophytes by wildlife species is much more common than with fish and is probably an under-appreciated aspect of energy and nutrient transfer in the littoral zone. Pelikan et al. (1971) reported that 9-14% of the net annual cattail production is consumed or used as lodge construction by muskrats. Smith and Kadlec (1985) reported that waterfowl and mammalian grazers reduced cattail production by 48% in the Great Salt Lake marsh. Muskrat grazing or "eat out" is important for maintaining diversity in the emergent zone. Open areas in the cattail marsh are produced that increase edge effect and allow submersed species and other emergent species to invade areas previously occupied by a single species of dense emergent vegetation.

Seeds, tubers, and foliage of submersed species are used as food by a variety of wildlife, especially waterfowl. Plant material is often high in carbohydrates, which provide energy for long migratory flights. Scientists estimated that waterfowl consumed 40% of the peak standing crop of sago pondweed in Delta Marsh, Manitoba. The scientific name of canvasback ducks (*Aythya valisinera*) shows their close association with wild celery or eel-grass (*Vallisneria americana*), which they eat in abundance during fall migration and on their wintering grounds in Chesapeake Bay. A major concern about the invasion of Eurasian watermilfoil is its ability to displace wild celery in large shallow lakes in Minnesota, Wisconsin, the upper Mississippi River, and Chesapeake Bay -- traditional resting areas for canvasbacks, a species with generally declining numbers.

Invertebrates, produced in macrophyte beds, are also important to many wildlife populations. The invertebrates produce the protein that is vital to laying hens and chicks of many waterfowl and other waterbirds. Higher up the food chain, eagles, osprey, loons, mergansers, cormorants, mink, otter, raccoons, and herons, to name a few, feed on fish or shellfish that dined on invertebrates that lived in aquatic plant beds.

Nesting sites in, or nesting materials from the emergent zone are important to species like red-winged and yellow headed blackbirds, marshwrens, grebes, bitterns, Canada geese, and muskrats. Sometimes the importance is not direct. Geese and other waterfowl sometimes nest on top of muskrat houses or muskrat food piles made of cattails.

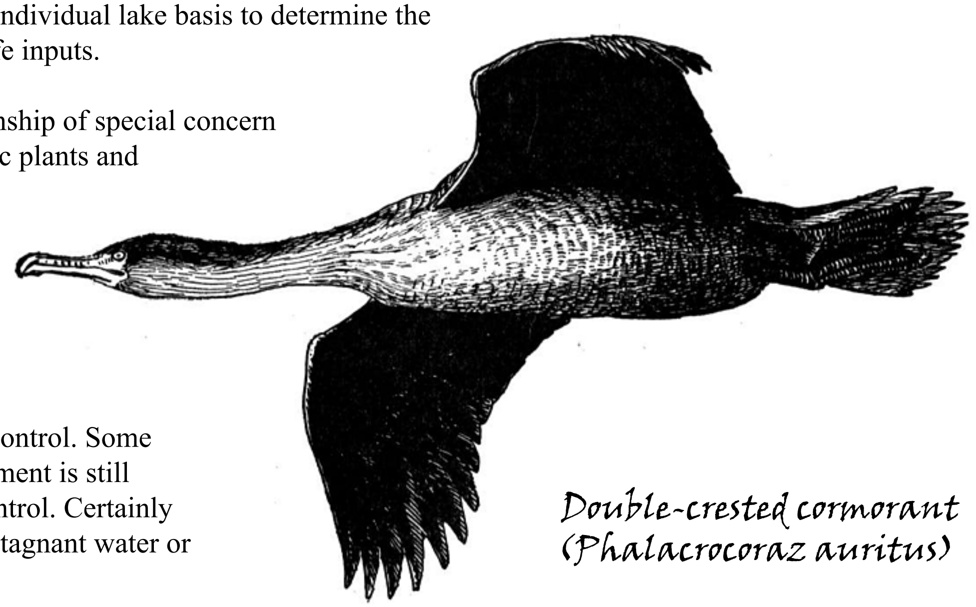
Richness of bird species is positively correlated to lake surface area and trophic state of Florida lakes but not with aquatic plants (Hoyer and Canfield 1994). As aquatic plant abundance increases, however, birds that used open-water habitats are replaced by species that use macrophyte communities. Some bird species require specific types of aquatic vegetation and removal of that type may exclude individual bird species from a lake system.

Mark Hoyer

Alligator nesting among emergent vegetation in Lake Tohopekaliga, Florida.

A topic seldom discussed is the ability of wildlife to import and recycle nutrients. Hoyer and Canfield (1994) estimated that phosphorus loads into 14 Florida lakes by birds ranged from 0.1% to 9.1% of the annual phosphorus budget, an amount they thought was insignificant. The nutrient inputs to a small lake however, by a few hundred resting Canada geese, after feeding all morning in a nearby cornfield, may be a different matter. Nutrient budgets need to be analyzed on an individual lake basis to determine the significance of wildlife inputs.

A wildlife relationship of special concern is that between aquatic plants and mosquitoes. Prior to the invention of chemicals for mosquito control, the removal of aquatic plants was the dominant method of mosquito control. Some aquatic plant management is still done for mosquito control. Certainly anything that causes stagnant water or offers protection from predators of mosquito larvae has the potential to support a mosquito nuisance. This includes temporary ponds, knotholes in trees, and old tires lying in the backyard. Where aquatic plants exacerbate these conditions, they may contribute to the mosquito problem. If water circulation and predators are present, mosquitoes are much less of a nuisance.



Double-crested cormorant
(Phalacrocoraz auritus)

Section 2: Aquatic Plant Management Problems

A weed is any undesired, uncultivated plant that grows in profusion so as to crowd out a desired plant.
~Modified from Webster's New World Dictionary

Introduction

Aquatic macrophytes can be beneficial or problematic in aquatic systems depending on the defined uses of the aquatic systems (Table 1). Because lakes and reservoirs cannot be all things to all people, even the macrophyte abundance within a given lake can be beneficial or problematic depending on one's use of the lake or reservoir. Thus, defining the primary uses of a lake or reservoir is the first step when developing a lake management plan and determining if there is an aquatic weed problem.

Even when reasonable people join to help shape a management strategy for a water body, several elements inevitably come into conflict. Among the more obvious are differences in desired uses for the water from each of the various interest groups, and varying degrees of knowledge about water quality, fisheries management, and aquatic plant management options. Another important difference can be simply our own level of experiences with aquatic and wetland plant management problems.

It is probably safe to say that no two people see exactly the same things when they assess a water body. Long-term residents who have witnessed hydrilla or Eurasian watermilfoil mats come and go will probably react very differently than new arrivals to the neighborhood who have never before seen the dramatic changes that can occur as these weeds fill the water column of a lake. The loudest voices at the homeowner's association meeting may be from the members unable to remember how extensive the cattails were before the dredging project was undertaken. Others may simply have never recreated or lived around water before, and may be very unsure about exactly what constitutes a serious problem, and what is a normal occurrence. Imagine, for instance, what a visitor from Okeechobee, Florida thinks when confronted with the excellent, but very different looking bass habitat of Lake Casitas in southern California. "No grass, no bass" may be the southern cry but not when they are regularly catching 18-pound largemouth bass in 60-100 feet of water in Lake Casitas.

To further complicate the situation, things that look like problems may not be, and seriously degraded conditions may not attract any attention at all. We humans are extremely visually oriented, and easily impressed by rather small changes in large items. Doubling of cattail from four to eight acres over a two-year period may mean something dramatic is happening to water depth. Is sediment filling in the bottom or is it simply the re-invasion following last year's mechanical removal project? Regardless, the expansion of cattail will probably be noticed by many, unlike the more subtle and probably far more important changes that may be taking place to the water chemistry of the lake. Reliable historical information, collected in an appropriate manner by knowledgeable people, can do more than almost anything else to resolve discussions of "what is happening to the lake?" A water quality monitoring system like the citizen volunteer programs in New Hampshire, Vermont, Wisconsin, and Florida can yield valuable information to help guide lake management decisions.

The purpose of this section is to identify the many types of aquatic and wetland plant management problems, both to inform ourselves about the many issues and options involved, and to help recent arrivals to the lakefront gain a better understanding about how serious their "own" particular problems are or are not. Another introductory point to consider is that a perceived problem can be a real problem, regardless of the water body conditions. Finally, if a lake manager believes in a different management strategy than the user groups, it may ultimately be the politicians that determine the outcome. Recognizing that there is science, there is human experience, there are disparate interests, and that these are rarely isolated from each other, is an important part of learning about resolution of aquatic and wetland plant management problems.

Lake Use	Aquatic Macrophyte Abundance Zero	Moderate	High
Consumptive Uses			
1) Drinking water	(-,+)	(-,+)	(-,+)
2) Power Production	(+)	(-,+)	(-)
3) Irrigation	(+)	(-)	(-)
4) Industrial uses	(+)	(-,+)	(-,+)
5) Depository for storm water and treated sewage effluent	(+)	(+)	(+)
6) Flood control	(+)	(-,+)	(-)
Navigation			
1) Commercial	(+)	(-,+)	(-)
2) Recreational:			
a. Power boating	(+)	(-,+)	(-)
b. Sailing	(+)	(-)	(-)
c. Rowing	(+)	(-,+)	(-)
Aesthetic properties			
1) Property values	(-,+)	(-,+)	(-)
2) Scenic values	(-,+)	(-,+)	(-,+)
3) Health	(-,+)	(-,+)	(-,+)
4) Body contact (e.g., swimming)	(+)	(-,+)	(-)
5) Education	(-,+)	(-,+)	(-,+)
6) Scientific	(-,+)	(-,+)	(-,+)
Flora and Fauna			
1) Fishing	(-,+)	(-,+)	(-)
2) Hunting	(-,+)	(-,+)	(+)
3) Non-consumptive viewing (e.g., photography)	(-,+)	(-,+)	(-,+)
4) Species composition, natural, managed, threatened, and endangered.	(-,+)	(-,+)	(-,+)
a. Plants	(-,+)	(-,+)	(-,+)
b. Invertebrates	(-,+)	(-,+)	(-,+)
c. Mollusks	(-,+)	(-,+)	(-,+)
d. Reptiles	(-,+)	(-,+)	(-,+)
e. Amphibians	(-,+)	(-,+)	(-,+)
f. Fish	(-,+)	(-,+)	(-,+)
g. Birds	(-,+)	(-,+)	(-,+)
h. Mammals	(-,+)	(-,+)	(-,+)

Table 1. Impact of Varying Aquatic Macrophyte Abundance's on Some Lake Uses
(-), problematic (+), beneficial (-,+), both problematic and beneficial depending on circumstances

Visible Problems

Physical Blockages

It is often easier to work with visible (e.g., physical blockages of access to lakes with aquatic vegetation) than invisible (e.g., dissolved oxygen depletion caused by an excess of aquatic vegetation) problems that appear in aquatic and wetland areas. Many of the visible problems, however, are more social than biological in importance.

Access problems occur when emergent, floating-leaved, submersed, freely floating or woody vegetation obstructs boat ramps or boat trails. Some of these problems are purely in the eyes of the user. For example, if a boat ramp is constructed in a shallow water area with dense populations of cattail, normal sedimentation processes, compounded by boat and vehicle traffic, will operate to fill in the dredged areas, and cattails will probably return. At this point, we would want to know if this is a real problem, and what is the cause. In our cattail example, it's a real problem to the boating public, but it is probably not a problem to the water chemistry and related biology of the whole lake, unless it is somehow linked to changes in water elevation, hydroperiod (seasonal water elevation), nutrient loads, or other variables, and only a problem then if the changes do not coincide with management objectives.

Organic sedimentation

Organic sedimentation is a more complex visual problem resulting in the filling of reservoir and lake bottoms with decomposing terrestrial and aquatic plants (both phytoplankton and macrophytes). This problem may be more significant in warmer latitudes, where aquatic plant productivity is enhanced by warm weather. While little is known about organic sedimentation in most water bodies, some studies have measured a significant contribution made by aquatic plants (e.g., giant reed *Phragmites spp*., cattail, water hyacinth) to the accumulation of materials in a lake bottom. Thus, keeping aquatic plant populations low during the growing season can greatly extend the time before mechanical dredging might be necessary to keep water depth at the desired level.

Whether this particular example is an ecological or user problem, or both, depends on several things. For instance, accumulation of aquatic vegetation in ponds, lakes, and bogs is an integral part of the natural succession of shallow open water bodies to vegetation-covered wetlands, or even terrestrial vegetation. Active management would be necessary to stop, reverse, or slow succession. Compounding the problem, many of the water bodies that are rapidly filling in are now dominated by invasive, non-indigenous plants. Biomass production by these species can be many times that of the native species that are reduced or eliminated from the sites because of competition. Again, depending on the stated uses for an aquatic system, managers may want to reduce the added accumulation of decaying biomass by reducing non-native species and being less concerned about the consequences of native plant growth.

Non-native or exotic plant species are often deemed undesirable because of their growth potential and because they replace native species. There is, however, little hope of totally eradicating these exotic plants, so a better title for them may be "naturalized flora." In some cases, non-native or exotic plant species have even been reported beneficial to fish populations. This is something to consider when deciding how to manage "naturalized flora."

In a particularly interesting way, water control structures on many of our water bodies act to prevent natural processes that often remove decaying vegetation. Flood waters scour river channels, and may act to remove accumulating sediment from larger rivers, but most large lakes and reservoirs act as sediment traps. Some individual water bodies, however, may be susceptible to scouring during exceptionally violent storms. The dramatic rainfall associated with intense storms (e.g., hurricanes) may operate periodically to scour sediment from shallow lakes. Water control structures, however, are now designed to reduce this active process and some reduction of aquatic plant vegetation may actually be needed to offset the scouring that is no longer occurring as frequently as it had in the past.

Sediment accumulation frequently increases when aquatic plants become established. Sediment movement and accumulation in aquatic systems follow standard laws of physics. High energy water carries a greater sediment load than low energy water, with large items settling quicker than small items as water energy decreases. Sediments also tend to travel down hill, and holes in the bottom of water bodies tend to fill over time. Because sediment (sand, clay, silt, and organic matter that forms the bottom of a water body) type greatly affects plant establishment and growth, invertebrate populations, and fish spawning and feeding, it is not surprising that small changes in sediment type and depth can affect a water body in a number of ways. Thus, potential impacts of aquatic plant management on sediment characteristics should be included in any assessment of aquatic plant management options.

Mark Hoyer

Island constructed of muck and aquatic plant material that was scraped from the littoral zone of Lake Tohopekaliga, Florida.

Plant Piles

Unwanted piles of live or dead (decaying) vegetation along residential shorelines, on boat ramps, in swimming areas, and in commercial boating areas are common sources of complaint. Floating plants and plant parts are wind driven, and so commonly accumulate in downwind areas. Rooted plants sometimes break free during storms, or slough off stems and leaves when water temperatures drop in the fall and winter. Some breakage of plant parts occurs with most species throughout the growing season. Large accumulations of plant parts can result from mechanical removal of aquatic or wetland plants if little effort is made to collect plants cut by harvesters. Chemical control can act to shear off plants near the hydrosoil surface. Even biological control with grass carp can produce large amounts of moving vegetation. Grass carp often grasp stems near the middle or bottom of the plant, feed on part of what is removed, and allow the uneaten parts to drift.

Accumulated vegetation can create odor problems, and can provide breeding locations for mosquitoes and other disease-carrying organisms. Nutrients leaching from a decaying mound of vegetation may cause small local problems (e.g., algal blooms), but nutrient cycles in large water bodies are generally not altered significantly by concentration of plant biomass in small areas. For example, the Florida Fish and Wildlife Conservation Commission scraped approximately 1.2 million cubic yards of accumulated muck and plant material from Lake Tohopekaliga and piled it onto the lake bottom creating 29 islands with a total footprint of about 66 acres. Water quality monitoring data showed that these islands did not significantly change the whole lake water chemistry.

Under several environmental conditions, aquatic plants can form floating islands sometimes call tussocks. Floating vegetation can also form a substrate for the germination and growth of other plant species increasing the size of the islands. These floating islands can become large and complex, causing many problems of their own. Large floating islands have blocked boat ramps and boat trails, and can shade out or uproot other plants beneath them. Floating islands pose problems for water control structures, especially during high water flow. Movement of water through the structure can be partially or totally blocked, and large islands are capable of removing some structures. This is especially important when considering flood control programs.

Blocking Water Management Structures

The number of ways that aquatic plants can cause problems with water management structures seems endless, and may actually be endless with the continuing development of new types of water management equipment. The simplest problems to imagine, not necessarily solve, is the accumulation of aquatic plants that block gates open, block gates closed, and prevent gate movement, often when it is most critically needed. Failure of a water control gate to move appropriately can result in minor amounts of water going where it is not wanted or not going where it is wanted. Failure during emergencies, however, can result in the loss of property from flooding (damage to crops, damage to buildings and equipment), or from drying (damage to crops, added expense for water treatment or alternative water supply), and the potential for loss of life. When maintenance crews are attempting to clear aquatic plant accumulations from the intakes of hydroelectric systems on canals, the expenses fill many categories, including overtime for crews, loss of hydroelectric generating capability, and added equipment requirements. Sometimes, even specially trained underwater dive teams are required.

As water measurement devices become more sophisticated, impacts from aquatic plant accumulations seem to be getting worse instead of better. While the presence of plant material in measuring devices (water wheels, measured gate openings) can require physical removal to restore accurate readings, the arrival of remotely sensed measuring devices and gate adjusters means that frequently no person is present to know if plant accumulations are interfering with water delivery quantification. Hydroacoustic equipment can be used to measure water flow through measured weirs in canals, but those measurements are spurious at best when aquatic plants are present.

Concern about aquatic plants and their impacts to water management structures often reaches a maximum during natural storm events. Floodwaters can float water hyacinth and other species into and out of areas where they do not normally accumulate. Impacts of the flood-waters are magnified by the additional load of aquatic vegetation, which tends to become attached to structures. In extreme circumstances, accumulation of aquatic plants can result in the tearing out of a control structure or removal of highway bridges. These situations rarely confront a lake front property owner, but they can be important discussion points when explaining the benefits of controlling nuisance growth of aquatic plants, especially to utility and resource managers, and elected officials.

Physical problems caused by aquatic vegetation can be colossal enough to shut down a power plant or modest enough to fill in a boat ramp. As discussed previously, if the determined use of a water body is impaired by accumulations of aquatic plants, then there is a problem.

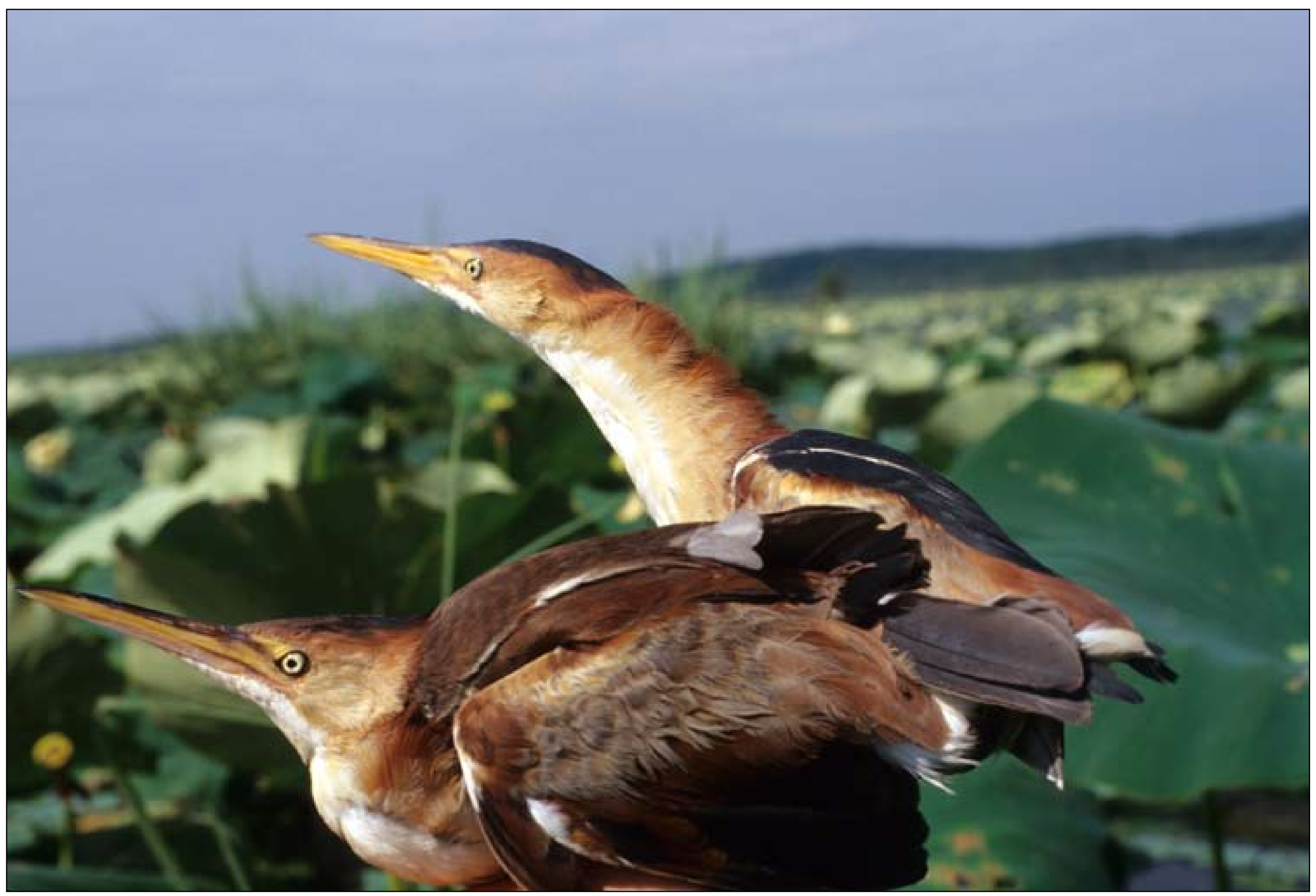
Ken Langeland

Submersed plants piling up on a bridge in South Florida.

Biological Problems

Physical problems of water bodies are usually relatively straightforward and solvable when compared with the issues related to plant and animal community ecology. Most aquatic organisms fall into three categories: 1) organisms that increase in abundance as aquatic vegetation increases, 2) organisms that decrease in abundance as aquatic vegetation increases, and 3) organisms that are unaffected by aquatic vegetation density. A good example of this comes from the aquatic bird populations that use lakes in the southeastern United States. Bird abundance and total species richness remain relatively stable as aquatic plant abundance increases in a water body, but birds that use open-water habitats (e.g., double-crested cormorant, *Phalacrocorax auritus*) are replaced by species that use aquatic macrophytes (e.g., ring-necked duck, *Athya collaris*). Some species, however, maintain a constant density as aquatic plant abundance increases in a water body (e.g., least bittern, *Ixobrychus exilis*). Thus, increasing aquatic vegetation in a southeastern lake is problematic to the person who enjoys watching double-crested cormorants feeding on shad, beneficial to duck hunters, and inconsequential to the photographer attempting to take a picture of a least bittern.

The above bird example can be repeated for individual species of plants, invertebrates, mollusks, reptiles, amphibians, fish, and mammals inhabiting aquatic systems. The question, "What user or what species do we manage a lake for?" becomes even more complicated when we consider exotic, threatened and endangered species. Do we use all of our resources to try and eliminate exotic species or do we realize they are here to stay and manage lakes for a defined use? Do we ignore all other flora and fauna and manage lakes to promote the reproduction and success of threatened and endangered species and if we do, what about biodiversity? It is not difficult to see why biological problems caused by aquatic plants are more difficult to define and attempt to solve than physical problems caused by aquatic plants.



Photographer unknown

Least bitterns in Orange Lake, Florida.

Water Clarity

As shown in Figure 3, aquatic macrophytes have an inverse relationship with water clarity. As aquatic macrophyte abundance increases in a lake, the abundance of suspended solids (e.g., algal cells, dead organic matter, clay particles), which are the primary determinant of water clarity in most reservoir and lake systems, decreases. There are several hypotheses used to explain this inverse relationship. One hypothesis suggests that aquatic plants and the attached algae compete for the nutrients that would otherwise be expressed as suspended algae (e.g., phytoplankton). Another hypothesis suggests that aquatic plants stabilize sediments and reduce the resuspension of nutrients that could be used by suspended algae. Stabilizing the sediments also reduces the resuspension of dead organic matter and clay particles. It does not matter if both of these or other mechanisms are working independently or together to cause this inverse relationship, because the fact that it exists has been documented many times.

The information on the inverse relationship between aquatic plants and water clarity needs to be discussed when planning any aquatic plant management because the control of abundant aquatic plants to alleviate a defined problem may cause another perceived problem. Most people consider clear water as a good attribute in lakes and when it decreases from 15 feet to 3 feet after controlling aquatic plants, people may decide that the aquatic plant problem was not as bad as the reduced water clarity.

A whole-lake reduction in water clarity usually will not occur when aquatic plants, covering less than 30% of the lake's surface area, are controlled. However, a whole-lake reduction in water clarity will most likely occur when aquatic plants covering more than 50% of the lake surface area are controlled. Thus, significant reductions in water clarity usually occur only when whole-lake aquatic plant control programs are initiated. The use of grass carp is a good example of a whole-lake control technique because they, in almost all cases, control all aquatic plants in a lake. When sufficient grass carp are stocked into a lake with 30-50% aquatic plant coverage, a significant decrease in water clarity can be predicted (Figure 5). This can also occur with other aquatic plant management techniques (e.g., herbicides), if sufficient aquatic macrophytes are controlled.

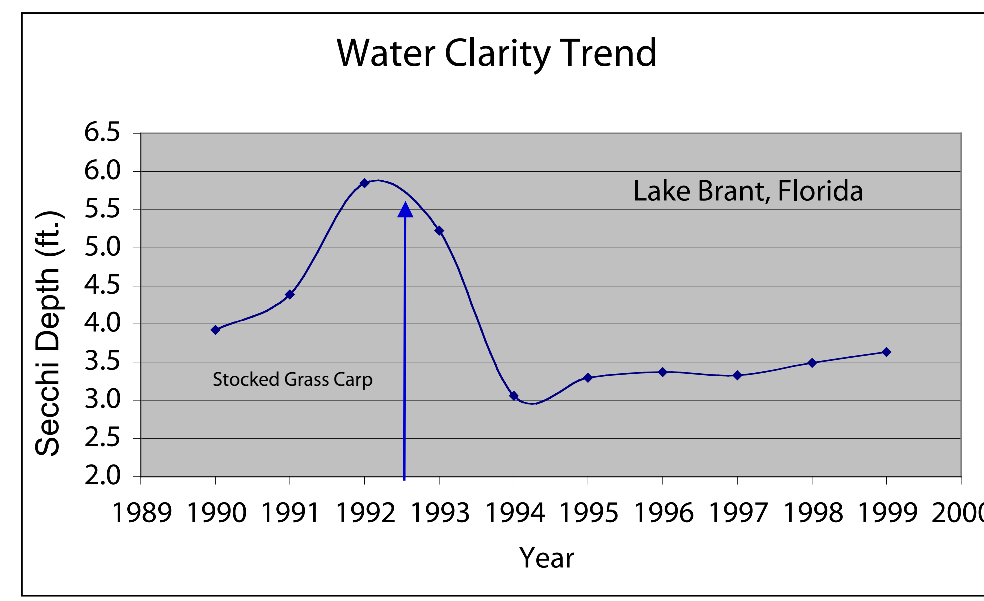
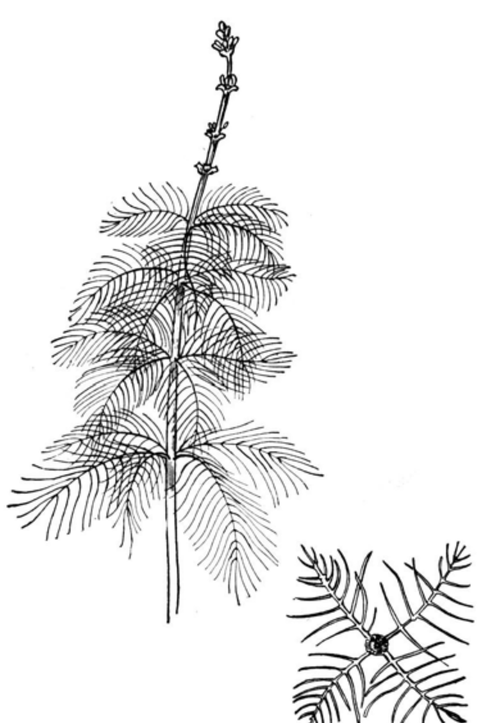


Figure 5. Trend in annual average water clarity measured with a Secchi disk before and after grass carp were stocked in Lake Brant, Florida.

Fishing

The impact that aquatic plants have on fish populations is visible and can be measured given sufficient money, equipment, and time. The impact that aquatic plants have on fishing, which is the catch and release or catch and harvest of sportfish, is also visible (no fish, no boats) but not so easy to measure. Anglers who are used to fishing the edge of water hyacinth and hydrilla mats for largemouth bass are usually disappointed and their catches decrease when that habitat is controlled. Anglers who routinely catch largemouth bass in the same lake by trolling crank-baits in open water, however, are not so affected. Now, not only does fish population biology dictate part of the equation, but also the availability of specific fish species to specific angling techniques. High numbers of largemouth bass may be present in a water body, and individual fish weight may be in the trophy category, but if angling methods and physical access do not match the water body's sportfish patterns, catch may be very low.

Largemouth bass are topographically related fish, which means that they are typically found in or around something physical, including changes in bottom slope, dead trees, etc. When rooted aquatic plant coverage in a lake is high, largemouth bass forage among openings in the weed mats. This pattern is one that can be observed easily, and catching of largemouth bass from openings in dense weed mats is a standard successful practice in many reservoirs and lakes. If vegetation is reduced, however, anglers often maintain their standard angling techniques, both in fishing location and baits used, while the largemouth bass are returning to their former habits of association with topographical features. Successful anglers adapt as conditions change and take of sportfish may have more to do with angler patterns than with the number, type, or dominance of the aquatic vegetation present. While it may be inconvenient to change angling techniques, the presence or absence of aquatic vegetation in this example is only a problem if the angling population views it as such.



Eurasian water milfoil (Myriophyllum spicatum)

There are several cases where aquatic vegetation can be a problem to all fishing regardless of the angling methods. Most of these are physical blockages of access for people with boats or bank fishing for people without boats. Aquatic macrophytes can also cause fish kills by contributing to oxygen depletions and it is hard to catch fish when there are few fish in the lake.

Invisible Problems

Most physical problems caused by aquatic plants are visible, easy to define and solve. Most biological problems caused by aquatic plants are also visible, but much harder to define and difficult to solve. Invisible problems, like insect-born diseases that could be linked to aquatic plants may be the most difficult aquatic plant problems to define and resolve. Aquatic plants can also change water chemistry slightly, yielding invisible behavioral changes in the biological components of an aquatic system. For example, abundant aquatic vegetation can decrease dissolved oxygen in the water that impacts fish feeding patterns that may cascade through an entire aquatic system. These are difficult problems to understand, let alone incorporate into a management plan. Thus, it is important for all parties helping to develop a management plan to have at least a general understanding of what's going on in the water that we can't "see," why and how it is measured, and what the measurements tell us.

Insects, Diseases, and Other Problems

Each year, a number of cases of equine encephalitis are reported to disease centers in the U.S. This disease, and several other equally dangerous diseases, is carried by mosquitoes. Mosquitoes and other insects find suitable breeding sites in slow-moving waters found in many aquatic systems. Successful recruitment of mosquitoes and other insects into biting adults requires the escape of immature larval stages from predators.

Aquatic plants can provide excellent mosquito hiding areas in slow-moving water. Roots of water hyacinth often shelter numerous organisms, and thick mats of submersed vegetation can screen prey from hungry fish and invertebrate predators. Reduction of thick aquatic plant growth may not reduce the number of eggs laid in a particular area, but it may allow small fish and invertebrates the opportunity to feed on mosquito eggs, larvae, and emerging adults.

Insect problems related to aquatic plants are not really "invisible," since some simple observations can often identify the types and general amounts of larval insects in a water body. Many parts of the country have mosquito control districts that perform assessments of mosquito levels, and staff of these organizations may be available to assess the water body in question. In addition to observations of the water body, some districts also conduct sophisticated examinations of the disease levels within the insect vector populations.

"Swimmer's itch" is probably best described as a collection of skin irritations associated with water contact. The organisms that cause swimmer's itch are highly varied, but some are part of a life cycle between parasites and animals. In one example, a trematode uses birds, fish and some invertebrate (e.g., snail, clam, or worm) to complete its life cycle. At one stage in the cycle, a free-swimming cercaria (the larval stage of a trematode's lifecycle) actively seeks to penetrate a host, which is usually a bird or fish, to form metacercaria. The free-swimming cercaria are also able to penetrate human skin just enough to cause a reaction, either a physical reaction to the invasion, or an actual allergic reaction. Populations of the snails are often high in reservoirs and lakes with large aquatic plant populations. Control of aquatic plants is often used as a first step in reducing the human health hazard of this collection of organisms.

Dissolved Oxygen

Living in an atmosphere that readily and regularly mixes thoroughly, we don't often stop to think about the distribution of oxygen and its levels of availability for us to breathe, at least until we climb to 10,000 feet of elevation or higher. Even in fairly confined spaces (cars, homes, closed offices), enough air exchange normally occurs with the "outside" to keep oxygen deprivation from being a recognized problem.

It is a different story in water. Oxygen moves very slowly through liquids, and very, very slowly through solids such as ice. If the oxygen level in a small deep reservoir could be indicated by various shades of blue (dark blue = very little oxygen, light blue = oxygen rich), the bottom layer of the reservoir might be almost black, indicating no oxygen at all. We could see fish and invertebrates avoiding the oxygen depleted water; possibly moving into it briefly, but then moving to more oxygenated water very quickly. If we could somehow get very close to the black water, we might also see small organisms, even some fish, dying as they lose muscle control before getting into better quality water.

How do aquatic plants affect oxygen concentrations in a water body and can they cause a problem? A difficult concept to grasp for many people, is that plants need oxygen just like animals, and plants can also die under very low oxygen conditions. If plants photosynthesize (produce their own food from sunlight, carbon dioxide, and an impressively complex set of associated chemical products, enzymes and reactive surfaces), which yields oxygen as a by-product, why do they need oxygen? The answer is very simple: they need oxygen for exactly the same reasons that animals need oxygen, to allow the complete breakdown of energy storage products (sugars and starches) to release chemical products for growth, and energy for chemical reactions (respiration).

Plants use carbon dioxide and sunlight to photosynthesize energy storage products (sugars and starches), but to use those products efficiently, they, like animals, must have access to oxygen. In a 24-hour period under situations of low light on cloudy days, the amount of oxygen used in respiration exceeds the amount produced in photosynthesis. If the situation persists, oxygen depletions can occur, drastically affecting all organisms in the area. Managing aquatic plants at a moderate abundance can reduce the probability of having oxygen depletions caused by aquatic plants during cloudy weather.

The use of controls that leave dead plants in the aquatic system can also create an oxygen problem. Dead aquatic plants are no longer supplying oxygen through photosynthesis and bacteria use oxygen as they break down the aquatic plants, causing an oxygen depletion. This information should always be considered whenever the management of aquatic plants is planned.

Section 3: Aquatic Plant Management Techniques

The individual who perceives an aquatic plant problem should first determine what state agency or agencies are responsible for aquatic plant management. The agencies should then be contacted to determine what assistance is available and what the individual can legally do on his or her own. Problems on public lakes, which affect the public's access and use of the lake, will normally be the responsibility of a public agency. Decisions concerning perceived whole-lake problems on private lakes should be addressed through the consensus of a home-owner's association after obtaining recommendations from public agencies.

Whole-lake aquatic plant problems are generally managed by public agencies. Sometimes, these aquatic plant problems are handled by commercial management firms that have the necessary equipment and expertise to solve the problem. Management of aquatic vegetation in small areas along private beaches or around boat docks may be accomplished by the individual property owner, although even in these situations, it usually is best to obtain the services of an experienced aquatic plant manager. It is essential for an individual who decides to conduct his or her own aquatic plant management to determine what can be legally done. If herbicides are used, the plants must be properly identified, and it is essential to use only herbicides that are registered for use in aquatic sites and to become fully trained in their use. This information should be available from a county Cooperative Extension Service Office, state natural resources agency, or state department of agriculture.

The diversity of lake types dictate that commercial and public aquatic plant managers, as well as individual waterfront property owners, carefully choose the most appropriate method or combination of methods to manage aquatic plants for each individual situation. The effectiveness and benefits of methods used for controlling the pest plant must be weighed against potential impacts on non-target plants and animals and impacts on water uses such as swimming, fishing, irrigation, livestock watering, and domestic consumption. This section will discuss the following most often used methods for managing aquatic weeds:

- Physical removal
- Habitat alteration
- Biological controls
- Herbicides

Spatterdock
(Nuphar advena)

Physical Removal

Hand Removal

Removal of small amounts of vegetation by hand, which interfere with beach areas or boat docks, may be the only vegetation control that is necessary. Of course, hand removal is labor intensive and must be conducted on a routine basis. The frequency and practicality of continued hand removal will depend on availability of labor, regrowth or reintroduction potential of the vegetation, and the level of control desired.

Regrowth of vegetation will depend on the plant species present, lake trophic state, and the seasonal growth trends of plants. Plants such as cattails and many grasses, which can reproduce from small root fragments, require frequent removal because it is impossible to remove these plants without leaving root fragments in the sediment, from which regrowth occurs. Most aquatic plants tend to grow rapidly during spring, while growth slows during fall and may cease during winter. This growth pattern becomes more pronounced as one moves from southern to northern climates.

Introduction or reintroduction of new plants can result from natural seed dispersal; plant fragments generated naturally, by boat traffic or by the actual harvesting operations; wind or current dispersal of floating plants or spread by waterfowl and various human activities.

Frequency of hand removal will depend on the combination of factors for each individual situation. For example, weekly removal of water hyacinth plants may be necessary from a boat dock area on a productive Florida Lake, while a single spring removal of grasses may be the only effort needed from a beachfront on an unproductive Wisconsin lake.

Hand removal for control of aquatic vegetation may be used in combination with other methods such as herbicides or benthic barriers to minimize regrowth. However, hand removal has a distinct advantage that it can be very selective for removing undesired vegetation while maintaining desired plants.

Ken Langeland

Harvesting floating-leaved plants in Orange Lake, Florida.

Mechanical Removal

Specialized machines are available in a wide variety of sizes and with various accessories for removing aquatic vegetation in a variety of situations. Small machines are practical for limited areas, as well as large machines in combination with transports and shore conveyors for large whole-lake operations. These machines are commonly called mechanical harvesters or weed harvesters and the process is called mechanical harvesting or removal.

Mechanical removal is an important method of aquatic plant management in certain circumstances, such as cutting boat trails through dense stands of vegetation. It has several advantages over other methods. Immediate control can be achieved in small areas. Water can be used immediately, as compared to water-use restrictions that may be associated with herbicide use. Objectionable dead and dying vegetation that may be associated with other methods is minimized.

Use of mechanical removal for aquatic weed control is limited in many regions because of several disadvantages. It is usually higher in cost, slower, and less efficient than other methods and there are high maintenance and repair costs. Some water bodies are not suitable for mechanical removal because of water depth and presence of obstructions. Plant fragments drift to infest new areas. Temporary increases in turbidity may result from disturbance of sediments while harvesting aquatic plants. A suitable area for disposal of harvested plants must be available. Additionally, wildlife (e.g., small fish, snakes, newts, turtles) and desirable vegetation is also removed with harvested weeds.

Dredging

In extreme cases of overgrown aquatic vegetation, conventional or specially adapted dredging machines may be used to remove vegetation and associated sediments. Dredging is expensive, especially if a nearby disposal sight is not available. Careful consideration to secondary environmental effects must be considered and permits from regulatory agencies are usually necessary before conducting dredging operations. Following dredging, other methods should be used to maintain vegetation growth and prevent recurrence of the extreme situation. Dredging is usually short lived if not done deeper than the photic zone.

Habitat Alteration

Water Level Manipulation

Water level manipulation refers to the raising of water levels to control aquatic vegetation by drowning or lowering water levels to control aquatic vegetation by exposing them to freezing, drying or heat. Use of water level manipulation for aquatic plant management is limited to lake and reservoirs with adequate water control structures.

Drawdown, which refers to the lowering of lake water level is more commonly used than raising water levels. Drawdown has been used in lake management for many years to oxidize and consolidate flocculent sediments, to alter fish populations, and for aquatic weed control. In addition to the need for an adequate water control structure, use of drawdown for aquatic plant management may also be restricted by considerations such as water-use patterns and water rights (e.g., disruption of recreational or agricultural use) or a predictable source of water for refilling.

Water level guage in Lake Annie, Florida.

Drawdown is usually conducted during winter months so that plants are exposed to both drying and freezing. Summer drawdown can also be effective but usually results in greater impact to agricultural and recreational water use, stresses fish populations, and has a greater potential to enhance the spread of emergent plants such as cattails, rushes and willows.

Drawdown alters the composition of aquatic vegetation, but does not always produce desirable changes. The responses of various aquatic plant species to drawdown vary widely (Table 2) and sometimes unpredictably. Brazilian elodea (*Egeria densa*) is sensitive to drawdown and is often controlled for up to three years by this method. In contrast, drawdown only partially controls hydrilla, a near relative of Brazilian elodea, when it is growing in sandy lake bottoms and has little effect when hydrilla is growing in organic sediments. The hydrilla tubers that are produced deep within the sediment are protected from desiccation and can survive several consecutive drawdowns. In general, submersed aquatic plants have variable responses to drawdown, while emergent plants tolerate or are stimulated by drawdown.

The advantages of drawdown as a method of aquatic plant management includes low cost (unless recreational or power generation is lost) and the secondary benefits of sediment oxidation and consolidation and fisheries enhancement. Potential undesirable effects of drawdown include reductions of desirable species, increases of undesirable tolerant species like hydrilla, expansion of undesirable species to deeper areas, the creation of floating islands, and the loss of storage water and recreational benefits if insufficient water is available to refill the basin.

Effects on Light Penetration

All plants require a certain amount of light to grow. Submersed aquatic plants can sometimes be controlled or suppressed by reducing light penetration into the water. Light penetration can be reduced by the use of special dyes, special fabric bottom covers, fertilization, and/or raising water level.

Even though dyes are not pesticides, only those that are approved for use in water should be used. These specially produced dyes block light that plants need for photosynthesis and are not toxic to aquatic organisms, humans or animals that might drink the treated water. Dyes are only effective in ponds that have little or no flow through them and they are generally effective only in water greater than 3 feet in depth.

Various materials, including black plastic and specially manufactured bottom covers, have been used to prevent rooted aquatic plants from growing. Gases that are produced on pond bottoms accumulate under nonpermeable bottom covers, such as plastic, and cause them to float to the surface. However, specially made bottom covers can be effective for preventing submersed aquatic plant growth. In addition to preventing light from reaching the pond bottom, these materials also physically prevent rooted aquatic plants from becoming established. These special materials are expensive and must be maintained to prevent sediment accumulation on top of the cover. Therefore, their use is generally restricted to ornamental ponds, swimming areas or around boat docks (care must be taken to prevent the bottom cover from becoming tangled in boat propellers).

Nutrient Limitation

Plant growth can be limited if at least one nutrient that is critical for growth is in short supply. Nitrogen, phosphorus, and/or carbon are usually the nutrients limiting plant growth in lakes. Therefore, if at least one of these nutrients can be limited sufficiently so that plants do not grow to an objectionable level, theoretically nutrient limitation could be used as a method of aquatic plant management. Generally, however, unless a lake is truly oligotrophic, there are enough nutrients in the sediment to sustain abundant rooted aquatic plants.

In some areas, nutrients are naturally in short enough supply that aquatic plants do not grow to problem levels. Where human inputs have accelerated plant growth, nutrients can be limited by identifying and abating the nutrient source(s). If the lake has received external phosphorus inputs for a long period of time, it may also be necessary to affect internal nutrient availability by precipitation with agents such as alum. While nutrient limitation is theoretically possible, there are no good examples in the literature where nutrient limitation has managed nuisance populations of aquatic plants.

A problem that should be considered when attempting to manage nuisance populations of aquatic plants with nutrient control is that it may actually aggravate an existing aquatic plant problem. There are well-documented cases where nutrient limitation has controlled planktonic algae populations. This control increased light penetration to the sediment allowing aquatic plants to expand their coverage in the lake or reservoir.

Biological Control

Insects

Biological control is the purposeful introduction of organisms, such as insects and pathogens, to keep the growth of problem plants in check. Biocontrol agents have to be released into the problem plant's range to help suppress its growth. Small numbers of biocontrol agents are released so that they can increase to a point where they control the problem plant and are in balance with the target plant, so a self-perpetuating population is established. In some cases, like the milfoil weevil, a native insect shows a preference for the exotic nuisance plant over its previous plant habitat and helps control the exotic species.


Muskgrass (*Chara vulgaris*)

The most attractive aspect of biological control is that it can be permanent and self-perpetuating. Once established, additional releases are usually unnecessary, so additional expenses are avoided. However, exceptions occur when it becomes necessary to move field-collected bioagents to new locations. While the initial expense is high, over the long run, biocontrol agents are among the least expensive control options. Benefit to cost ratios of this approach have been estimated at 50 – 100:1 or even higher.

A foreign insect species must be extensively tested and proven to be host-specific (cannot reproduce in the absence of the host) before it can be released in the United States. These tests are designed to demonstrate that the bioagent will not feed appreciably or reproduce on any plant other than the target weed. This ensures that it will not harm crop plants or other desirable species.

The first aquatic weed target for biocontrol in Florida was alligator-weed (*Alternanthera philoxeroides*). Three host-specific South American insects were found and eventually released. These include the alligator-weed flea beetle (*Agasicles hygrophila*), which was released in 1964; the alligator-weed thrips (*Amynothrips andersoni*), which was released in 1967; and the alligator-weed stem borer (*Vogtia malloi*), a moth, which was released in 1971. These insects are very effective and usually suppress the growth of alligator-weed below problem levels. However, their effectiveness is diminished toward the northern limits of the plant's range in North Carolina. These insects are naturalized throughout the southeastern United States, but populations sometimes are diminished following harsh winters. When this happens, control can be enhanced on a localized level by importation of insects from more southerly regions.

Three species of insects have been released for control of water hyacinth. The first was the mottled water hyacinth

Submersed Plants	Emergent and Floating Plants
Sensitive	
Cabomba spp.	*Nuphar advena*
Egeria densa	*Nuphar luteum*
Najas quadalupensis	*Nymphaea tuberosa*
Potamogeton americanus	*Scirpus californicus*
Potamogeton robbinsii	
Sagittaria subulata	
Sensitive to Tolerant	
Ceratophyllum demersum	*Hydrochloa caroliniensis*
Myriophyllum spicatum	*Nuphar macrophyllum*
Najas spp.	*Nuphar variegatum*
Najas flexilis	*Nymphaea odorata*
Potamogeton amplifolius	*Polygonum coccineum*
Potamogeton crispus	*Scirpus validus*
Potamogeton diversifolius	*Typha spp.*
Potamogeton epihydrus	
Potamogeton foliosus	
Potamogeton gramineus	
Potamogeton natans	
Potamogeton pectinatus	
Potamogeton richardsonii	
Potamogeton zosteriformis	
Utricularia spp.	
Vallisneria americana	
Tolerant	
Chara spp.	*Alternanthera philoxeroides*
Hydrilla verticillata	*Eichhornia crassipes*
Myriophyllum heterophyllum	*Eleocharis spp.*
Potamogeton illinoensis	*Nuphar polysepalum*
Potamogeton nodosus	*Panicum hemitomon*
Sagittaria graminea	*Polygonum natans*
	Pontederia spp.
	Sagittaria latifolia
	Scirpus spp.

Table 2. Aquatic plants responses to water level drawdown. Sensitive plants are those species that have been shown to decrease after drawdown activities. Sensitive to Tolerant plants are those species that have been shown to decrease, remain the same, or increase after drawdown activities. Tolerant plants are those species that have been shown to remain the same or increase after drawdown activities.

weevil (*Neochetina eichhorniae*), which was released in Florida in 1972. The second was the chevroned water hyacinth weevil (*Neochetina bruchi*), which is quite similar to the first. It was released in Florida in 1974. The third insect was a moth, the water hyacinth borer (*Sameodes albiguttalis*), which was released in 1977. These three insects are naturalized throughout the Southeast. A good indication of the presence of water hyacinth weevils is the occurrence of distinctive adult feeding scars on the leaves. Mature larvae can often be found in the petiole bases or in the stem. The weevils (especially the chevroned) have been the most effective of the water hyacinth insects. It has been difficult to quantify the impact of these insects on water hyacinth populations, but suppression has not been sufficient to diminish the need for aggressive maintenance management of water hyacinths with herbicides.

Several insect biological controls are in various stages of research, quarantine, and early release for control of water lettuce (*Pistia stratiotes*), hydrilla (*Hydrilla verticillata*), and Eurasian watermilfoil (*Myriophyllum spicatum*). The interested reader is urged to contact an information source such as the University of Florida/ Institute of Food and Agricultural Sciences, Aquatic Plant Information Retrieval for current information on biological control progress (APIRS University of Florida/Institute of Food and Agricultural Sciences, Center for Aquatic and Invasive Plants, 7922 NW 71st. Street, Gainesville, Florida 32653-3071; http://aquat1.ifas.ufl.edu/).

Pickerel-weed (*Pontederia cordata*)

Pathogens

The introduction approach would seem ideal for the use of pathogens. However, restrictions regarding the importation of plant pathogens from abroad tend to prohibit this approach and limit the scope to native pathogens. Pathogens also tend to be environmentally sensitive and populations do not remain high enough for sustained suppression of weed populations. Therefore, the use of pathogens for biological control of aquatic weeds has more promise as an augmentation approach. Suspensions of fungal spores can be formulated and applied to weed populations. One fungal pathogen (*Cercospora rodmanni*), has been formulated as a mycoherbicide for water hyacinth. However, it has not been very effective and research in this area is continuing. Research is also currently being conducted to develop methods for biological control of hydrilla and Eurasian watermilfoil with pathogens. Insects, especially stem borers and piercing-sucking types, often provide points of entry for native plant pathogens. While neither the insect nor the pathogen has a substantial impact on the nuisance plant population, in combination they may help control nuisance situations.

Snails, Manatees, etc.

Two snails (*Marisa cornuarietis* and *Pomacea australis*) have been studied as potential biocontrol agents for aquatic weeds. Large numbers will control several species of submersed aquatic plants under confined conditions. However, snails are not currently under consideration as biocontrol agents for aquatic weeds because of environmental risk associated with the purposeful propagation of prolific, generalized herbivores. They are intermediate hosts for certain fish and human parasites and they are not effective under natural, unconfined conditions.

Manatees or sea cows (*Trichechus manatus*) have been experimentally used, mainly in canals, for aquatic weed control in Florida. Manatees effectively removed submersed and floating plant species. During winter, however, heaters were required to keep manatees warm. In a study of King's Bay (Crystal River, Florida) conducted by the U.S. Fish and Wildlife Service, biologists found that 10 times as many manatees as normally wintered there could not consume the existing hydrilla biomass, much less keep up with the growth of plants.

Other biological controls for aquatic weeds that have been suggested and/or tested include ducks, geese, crayfish, nematodes, viruses, and water buffalo. Any of these may be useful under highly specialized conditions, but none have proven practical. Some of these agents may also cause more harm to aquatic systems than any aquatic plant nuisance. For example, the rusty crayfish (*Orconectes rusticus*) has denuded some northern lakes of plants vital for fish habitat, and prey on fish eggs.

Triploid Grass Carp

Grass carp (*Ctenopharyngodon idella*) are the most commonly used and effective biological control currently available. The success of grass carp is also the primary reason this biocontrol agent is so controversial. If stocked at a high enough densities, grass carp can remove virtually all aquatic vegetation for a decade or longer. Because of the fear that grass carp would escape and reproduce in open waters, sterile triploid grass carp are now required by most states that allow grass carp for aquatic plant control.

Triploid grass carp are produced in hatcheries and possess three sets of chromosomes instead of the normal two. This abnormal condition causes sterility, so these are the only non-indigenous fish that can be legally used for aquatic weed control in most states. A permit is usually required for possession and use of triploid grass carp. Because they cannot reproduce, the number of fish will not increase beyond the initial stocking. However, they cannot be effectively removed from large bodies of water and they are often hard to contain.

Triploid grass carp prefer to consume submersed plants, so they are effective controls of this type of vegetation. Grass carp also browse tips of young, tender emergent plants which often provide control of emergent species, which may be non-target species. Although young grass carp feed on filamentous algae such as Cladophora and Spirogyra, they are not effective for control of most filamentous algal species unless all other aquatic plants are gone and they are stocked at high rates (>50 per acre). Grass carp do not control phytoplankton.

The ability of grass carp to consume aquatic plants depends on the size of both plants and fish. Factors such as age, gender, and population density of the fish can determine the consumption rate of the stocked fish. The species, abundance, and location of the aquatic vegetation also influence the feeding behavior of the grass carp.

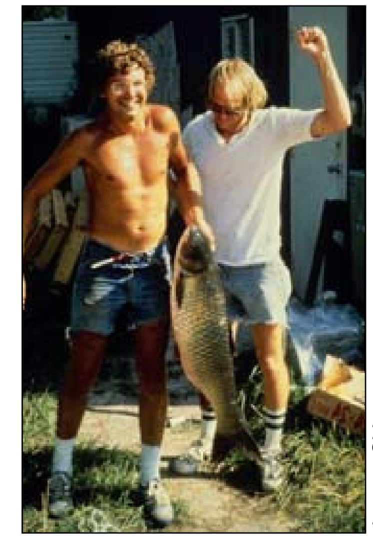
Because predators like birds, snakes, other fish, and some mammals are normally present, grass carp that are 1 pound (10-12 inches) or larger should be stocked to maximize survival. Some mortality will occur even when these larger fish are stocked; therefore, it is not possible to know exactly how many fish are present after being stocked into a pond or lake.

Stocking rates of 20 – 25 grass carp per acre of lake effectively controls all aquatic plants in southern latitudes, but rates as high as 150 grass carp per acre are required before similar control is achieved in northern lakes. At any latitude, if enough grass carp are stocked where the consumption rate of the grass carp exceeds the growth rate of the aquatic plants, grass carp are an effective method of controlling aquatic vegetation (except for a few non-susceptible species, such as spatterdock, *Nuphar luteum*). Because of their nonselective feeding behavior and lack of predictability, grass carp should only be used in lakes where complete control of aquatic plants is an acceptable part of a management plan.

Many management agencies are currently attempting to use low stocking densities of grass carp (2-5 per acre) with herbicides to control nuisance aquatic plants, while maintaining certain levels of aquatic vegetation. Because of the dynamic nature of aquatic systems and the inability to determine mortality rates of grass carp after stocking, this technique is unpredictable and should only be used with the understanding that total control of aquatic plants is a possibility.

With little hard evidence that submersed aquatic plant control can be achieved with low-density stocking of grass carp, while maintaining some submersed aquatic vegetation, a common warning in the grass carp literature is the statement that “unless complete elimination of submersed aquatic vegetation can be tolerated, grass carp stocking is not recommended.” Thus, the key to universal use of grass carp for plant management is to have the ability to develop a cost-effective strategy to remove the fish from a system if the amount of plant control exceeds target amounts. Historically, managers have experimented with several methods for removing grass carp from lake systems including: herding, angling, attracting, use of lift nets, and toxic fish baits. Unfortunately, all techniques used in the removal studies were time consuming, labor intensive, sometimes quite expensive and in each case failed to remove a major portion of the grass carp population. This is especially important in light of evidence suggesting that it may take only 0.5 grass carp per acre to maintain complete control of submersed vegetation regrowth after complete control of submersed vegetation is achieved.

To make grass carp a more predictable tool for managing aquatic plants, there is ongoing research designed to develop an implantable device suitable for limiting the lifespan of stocked grass carp. The ability to manage the life-span of grass carp would provide aquatic plant managers a tool with much greater short-term utility and this would reduce the potential for overstocking and controlling vegetation for decades after stocking. Moreover, such a device would permit controlling dispersal by limiting the length of time that stocked grass carp roam freely and disperse to other waters.


Jerome Shireman

A spawning-size grass carp at the Department of Fisheries and Aquatic Sciences, University of Florida.

Tilapia

Tilapia are tropical species that can suppress growth of softer aquatic vegetation such as filamentous algae and bladderwort (*Utricularia spp.*) when stocked at high density (300 per acre). Two species of Tilapia have been considered for aquatic weed control. The blue tilapia (*Oreochromis aurea*) feeds entirely on algae (planktonic and filamentous) but does not readily consume larger, coarser vegetation. The redbelly tilapia (*T. zilli*) feeds on larger submersed vegetation rather than algae. However both species reproduce rapidly and consume both vegetation and small animals that are important food sources for desirable fish populations. Therefore, use of tilapia can have unwanted environmental consequences.

Tilapia will not over winter in water below 43 to 65° F. This is a benefit from an environmental standpoint, but annual restocking is necessary in temperate climates unless a warm water supply (such as a thermal spring or power plant cooling effluent) is available as a refuge during winter. In tropical climates, where they do over winter, they are prolific and can be detrimental to sportfish populations.

Before stocking any type of biological control of aquatic weeds, you must check with the appropriate state agencies to determine state regulations!

Herbicides

What are Herbicides?

Generally, a herbicide is defined as a plant or weed killer. Weed scientists define herbicides more precisely as chemicals used for killing plants or severely interrupting their normal growth processes. For the aquatic plant manager or waterfront homeowner, herbicides are tools that can be used to manage aquatic vegetation in a safe, efficient, and cost effective manner. A herbicide formulation consists of an organic (carbon-containing) or inorganic active ingredient, an inert carrier, and perhaps adjuvants (wetting agents).

Herbicides must be registered by the Environmental Protection Agency (EPA) for use in the United States. There are about 200 herbicides (active ingredients) currently registered in the United States. Currently, only ten are labeled for use in aquatic sites. The ten active ingredients (carfentrazone, copper, 2,4-D, diquat, endothall, fluridone, glyphosate, imazapyr, penoxsulam and triclopyr) that are contained in herbicide formulations that are currently labeled for use in aquatic sites in most states. It should be noted that only fluridone is exclusive to aquatic use. All of the other compounds are used in terrestrial environments including food uses (e.g., Glyphosate on Roundup Ready crops, carfentrazone and triclopyr on rice) and forestry and rights of way (e.g., glyphosate, triclopyr, 2,4-D, and imazapyr). With all of these terrestrial and aquatic uses, it remains VERY IMPORTANT TO USE COMPOUNDS THAT ARE LABELED FOR AQUATIC USE. Use of a herbicide that does not specify aquatic sites on the label is a violation of law.

The reasons there are few aquatic herbicides compared to crop production herbicides is primarily because of the unique characteristics of the aquatic environment. This sets limits to the number of compounds that will effectively control aquatic plants and also meet the rigid environmental and toxicology criteria necessary for registration. Aquatic herbicides must have the capacity to be taken up by plants quickly in sufficient amounts from water to be toxic to target plants and have sufficiently low toxicity to man and other organisms in the aquatic environment. The market for aquatic herbicides is also small compared to the giant agricultural market. With this said, there are currently several new herbicide modes of action being evaluated in the aquatic market. These new compounds tend to be plant enzyme inhibitors that exhibit very low toxicity to fish and wildlife.

The Herbicide Label

Before a herbicide is labeled by the United States Environmental Protection Agency (USEPA), extensive research that requires many years to complete must be conducted. In addition, aquatic herbicides that were registered prior to guidelines that were established by 1978 amendments to the Federal Insecticide, Fungicide, Rodenticide Act (FIFRA) must be reregistered under guidelines established by the Food Quality Protection Act (FQPA) to address data gaps that may exist. Data required for pesticide registration includes, but are not limited to the following:

1. Potential residue in potable water, fish, shellfish, and crops that may be irrigated;
2. Environmental fate of the compound, or where it goes after application and what happens to it when it gets there;
3. How the compound breaks down and what the breakdown products are;
4. Whether the compound is absorbed through the skin or other routes of entry by test animals;
5. Acute (short-term) and chronic (long-term) toxicity of the compound to test animals;
6. Whether the compound causes birth defects, tumors, or other abnormalities after long-term exposure; and
7. Toxicity of the compound to aquatic organisms such as waterfowl, fish, and invertebrates.

Based upon registration data, residue tolerances are set by dividing the amount of residue that causes no observable effect to chronically exposed test animals by 100 or 1000 and estimating how much residue can be allowed in a commodity so that an average sized person would ingest or come in contact with less than that amount.

Have all appropriate labels at the application site, including supplemental labels, special local need labels and emergency use labels. Also have the manufacturer's material safety data sheets (MSDS) on hand. Read labels often, even if you use the herbicide routinely. You may have missed something or it may have changed. Labels are often changed by industry.

Based upon tolerances, residue data, and environmental fate, water-use restrictions or precautions for drinking, swimming, fish consumption, irrigation and watering livestock are placed on the label. Some compounds such as copper and glyphosate have no use restrictions at labeled use rates, while others have various restrictions on certain uses. It is important that you read the label carefully to determine the water use restrictions associated with the aquatic herbicide that you apply.

All herbicide containers must have attached to them a label that provides instructions for storage and disposal, uses of the product, and precautions for the user and the environment. The label is the law. It is unlawful to alter, detach, or destroy the label. It is unlawful to use an herbicide in a manner that is inconsistent with or not specified on the label. Note that aquatic weeds that are not specified on the label may be treated, and application methods not mentioned on the label may be used as long as they are not prohibited on the label. It is unlawful to transfer a herbicide to an improperly labeled container. Misuse of a herbicide is a violation of federal and state law, and herbicides used in water contrary to label directions may make water unfit for fishing, irrigation, swimming, or domestic use.

Each herbicide contains a signal word of Caution, Warning, or Danger[1] on the label. Some of the aquatic herbicides are quite toxic in the concentrated form and special care must be taken when handling these products. The label contains valuable information on personal protective equipment for the use of each aquatic herbicide.

The herbicide label contains a great deal of information about the product and should be read thoroughly and carefully before each use. Before applying a herbicide, read the label to determine the following: Is the product labeled for the site, i.e., ditch banks only, canal banks, ponds, lakes, rivers, etc.? Can the weed be controlled with the product? Can the herbicide be used safely under particular application conditions? How much herbicide is needed? What restrictions apply to watering livestock, fishing, swimming, consuming potable water, and irrigation? What is the toxicity to fish and non-target vegetation? When should the herbicide be applied (time of year, stage of plant growth, etc.)? Is the herbicide classified restricted use? What is the signal word? (DANGER, WARNING, CAUTION[1]) What safety equipment should be worn?

Herbicide Use Rates

Often, there is the perception that aquatic herbicides used for submersed plant control are dumped into the water column with little thought given to the amount being applied. This would be both environmentally and fiscally irresponsible. The reality is that herbicides are applied according to the use rates recommended on the herbicide label for a given target plant. Aquatic managers tend to refer to treatments in terms of the parts per million (ppm) or parts per billion (ppb) that they wish to achieve in a given area and volume of water where the target plant resides. For example, if an applicator wants to treat a 10-acre area with an average depth of 6 feet, they would calculate this as 60 acre-feet (10 acres x 6 feet deep). In order to achieve a target concentration of the herbicide endothall at 3 ppm, the applicator would apply 115 gallons of product to the 10-acre area (11.5 gallons per acre). The amount of water in this 60 acre-foot area comes to 19.58 million gallons. Application equipment is calibrated to deliver a known concentration of herbicide as the boat makes numerous passes within the treatment area. For emergent plant control, the use recommendations are very similar to those used in terrestrial agriculture. A typical emergent application will be in the range of 1 quart to 2 gallons of product per acre, and the objective is for the vast majority of the herbicide to come in contact with the emerged portions of the plant. There is a small amount of this herbicide that comes in contact with the water and this is why certain herbicides such as glyphosate and imazapyr, which are for emergent plant control only, must have an aquatic label. Aqueous herbicide residues that follow applications for emergent plant control do not typically impact submersed vegetation due to the very low concentrations that result from these treatments.

Contact Herbicides

Contact herbicides act quickly and are generally lethal to all plant cells with which they come in contact. Because of this rapid action, or other physiological reasons, they do not move extensively within the plant and are effective only where they contact plants. For this reason, they are generally more effective on annual plants (plants that complete their life cycle in a single year) or smaller perennial plants (plants that persist from year to year). Large perennial plants can be defoliated by contact herbicides, but it is extremely difficult to contact all of the plant parts (think of a dense cattail stand with plants growing 8 to 10 feet tall) and perennials often resprout from unaffected plant parts and rhizomes growing in the substrate. Submersed aquatic plants that are in contact with sufficient concentrations of the herbicide in the water for long enough periods of time are affected, but regrowth often occurs from unaffected plant parts, especially plant parts that are protected beneath the sediment. Because the entire plant is not always killed by contact herbicides, retreatment is often necessary, sometimes two or three times per year. Endothall, carfentrazone, diquat, and copper are contact aquatic herbicides.

Systemic Herbicides

Systemic herbicides are absorbed into the living portion of the plant and move within the plant. Different systemic herbicides are absorbed to varying degrees by different plant parts. Systemic herbicides that are absorbed by plant roots are referred to as soil active herbicides and those that are absorbed by leaves are referred to as foliar active herbicides (Imazapyr is the only soil active aquatic herbicide, and it is not applied as a pre-emergent herbicide for aquatic use). Other systemic herbicides, such as glyphosate, are only active when applied to and absorbed by the foliage. Triclopyr, 2,4-D, imazapyr, fluridone, and glyphosate are systemic aquatic herbicides.

When applied correctly, systemic herbicides act slowly in comparison to contact herbicides. They must move to the part of the plant where their site of action is located. Systemic herbicides are generally more effective for controlling perennial and woody plants than contact herbicides. Some systemic herbicides are inherently selective (e.g., 2,4-D, triclopyr) while others are more broad-spectrum (glyphosate, imazapyr).

[1]The signal words Danger, Warning, or Caution are included on each herbicide container and these terms denote the relative toxicity of the concentrated product in the container. A Danger signal word indicates the concentrated product is highly toxic via exposure routes such as ingestion or dermal exposure. A Warning signal indicates that the product may result in acute illness due to ingestion or dermal exposure, and a Caution signal indicates the product is slightly toxic or relatively non-toxic. These terms apply to the concentrated product in the container and do not refer to the toxicity of the product once it has been applied to the water.

Broad-spectrum Herbicides

Broad-spectrum (sometimes referred to as nonselective) herbicides are those that are used to control all or most vegetation or those that control a broad range of plant species. This type of herbicide is often used for total vegetation control in areas such as equipment yards, electrical substations and banks of aquaculture ponds where bare ground is preferred. Glyphosate is an example of a broad-spectrum aquatic herbicide. Diquat, endothall, and fluridone can be used as broad-spectrum aquatic herbicides, but can also be used selectively under certain circumstances that will be discussed later in this publication.

While many herbicides such as glyphosate or diquat naturally control a broad range of plant species, application techniques often allow these products to be used selectively. Concentrated glyphosate can be placed directly on large woody species and diquat spray can be directed on small patches of waterlettuce without causing widespread harm to nearby beneficial vegetation.

Selective Herbicides

Selective herbicides are those that have inherent properties that result in toxicity to some species and limited impact on others. A good example of a selective aquatic herbicide is 2,4-D, which can be used to control water hyacinth with minimum impact on maidencane or eel grass. Herbicide selectivity is based upon the relative susceptibility or response of a plant to a given herbicide. Many related physical and biological factors can contribute to a plant's susceptibility to an herbicide. Physical factors that contribute to selectivity include herbicide placement, formulation, and rate of application. Biological factors that affect herbicide selectivity include physiological factors, morphological factors, and stage of plant growth. A large percentage of aquatic herbicide treatments are applied with selective control in mind. Application can be selective simply by carefully placing the herbicide on target plants and avoiding non-target plants. For example, when small amounts of water hyacinth are growing among bulrush, an experienced applicator, using a handgun, can control water hyacinth with 2,4-D and minimize impact to the bulrush community. Although diquat is a broad spectrum herbicide, it is a contact herbicide and affects only the bulrush stems that are above the water surface, where they are contacted by the herbicide. The extensive underground rhizomes and roots are not affected and the plant quickly regrows after the initial effect of the herbicide. This is an example of selective weed control by herbicide placement.

Selectivity can be affected by the amount of herbicide applied. For example, water hyacinth is selectively controlled among spatterdock (i.e., cow lily) using the recommended rate of 2,4-D for water hyacinth, but spatterdock can be controlled by using higher rates and granular formulations.

An herbicide must be absorbed directly into cells or move through the plant (translocated) to the site where it is active. Herbicides may be bound on the outside of some plants or bound immediately after they enter the living part of the plant, so that they cannot move to their site of activity. For other reasons, not all of which are understood, herbicides are translocated more in some plants than in others and this results in selectivity of the herbicide. Once inside the plant, certain plants have the ability to alter or metabolize an herbicide, so that it no longer has herbicidal activity. Some herbicides affect very specific biochemical pathways in plants. Therefore, they may be selective against a particular group or groups of plants because they are the only ones that have that particular pathway.


Mark Hoyer

Glyphosate controlling terrestrial and aquatic plants along the edge of a fishing pond located at the Department of Fisheries and Aquatic Sciences, University of Florida.

The physiology of perennial plants changes during the annual growth cycle. During early stages of growth, upward transport of food reserves and other plant compounds are active and this represents a weak point in the life-cycle for some herbicides, although we don't typically use soil active herbicides in aquatic plant control (we get some activity with imazapyr). An herbicide such as imazapyr is quite effective on perennials during this active phase of new growth, whereas an herbicide such as glyphosate is most active on perennials in the fall of the year when the plant is actively translocating sugars to storage structures such as roots or rhizomes.

Environmental Considerations

Aquatic communities consist of aquatic plants including macrophytes (large plants) and phytoplankton (free floating algae), invertebrate animals (such as insects and clams), fish, birds, and mammals (such as muskrats, otters, and manatees). All of these organisms are interrelated in the community. Organisms in the community require a certain set of physical and chemical conditions to exist, such as nutrient requirements, oxygen, light, and space. Aquatic weed control operations can affect one or more of the organisms in the community that can in turn affect other organisms or it can affect water chemistry that in turn affects organisms.

Aquatic Plants

Aquatic plants are a natural and important component of aquatic communities (Section 1). They provide food for other aquatic organisms by fixing the sun's energy through the process of photosynthesis. Small invertebrate animals consume aquatic plants, periphyton (algae growing on larger plants) and phytoplankton, and are then consumed by larger animals such as birds or fish. Aquatic plants provide habitat for animals used as food by fish and provide protective cover for fish. They also provide nesting sites and provide food for birds and mammals. In addition, aquatic plants can improve the appearance of a water body. However, water is often naturally rich enough in the plant nutrients nitrogen and phosphorus for aquatic plants to grow so vigorously that they become a nuisance. They can hinder recreational use of water bodies or create flooding hazards by impeding drainage, which is often vital to low-lying residential communities. This is especially true for hydrilla, water hyacinth, alligator-weed, and Eurasian watermilfoil, which are non-native and invasive plants.

Although it is sometimes necessary to manage native aquatic plants, the majority of publicly-funded aquatic plant management programs are aimed at hydrilla, Eurasian watermilfoil, water hyacinth, water lettuce, and torpedograss (in Florida, alligatorweed is mainly controlled by the flea beatle). The reason for this is that these non-native plants compete with native plants and grow well in Florida's warm climate. This combination can cause decreased quality of fish populations, decreased water quality, and hinder water use. The herbicides used for managing these non-native aquatic plants can directly impact native aquatic vegetation if not used prudently. However, non-native weed problems can be managed with minimum impact on native plant populations by using appropriate application rates, timing, and application techniques of aquatic herbicides. In this way, the aquatic weed problem can sometimes be managed while maintaining a beneficial aquatic plant community for fish and wildlife habitat. However, sometimes it will not be possible to satisfy the demands of all water users and certain tradeoffs must be made. For example, it may not be possible to manage aquatic plants in a shallow eutrophic lake for fish habitat, waterfowl habitat, and water skiing all at the same time.

Aquatic plant control operations can have an indirect impact on phytoplankton. When large amounts of aquatic vegetation (>30% area covered with aquatic plants; see Section 1 for more information) are controlled in a lake with herbicides or grass carp, the plant nutrients nitrogen and phosphorus, which are often limiting to phytoplankton growth, are released into the water. These nutrients can allow additional phytoplankton growth to occur in the lake. This growth causes the water to take on a green coloration and water clarity is decreased (Figure 5 on page 25).

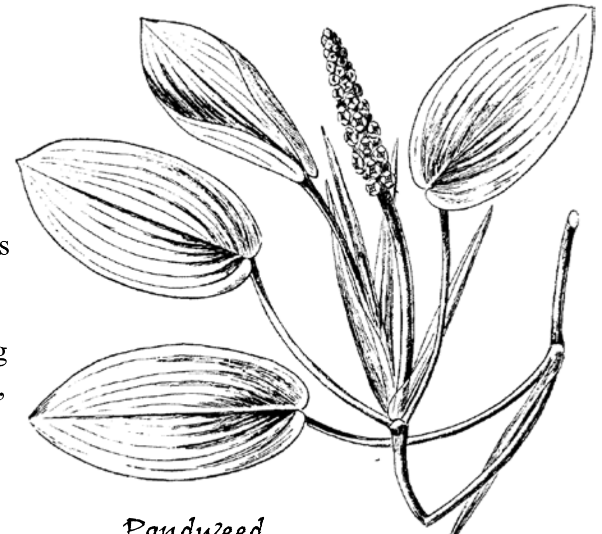
Effects on Fish and Other Organisms

When used according to the label specifications, currently available aquatic herbicides are not toxic to fish, birds, or other aquatic organisms. They are also short-lived in the environment and do not accumulate in organisms. Environmental conditions are not always predictable, however, and under certain circumstances, fish kills can occur, usually as an indirect result of aquatic herbicide applications.

Fish kills are only likely to occur as a direct effect of herbicide application if an herbicide formulation known to be toxic to fish, such as the amine salt of endothall, is applied in an enclosed water body. The concentration of copper that is used for most herbicide applications is below toxic concentrations. However, rates recommended for difficult-to-control filamentous algae can be toxic to fish in enclosed ponds and care should be taken when making this type of application. The greatest concern for copper toxicity is in low alkalinity water, because the toxicity of copper to fish and many invertebrates (e.g., crayfish) increases as the alkalinity of water decreases (Table 3). This is especially true for most trout species. Most aquatic herbicides have very low toxicity to fish and the concentration that occurs after application of recommended rates is less than concentrations that are toxic to fish (Table 4).

The most common reason for fish kills due to aquatic herbicide application is the indirect effect of lowered dissolved oxygen (DO) in the water. DO in lakes and ponds commonly ranges between 5 and 12 ppm (mg/liter). Aquatic plants and algae produce oxygen during the day via photosynthesis. Plants, algae, and animals consume oxygen throughout the day and night. Lowest concentrations occur during early morning hours, because aquatic plants consume oxygen during the night but do not produce oxygen because of the lack of sunlight. Fish populations can usually withstand the everyday fluctuations of DO, but many types of fish cannot tolerate prolonged periods of low DO. Natural fish kills can also occur in highly productive waters when phytoplankton populations die and cease producing oxygen after prolonged cloudy, still, warm weather.

When large amounts of aquatic plants are killed by an herbicide application, the decaying vegetation and lack of oxygen production may cause DO to become so low that fish cannot survive in the water and a fish kill occurs. If an herbicide that is effective on higher plants and not phytoplankton is used, the potential for a fish kill can be minimized because phytoplankton will continue to produce oxygen. Also, the danger of fish kills is less in cooler water because it can hold more oxygen than warm water and bacterial decay of the dead vegetation is slower. Herbicide applications to large weed populations in warm water during periods of prolonged still and cloudy weather, and where fish movement is restricted should be avoided to minimize the potential for fish kills. Large weed populations should be brought under control by a series of applications to portions of the water body and treated during the spring when water temperatures are lower. Once under control, weeds should be maintained at low densities.



Pondweed
(*Potamogeton natans*)

Herbicide-related fish kills, either direct or indirect, are not likely to occur as a result of partial area applications in large water bodies because fish have avoidance mechanisms to low DO and are mobile. If possible, fish will move to other parts of a lake to avoid adverse conditions. When making partial applications of herbicides such as using the diethylalkylamine salt of endothall, which can be toxic to fish at recommended use rates, applications should be started near shore and proceed toward open water. This allows fish to escape to untreated water. All precautions should be taken to avoid conditions that can lead to potential fish kills when applying aquatic herbicides.

48 hour TLM (ppm)	Total Hardness (ppm)	Total Alkalinity (ppm)
0.6	15.0	18.7
0.8	68.0	166.0
10.0	100.0	245.0
45.0	132.0	1544.0

Table 3. Toxicity of copper (48-hour TLM) to bluegill at different water hardness and alkalinity. A 48-hour TLM is defined as the median tolerance limit and is an acute test where the critical limit of the test factor is at a level where 50% of the test organisms survive for a given time.

		96-hour LC-50 (ppm)	
Herbicide	Theoretical Concentration (ppm)	Bluegill	Rainbow Trout
Rodeo (glyphosate)[1]	(-)1	>1000	>1000
Aquathol K	1.0 - 3.0	343	230
Diquat	0.12- 1.5	245	-
2,4-D, DMA	1.0 - 4.0	168	100
Sonar (fluridone)	0.05- 0.15	14	11
Hydrothol 191	1.0 - 3.0	0.94	0.96
Copper Sulfate (soft water)	0.5- 3.0	0.88	0.14

[1]Application to emergent vegetation only; concentrations in water are insignificant.

Table 4. Theoretical concentrations of aquatic herbicides after application and their experimental 96-hour LC-50 (ppm). A 96-hour LC-50 is an acute toxicity test where the concentration of a chemical in the test environment is at a level where 50% of the test organisms will survive for 96 hours. Theoretical concentrations are based upon low and high label rates applied in 3 feet of water.

Fate of Aquatic Herbicides in the Environment

The concentration of herbicide in water immediately after proper application of aquatic herbicides for submersed weed control is very low (Table 5). For example, when 2 gallons of diquat are applied to an acre of water that is 6 feet deep, the nominal concentration is 0.12 ppm. Lower herbicide concentrations in water result from foliar applications to floating or emergent plants because the herbicide is directed onto the plants and very little herbicide reaches the water.

Herbicide residues are subject to dispersion, dilution, sorption, uptake, and degradation in the aquatic environment. Dispersion refers to movement of herbicide residues outside of the treatment zone and this leads to dilution of the residues to a lower concentration. Dispersion and dilution are major processes when smaller areas of larger water bodies are treated. Sorption refers to the binding of herbicide residues to particulate matter (e.g., clay and suspended organic matter) or to ions in the water. Diquat residues are rapidly bound and inactivated by adsorption to clay or suspended organic matter, while glyphosate residues are inactivated by ionic bonding to cations (positively-charged particles) in the water column such as calcium and magnesium. For emergent treatments, plants account for a large fraction of herbicide uptake while submersed plant uptake accounts for only a small fraction of the herbicide applied. Degradation refers to the ultimate fate of the herbicide molecule. Herbicides are degraded via processes such as hydrolysis (carfentrazone), microbial activity (endothall), and photolysis (fluridone and imazapyr). Compounds such as diquat and glyphosate are rapidly inactivated by sorption, and then slowly degraded via microbial processes. Both dispersion and degradation are important considerations to the fate of herbicides in the environment because even if dissipation is slow, deactivation due to processes such as adsorption to bottom sediments will make an herbicide biologically unavailable.

Aquatic herbicides are non-persistent in treated water, that is, they disappear rapidly. Herbicide half-lives are shortest when spot treatments are made in large bodies of water because the dominant effect is dilution. Aquatic herbicides are water soluble and quickly dilute to non-detectable concentrations. Residues decline at different rates and by different methods. Table 5 lists rates of breakdown and major routes of degradation of aquatic herbicides. Because of environmental factors, degradation is often much faster than listed in Table 5 and these values should be used only for comparison.

Herbicide	Method of Disappearance	Half-life in Water (days)
Diquat	Adsorption Photolysis Microbial	1 to 7
Endothall	Microbial Plant Metabolism	4 to 7
Glyphosate	Microbial Adsorption	14
2,4-D	Microbial Photolysis Plant Metabolism	7 to 48
Fluridone	Photolysis Microbial Adsorption	20 to 90
Carfentrazone	pH Dependent Hydrolysis Microbial	<1 to 7
Triclopyr	Photolysis Microbial	3 to 14
Imazapyr	Photolysis Microbial	7 to 14
Copper	Adsorption	1 to 7
Penoxsulam	Photolysis Microbial Adsorption	20 to 90

Table 5. Major methods and rates of break down of ten aquatic herbicides. Half-life refers to the amount of time that it takes for one half of the material to break down. This information does not include the impacts of dilution or dispersion on residue half-lives in the treatment area.

Diquat

When applied to enclosed ponds for submersed weed control, diquat is rarely found longer than 10 days after application and is often below detection levels 3 days after application. The most important reason for the rapid disappearance of diquat from water is that it is rapidly taken up by aquatic vegetation and bound tightly to particles in the water and bottom sediments. When bound to certain types of clay particles, diquat is not biologically available. When it is bound to organic matter, it can be slowly degraded by microorganisms (bacteria). When diquat is applied foliarly (to the leaves), it is degraded to some extent on the leaf surfaces by photodegradation, and because it is bound in the plant tissue a proportion is probably degraded by microorganisms as the plant tissue decays.

Endothall

Endothall is rapidly and completely broken down into naturally occurring compounds by microorganisms. The by-products of endothall dissipation are carbon dioxide and water. Complete breakdown usually occurs in about 2 weeks in water and 1 week in bottom sediments.

Glyphosate

Glyphosate is not applied directly to water for weed control, but when it does enter the water, it forms ionic bonds with calcium, magnesium and other cations, resulting in rapid deactivation. Glyphosate is broken down into carbon dioxide, water, nitrogen, and phosphorus over a period of several months.

2,4-D

2,4-D photodegrades on leaf surfaces after foliar applications and is broken down by microbial degradation in the water and sediments. The speed of microbial degradation is directly related to air and water temperature. Complete decomposition usually takes about 3 weeks in water and can be as short as 1 week. 2,4-D breaks down into naturally occurring compounds. Two pounds of 2,4-D amine will break down into 1 pound carbon dioxide, 1/4 pound water, 1/4 pound ammonia, and 1/2 pound chlorine.

Fluridone

Dissipation of fluridone from water occurs mainly by photodegradation. Metabolism by tolerant organisms and microbial breakdown also occurs, and microbial degradation is probably the most important method of breakdown in bottom sediments. The rate of breakdown of fluridone is variable and may be related to time of application and water depth. Applications made in the fall or winter, when the sun's rays are less direct and days are shorter, result in longer half-lives. Residues tend to last longer in deeper water. Fluridone usually disappears from pond water after about 3 months, but can remain up to 9 months. It may remain in bottom sediment between 4 months and 1 year.

Carfentrazone

Carfentrazone is degraded via pH dependent hydrolysis; the higher the pH, faster the rate of degradation. Degradation of the carfentrazone molecule can occur within 1 day in more alkaline waters and may occur over several days in lower pH water bodies (pH of 5.5 to 7). Microbial activity eventually results in mineralization of the metabolites.

Triclopyr

Triclopyr is used for both submersed and emergent plant control and, once in the water column, the main degradation route is photolysis. Microbial activity is also an important process in the degradation of the triclopyr molecule. Rates of photolysis are dependent on water depth and clarity and microbial activity is influenced by water temperature.

Imazapyr

Like glyphosate, imazapyr is not applied directly to water for weed control, but residues that enter the water are subject to photolysis and microbial degradation. Typical half-lives of imazapyr in the water column are in the range of 7 to 14 days depending on water depth and clarity. Imazapyr is very soluble in the water column and high solubility does not result in strong binding.

Copper

Copper is a naturally occurring element and essential at low concentrations for plant growth. It does not break down in the environment, but it forms insoluble compounds with other elements and is bound to charged particles in the water. It rapidly disappears from water after application as an herbicide. Because it is not broken down, it can accumulate in bottom sediments after repeated high application rates. Accumulation rarely reaches levels that are toxic to organisms or significantly above background concentrations in the sediment.

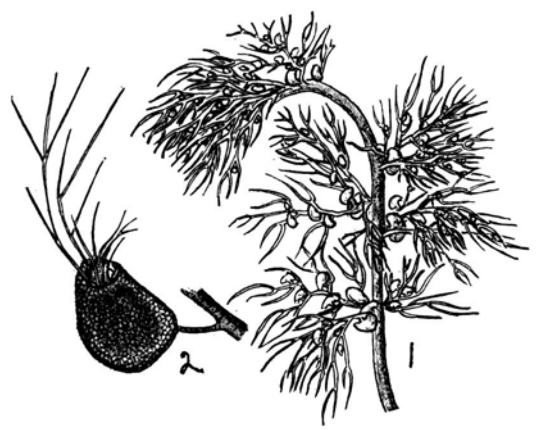
Penoxsulam

Photodegradation accounts for most of the dissipation of penoxsulam from water. Microbial degradation is probably the most important method of breakdown in bottom sediments, and metabolism by tolerant organisms and microbial breakdown also occurs. Penoxsulam breaks down at a variable rate; this may be related to time of application and water depth. Applications made in the fall or winter, when the sun's rays are less direct and days are shorter, result in longer half-lives, and residues tend to last longer in deeper water. Penoxsulam usually disappears from pond water after about 3 months, but can remain up to 9 months.

Maintenance Control of Aquatic Weeds

Maintenance control (or management) refers to controlling plants at low levels and before they reach a problem level. It has been defined in a Florida Statute as follows:

....a maintenance program is a method for the control of non-indigenous aquatic plants in which control techniques are utilized in a coordinated manner on a continuous basis in order to maintain the plant population at the lowest feasible level as determined by the department [Department of Natural Resources]. FAS 369.22



Bladderwort
(Utricularia vulgaris)

Maintenance control of aquatic weeds reduces the detrimental environmental effects caused by the weeds and reduces the potential for environmental impacts from aquatic plant control activities. Maintenance control offers the following advantages:

1. Detrimental impacts of aquatic weeds on native plant populations are reduced;
2. Detrimental impacts of aquatic weeds on water quality are reduced;
3. The amount of organic matter deposited on the lake bottom from natural processes is reduced;
4. The amount of organic matter deposited on the lake bottom after control of aquatic plants is reduced; and
5. Less herbicide is used in the long term.

For example, maintenance of water hyacinth to less than 5% coverage under experimental conditions reduced herbicide usage by a factor as great as 2.6; reduced deposition of detritus by a factor of 4.0; and reduced depression of DO that occurred beneath the vegetation mats.

A problem experienced when conducting a maintenance control program is that people do not perceive a weed problem and question the need to spray. Therefore, public education is an important part of a successful maintenance control program. Maintenance management is the most environmentally sound method for managing water hyacinth. Unmanaged, water hyacinth can double every 7 to 10 days. Ten plants can grow to cover one acre in a single growing season, often weighing 200 tons. Therefore, the benefit of controlling those 10 plants early should be obvious.

Maintenance management works for water hyacinth, but is more difficult for submersed weeds such as hydrilla. In South Florida canals, maintenance management of hydrilla has been successfully implemented but further research will be necessary to develop cost-effective programs for maintenance management of hydrilla in lakes. Once developed, maintenance management programs for hydrilla in lakes should provide more environmentally sound aquatic weed control. In northern lakes, cold weather, ice, and snow perform an annual natural maintenance management program. Aquatic plant management is often an annual affair but some evidence indicates that when properly planned and applied, management during one growing season may carry over to the following growing season or beyond.

Manipulating Plant Communities

The aesthetics, and fish and wildlife habitat values of lakes and reservoirs can sometimes be greatly enhanced by establishing and managing certain desirable aquatic plants. Many lakes have little vegetation, undesirable species, or plants growing in the wrong places. Manipulating habitat (e.g., substrate type, lake bottom slopes), selectively removing undesirable plants or plants that occur in undesired locations, and planting desired plants in desirable locations are all ways of managing aquatic plants to improve the quality of a lake.

Where it is legal, excavation can deepen aquatic environments to exclude plants from areas where they are not desired and the substrate can be used to form shallows for planting desired aquatic plants. When manipulating habitat like this, it is extremely important to determine the low, average, and high water lines of the lake. While some wetland plants will tolerate dry and wet seasons, there are many that will die if they are kept too wet or too dry. Individual plant species also require different water depth to be successful. Thus, when creating habitat for aquatic plants, it is important to create habitat of the proper depth for the desired plant species.

Some aquatic management techniques that control plants can also promote desirable species and improve habitat. The physical removal of problem aquatic plants, like mechanical harvesting of water milfoil, can sometimes stimulate wild celery by removing the shading canopy of watermilfoil. The herbicide 2,4-D can sometimes shift plant community composition from watermilfoil and coontail to beneficial pondweeds and wild celery (Nichols 1986). Screens and harvesters can channelize plant beds to produce island habitats, increase edge, and form cruising lanes for boaters and gamefish. Aluminum sulfate (alum) can reduce algae and thus improve water clarity for larger plants to grow. These are only a few of the many methods available to promote desirable aquatic plant growth in lakes and reservoirs. This is also a concept that should be part of any aquatic plant management plan.

Adding plants to lakes may be more important than removing them. Section 1 shows, however, that different types of plants (e.g., emersed, submersed) and individual species within each plant type require different conditions to survive. For example, water shield is an excellent food source for waterfowl and a potential plant for revegetation of lakes with no aquatic plants, but it only thrives in acidic, softwater lakes (Hoyer et al. 1996). Therefore, attempts to plant water shield in alkaline, hardwater lakes would be a waste of money and effort. Before attempting to revegetate, it is best to list the types and species of aquatic plants that can grow in that particular water body.

Conclusion

Aquatic plant management is a human endeavor. As the United States continues into the 21st century, there is widespread concern for the environment. This concern is certainly warranted, considering the large changes that have occurred to our planet since the turn of the 20th century. Some of these concerns, however, are based more on myth than on science. Scientists do not have all the answers, but our scientific knowledge is adequate enough to provide the guidance necessary to minimize environmental risks, while implementing an aquatic plant management program. Our goal is to provide information in this circular and others in this series on lake and fisheries management that will contribute to the elimination of many of the myths that have been associated with the management of our aquatic systems. It should always be recognized, however, that the ultimate success or failure of even the best management programs depends upon the people who decide to become involved.

Controversies related to how lakes should be managed will increase in number as increasing numbers of people use lakes. The history of aquatic plant management is clear. Although conflicts may seem diverse and unrelated, nearly all are rooted in conflicting values regarding what makes a quality lake and how lakes should be used. Value judgments are brought to the planning process not only by citizens, but by scientists and representatives from the federal, state, and local agencies charged with managing aquatic systems.

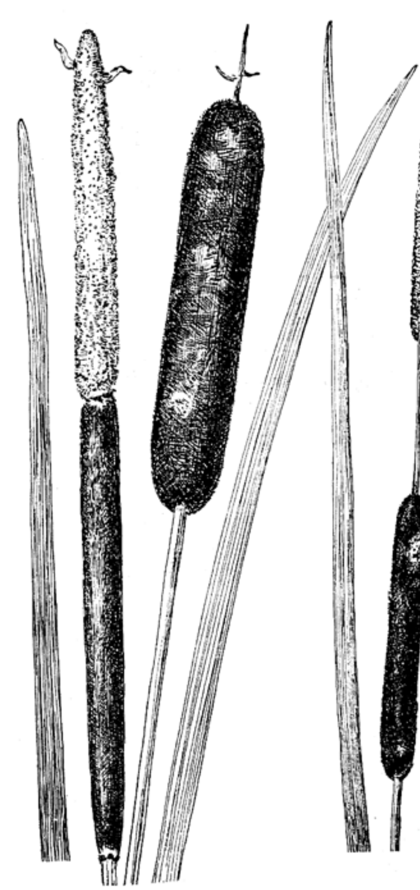
Florida LAKEWATCH long suggested that conflicts could be minimized if comprehensive, integrative management plans were developed for individual water bodies. The development of an aquatic plant or lake management plan, however, is not an easy task. Many management plans are either short-lived or dysfunctional when implemented because of disorganized citizen participation and disorganized input from the scientific community during the planning process. For example, the planning process can be drawn out over a long period of time (i.e., years) and the plan ultimately compromised by various stakeholders (e.g., regulatory agencies, homeowners, anglers, and business owners) unpredictably interjecting themselves into the process. The process is further complicated when these parties are supported by experts (e.g., academics, private professionals, or agency personnel) representing conflicting and seemingly irreconcilable opinions on technical issues.

Simon (1955) wrote that significant changes in human behavior can only be brought about rapidly if the persons who are expected to change participate in deciding what the changes shall be and how they shall be made. If we recognize the fundamental truth of Simon's statement, how then do we resolve conflict and develop comprehensive aquatic plant management programs, lake management programs, or water resource policy in a timely manner? The answer is that there is no surefire method. Search for the approach that is best suited for your community.

A new approach that attempts to improve upon traditional modes of public participation and scientific peer review in order to more efficiently integrate them with the policy making process is TEAM "Together for Environmental Assessment and Management: A process for Developing Effective Lake Management Plans or Water Resource Policy" (Canfield and Canfield 1994). TEAM's strength comes from combining in a new formula the most democratic attributes of public participation and scientific peer-review processes. TEAM provides citizens and professionals separate, but complementary, forums and responsibilities, unlike traditional approaches such as a task force or committee where lay citizens and professionals must work as a single unit. With the TEAM approach, citizens first identify and prioritize issues and potential courses of action that they believe are important. The experts then provide the citizens with a discussion of the technical issues, including pros and cons, relevant to the issues and courses of action identified. These complementary roles provide citizens with the technical information necessary to make informed choices and rescues experts from the inappropriate and sometimes awkward position of making policy judgments.

TEAM is designed to facilitate the development of an aquatic plant management or lake management plan in a timely manner. TEAM ensures that the opinions of stakeholders as well as those unable to become involved because of limited time are fairly represented. Using teams of experts that discuss the pros and cons of each issue offers a structure for a debate of technical issues which promotes identification of points of agreement and disagreement and of areas where more information is needed. TEAM permits experts' peers to judge the merits of their technical arguments, rather than forcing citizens or elected policy makers into the position of trying to become scientists. And importantly, TEAM, with the comprehensive participation of stakeholders, the busy public, and experts is intended to minimize potential delays and/or litigation.

The end product of the TEAM approach or any other approach is a plan of action, the PLAN. Lakes, ponds, reservoirs, and all other water bodies are dynamic, adaptable, and ever-changing ecosystems. Aquatic plant management plans or lake management plans must also be dynamic and adaptable. Aquatic plant management, like the environment, is often an ideological battleground, but in the final analysis compromise is necessary. Fortunately, management plans can be developed that protect and preserve the Nation's waters.



Cattail
(*Typha sp.*)

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Notes:

Florida LAKEWATCH

Florida LAKEWATCH (FLW) is one of the largest citizen-based volunteer monitoring endeavors in the country with more than 1,500 individuals monitoring more than 700 lakes and other bodies of water in more than 50 Florida counties. Staff from the University of Florida's Department of Fisheries and Aquatic Sciences train volunteers throughout the state to conduct monthly long-term monitoring of both fresh and saline waterbodies. LAKEWATCH uses the long-term data to provide citizens, agencies, and researchers with scientifically-sound water management information and educational outreach.

To become part of the Florida LAKEWATCH team, volunteers are required to have access to a boat and complete a two-hour training session. During the session, volunteers learn to collect water samples, take water clarity measurements, and prepare algae samples for laboratory analysis. Once a volunteer is certified by a regional coordinator and sampling sites are established, he or she will sample the designated stations once a month. Samples are frozen immediately upon being collected and are later delivered to a collection center, where they are stored until they can be picked up by Florida LAKEWATCH staff and delivered to the Univerity of Florida IFAS water chemistry laboratory at the Department of Fisheries and Aquatic Sciences.

In return for participation, volunteers receive:

• Personalized training in water monitoring techniques;
• Use of lake sampling materials and water chemistry analysis;
• Periodic data reports, including an annual data packet regarding their waterbody;
• Invitations to meetings where FLW staff provides an interpretation of the findings as well as general information about aquatic habitats and water management;
• Access to freshwater and coastal marine experts;
• Free newsletter subscription and educational materials regarding lake ecology and water management.

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