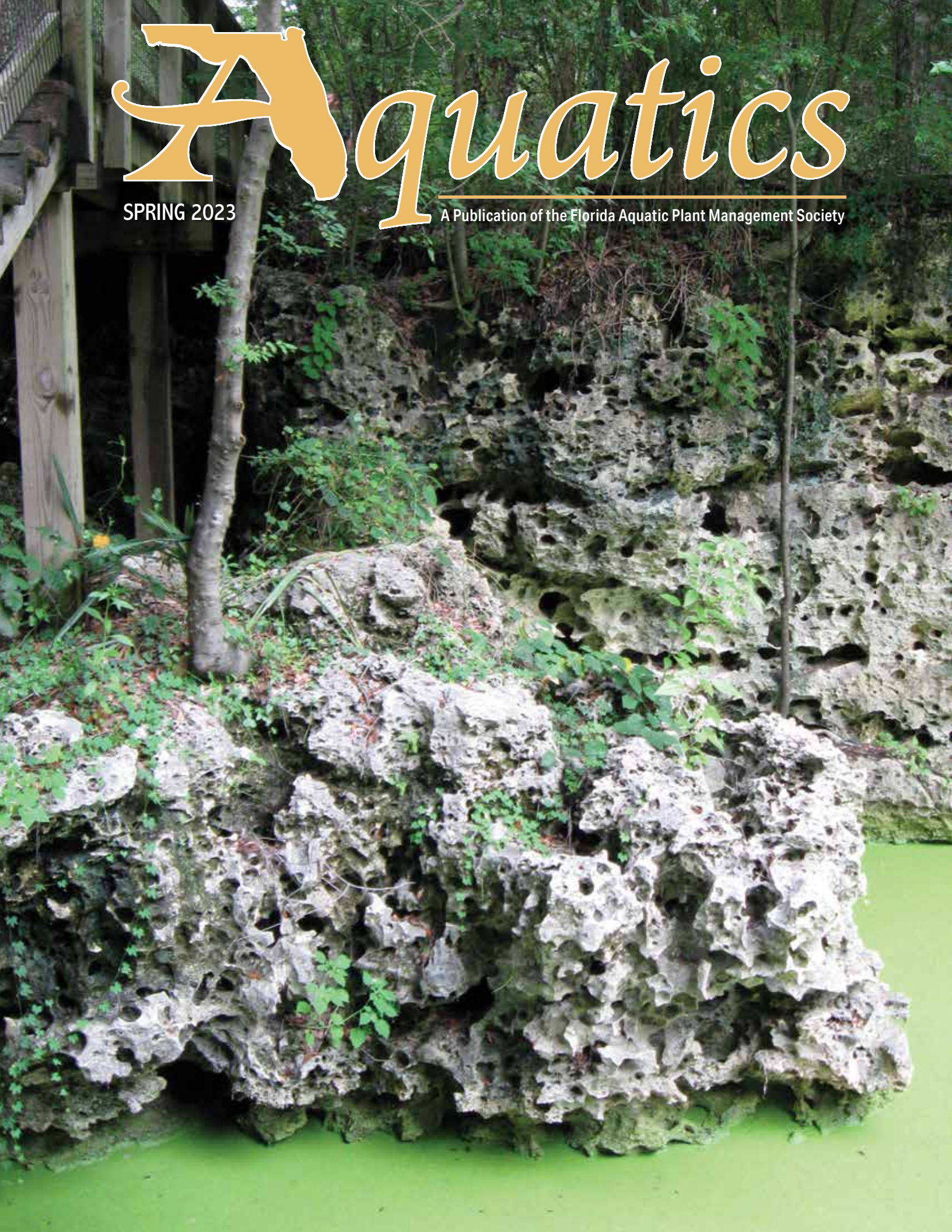
# Aquatics

SPRING 2023

A Publication of the Florida Aquatic Plant Management Society

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Aquatics
SPRING 2023
Volume 45, Number 2

Porous karst terrain surrounds a duckweed-covered Orange Grove Sink, an offset sink in Wes Skiles Peacock Springs State Park, Florida. Photo by Amy L. Giannotti

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To become a member of FAPMS and receive Aquatics magazine, please visit the website at: www.fapms.org

The vision of FAPMS is to be a leading resource for promoting excellence in the stewardship of Florida's aquatic ecosystems.

# Letter from the Editor

Amy L. Giannotti

Dear *Aquatics* Readers,

This is my last issue as Editor of *Aquatics*, and I have enjoyed the last five years serving FAPMS in this role. This issue is a little unique! I have tossed in a special archived article from each decade (almost) to illustrate how aquatic plant management has evolved over the years. I hope you enjoy this trip down memory lane as we flashback to the past.

Shelby Thomas

As I reflect on my time as Editor, I am immensely proud of the achievements we have accomplished in keeping this important publication going. From highlighting groundbreaking research in aquatic plant management, to featuring articles covering job safety, and including thought-provoking pieces on control strategies, we have made a significant impact on our readership and contributed to the broader understanding of invasion ecology in the important work that we do.

Although my background is rooted (pun intended) in science, my passion for outreach and education is a huge part of who I am. I love helping make scientific concepts and projects understandable and relevant to audiences of different ages, geographic locations, and professions. Effective science communication helps to foster a public understanding of what we as aquatic plant managers do, promotes scientific literacy, and facilitates informed decision-making (we hope) in the world of invasive plant management.

I'm so excited to hand over the reins of this position to Shelby Thomas, the new Editor for *Aquatics*. Shelby's background in natural resource management and communication is unmatched, and I know she will do an excellent job! Shelby has worked for agricultural and natural resource organizations throughout her career. Over the years, she has worked for the UF/IFAS Center for Aquatic and Invasive Plants, the FDACS Division of Plant Industry, the Florida Farm Bureau Federation, and most recently the UF/IFAS Department of Animal Sciences. Shelby now owns her own company, Shelby Thomas Creative, and works with organizations to assess and improve their current communication strategies. Please join me in welcoming Shelby to *Aquatics*!

I want to express my gratitude to our readers and to the team that makes each publication possible. It truly takes a village, and I have so enjoyed this adventure!

See you on the water,
Amy L. Giannotti, MS, CLM
Editor

# THE 1982 AQUATIC PLANT SURVEY

**by Jeff Schardt**
*Biologist Supervisor II*
*Dept. of Natural Resources*

In 1982, a survey was conducted to assess the aquatic plant coverage in Florida's public lakes and rivers along with their navigable tributaries. Canal systems were included if they provided public access or if they were maintained to provide flood control for the benefit of the general public. No lake size restrictions were incorporated into the 1982 survey as in 1979 and 1980 when manpower was more limited. Inspections which began on March 1 and concluded on November 15, were carried out primarily by the six regional biologists as part of their routine examinations while issuing aquatic plant control permits. The timing was selected to observe aquatic plants at or near their maximum concentrations. No attempt was made to estimate biomass or standing crop.

The 1982 report presents data for the aquatic plant manager on both a regional and statewide basis. The primary purpose is to estimate vegetation coverage in public water. Management efforts may then be directed toward areas of greatest need. After building a consistent data base and by comparing these data through time, the relative success of Florida's aquatic plant management programs can then be determined. Working toward this end, management programs were recorded as being funded at the private, local, state or federal level or as receiving no funding at all.

Aquatic systems have been divided into three general categories; lakes, rivers and canals. Within each of these systems, distinctions were made between types of aquatic plant communities. The four basic communities were: 1) submersed plants or those growing primarily below the water surface; 2) floating plants which were those with no rooted attachment to the hydrosoil; 3) emersed plants which were rooted to the hydrosoil with the stems and leaves extended into the air; and 4) floating-leaved plants which were attached to the hydrosoil with the leaves floating on or suspended just above the water surface. Water-lilies were included in the fourth category. A density rating of light, moderate or heavy vegetation was noted for each species to assess, to some degree, the importance of an individual aquatic plant species to a particular water body. Finally, a distinction was made between native and exotic plants to trace the origin of the aquatic vegetation present in Florida's public waters. Of primary importance to the Bureau of Aquatic Plants are the troublesome exotic species which, for the most part, have evolved in tropical or subtropical climates and have become quite competitive. When introduced into Florida's warm nutrient rich waters, many species quickly outcompete native vegetation and dominate entire water bodies. Three of the ten most abundant aquatic plants found during the 1982 survey are exotic in origin and accounted for 31 % of all vegetation found in public waters (Table 1).

Acreages of noxious aquatic plants listed in the survey are not necessarily estimates of the problems associated with individual water bodies. Ongoing management programs significantly reduce the abundance and distribution of problem aquatic plants in many areas. The survey is therefore a reflection of these management programs. For example, more than 1400 acres of hydrilla (*Hydrilla verticillata*) were recorded on Lake Trafford (Collier County) on May 5, 1982; however, approximately 40 acres remained when the lake was reinspected in December 1982. The decline was a result of experimental herbicide plots along with the ongoing control efforts of the Collier County Aquatic Plant Control Department. The Corps of Engineers conducted control operations on 24,500 acres of waterhyacinths (*Eichhomia crassipes*) and nearly 10,000 acres of waterhyacinths mixed with water lettuce (*Pistia stratiotes*) during 1982, but fewer than 8,500 acres of live water-hyacinths plants were observed during the survey (Table 1). Season variations in temperature, rainfall, light and nutrient availablility also affect aquatic plant growth and influence the time and location that different species reach their peak abundance. Since there was no way to determine these peaks beforehand, the survey should be considered as an estimate of the aquatic plant coverage of both beneficial and problem species in Florida's public waters.

The following discussion presents an overview of the project's results. A total of 1,235,123 acres of fresh water was surveyed encompassing 300 lakes, 55 rivers and 72 canal systems. This represents approximately 49% of Florida's reported 2.5 million acres of fresh water. One hundred twenty-nine aquatic plant species were identified. Forty-four species, mostly emergent, shoreline plants, were each reported to cover fewer than ten acres statewide. Nearly one half of the 183,475 acres of aquatic plants recorded was comprised of six species (Table 1). Thirty exotic species were identified totalling 70,305 acres or approximately 38% of the coverage of all species observed. Note that although

**TABLE 1**

**Ten Most Abundant Aquatic Plant Species Found in Florida's Public Waters (427 Water Bodies Surveyed)**

| | PLANT SPECIES | PLANT ACREAGE | ORIGIN* | NUMBER** |
|---|---|---|---|---|
| 1 | Hydrilla verticillata | 42,026 | E | 176 |
| 2 | Typha spp. | 14,774 | N | 327 |
| 3 | Eichhornia crassipes | 8,466 | E | 239 |
| 4 | Potamogeton illinoensis | 7,846 | N | 52 |
| 5 | Nymphaea odorata | 7,837 | N | 117 |
| 6 | Nuphar luteum | 7,743 | N | 248 |
| 7 | Panicum repens | 6,883 | E | 302 |
| 8 | Vallisneria americana | 6,810 | N | 95 |
| 9 | Paspalidium geminatum | 6,652 | N | 71 |
| 10 | Panicum hemitomon | 5,960 | N | 311 |

* E = exotic, N = Native
** Number = number of water bodies in which the plant was present

**Flashback 1982** — *Looking at Aquatic Plant Management through the Years.*

TABLE 2

Ten Most Abundant Aquatic Plant Species Found in Florida's Public Lakes (300 Lakes Surveyed)

| PLANT SPECIES | PLANT ACRES | ORIGIN* | NUMBER** |
|---|---|---|---|
| 1 Hydrilla verticillata | 34,725 | E | 87 |
| 2 Typha spp. | 12,650 | N | 240 |
| 3 Nymphaea odorata | 7,574 | N | 110 |
| 4 Potamogeton illinoensis | 7,470 | N | 35 |
| 5 Paspalidium geminatum | 6,652 | N | 58 |
| 6 Nuphar luteum | 6,211 | N | 184 |
| 7 Vallisneria americana | 5,987 | N | 69 |
| 8 Eichhornia crassipes | 5,281 | E | 155 |
| 9 Panicum hemitomon | 4,966 | N | 253 |
| 10 Scirpus validus | 4,497 | N | 27 |

* E = exotic, N = native
** Number = number of water bodies in which the plant was present

183,475 acres of plants were recorded, total water surface coverage was much less because of overlapping ranges. For example, a three acre water body could support a three acre coverage of submerged hydrilla underneath three acres of water-hyacinths totalling six acres of plants. No record was kept of net water surface coverage.

Table 1 lists the ten most abundant species by origin (native or exotic) and the number of water bodies in which the plant was found. Tables 2, 3 and 4 list the ten most common species by lake, river and canal respectively. Hydrilla continues to be the state's most abundant aquatic plant and the number one problem facing the aquatic plant manager. Statewide coverage amounted to greater than 42,000 acres. Although ten species were found in more water bodies than the exotic hydrilla, including the beneficial native plant *Nymphaea odorata*, none possesses the inherent capabilities to dominate a water body as quickly and extensively as hydrilla. Hydrilla occurred in 176 (41 %) of the water bodies surveyed; 44% of the rivers, 29% of the lakes and 90% of the canal systems. Hydrilla was present in 36 counties with the greatest abundance in Central to South Florida. Figure 1 shows the relative coverage of hydrilla by county. Figure 2 presents the same data in a three-dimensional form for easier comparison. The thirty most common species or groups of plants will be presented in this manner as well as by water management district in the 1982 survey.

The second most abundant group of aquatic plants, and most common aquatic plants in terms of water body presence, were the native cattails (*Typha* spp.). Cattails were most prevalent in lakes, including 6,678 acres reported in Lake Okeechobee, but were considered to be more of a nuisance in canal systems by impeding water flow. Cattails occurred in 77% of all waters surveyed. By habitat type, cattails were present in 65% of the rivers, 80% of the lakes and 71% of the canals inspected.

Water-hyacinth, another exotic species, covered nearly 8,500 acres of Florida's fresh water. Fifty-six percent of the rivers, 74% of the canals and 52% of the lakes supported water-hyacinths making them the second, fifth and eighth most common aquatic plants, respectively, in these systems.

Illinois Pondweed (*Potomageton illinoensis*) and eelgrass (*Vallisneria americana*) both native, submerged aquatic plants, were the fourth and eighth most abundant aquatic plants reported. Each of these plants are considered to have excellent wildlife value and are not often considered to cause navigational or water flow restrictions. Pondweed and eelgrass ranked as the 17th and 37th most abundant plants respectively in canal systems.

Pondweed was the 26th most prevalent plant in rivers, but ranked as number four in lakes, covering nearly 7,500 acres (65% of which was in Lake Okeechobee). Eelgrass was the sixth most prevalent species found in rivers, present in 42% of those surveyed, and the sixth most abundant plant found in lakes with a 23% frequency of occurrence and a coverage of nearly 6000 acres. Lake Okeechobee contained approximately 3000 acres of eelgrass.

Two native water-lilies, fragrant water-lily (*Nymphaea odorata*) and spatter-dock (*Nuphar luteum*) were the fifth and sixth most abundant aquatic plants reported. Together, they totalled nearly 13,800 acres in lakes, 1,000 acres in rivers and nearly 800 acres in canals (783 acres of spatter-dock were found in canals). Fragrant water-lily was found in 117 water bodies — spatter-dock was reported in 248. Although these two species comprised the majority of the floatingleaved plants found in Florida, a total of 19,055 acres of water-lilies were reported statewide including such species as water shield (*Brasenia shreberi*, 2,125 acres), American lotus (*Nelumbo lutea*, 842 acres), yellow water-lily (*Nymphaea mexicana*, 318 acres), and banana lily (*Nymphoides aquatica*, 190 acres).

The grasses, torpedograss (*Panicum repens*), knotgrass (*Paspalidium geminatum*) and maidencane (*Panicum hemitomon*) were the seventh, ninth and tenth most abundant aquatic plants found in public waters. Together they inhabited almost 19,500 acres of fresh water. Maidencane, a native species was the most common of the three, occurring in 73% of the water bodies surveyed. This species was encountered most often in lakes (84%), totalling 4,966 acres. The exotic torpedograss, which was found in 71% of the surveyed waters was most abundant in canals, occurring in 90 % and totalling approximately 3,700 acres. Knotgrass was as abundant as maidencane and torpedograss, but was only found in 17% of the surveyed waters. Greater than 90% of the 6,652 acres of knotgrass recorded was encountered in just three water bodies; West Lake Tohopekaliga — 2,800 acres, Lake Kissimmee — 2,040 acres and Lake Okeechobee — 1,196 acres. This species did not present the water flow restriction problems associated with maidencane and torpedograss since knot-grass was rarely found in canals or rivers. As with fragrant water-lily and spatter-dock, these three species comprised the majority of the grasses; however, ten additional species were identified raising the total acreage to approximately 21,100 acres.

Although this list represents the ten most abundant species in Florida, several other genera and closely related plants merit mentioning. Water-lettuce, an exotic, was reported to cover 4,278 acres spread over 109 water bodies. Encountered most often in canals (60% of those surveyed), water-lettuce ranked seventh among all aquatic species with a coverage of approximately 970 acres. The bullrushes (*Scirpus validus* and *S. californicus*)

**TABLE 4**

**Ten Most Abundant Aquatic Plants in Florida's Canals (72 Canal Systems Surveyed)**

| | PLANT SPECIES | PLANT ACRES | ORIGIN* | NUMBER** |
|---|---|---|---|---|
| 1 | Panicum repens | 4,010 | E | 73 |
| 2 | Hydrilla verticillata | 3,698 | E | 65 |
| 3 | Filamentous algae | 2,086 | N† | 52 |
| 4 | Typha spp. | 1,298 | N | 51 |
| 5 | Eichhornia crassipes | 1,269 | E | 53 |
| 6 | Najas guadalupensis | 996 | N | 27 |
| 7 | Pistia stratiotes | 967 | E | 43 |
| 8 | Nuphar luteum | 783 | N | 31 |
| 9 | Panicum hemitomon | 670 | N | 36 |
| 10 | Utricularia inflata | 606 | N | 11 |

* E = exotic, N = Native
** Number = number of water bodies in which the plant was present
† = some exotic species may be included.

and spikerushes (*Eleocharis cellulosa* and *E. interstincta*) covered greater than 11,500 acres. Six species of bladderworts ( *Utricularia* spp.) covered more than 4,.800 acres, primarily in quiet lakes and slowly flowing canals. The native coontail (*Ceratophyllum pemersum*) covered 4,182 acres of Florida's fresh water. Filamentous algal species inhabited more than 3,800 acres of water, predominately in canals — possible as a response to the intensive macrophyte control A combined surface acreage of 3,850 acres was reported for the duckweeds (*Lemna* spp.) and the floating ferns (*Salvinia rotundifolia* and *Azolla caroliniana*). Five milfoil (*Myriophyllum*) species totalled 3,750 acres of coverage. Eurasian watermilfoil (*Myriophyllum spicatum*) was the third most abundant aquatic plant found in the rivers (1,216 acres) due to the 750 acre coverage in Round Bay of the Apalachicola River system. The fanwort species (*Cabomba caroliniana* and *C. pulcherima*) covered 3,524 acres, naiad (*Najas* spp.) totalled 3,324 acres and the macrophytic algae (*Chara* spp. and *Nitella* spp.) covered slightly more than 2000 acres.

A more thorough report of the vegetation in Florida's waters is presented in the 1982 Aquatic Flora Survey Report. The survey is available by writing to:

Department of Natural Resources
Bureau of Aquatic Plant Research
and Control
3900 Commonwealth Boulevard, Room
304 Tallahassee, Florida 32303

**Flashback 1982** — *Looking at Aquatic Plant Management through the Years.*

# THE 1982 AQUATIC PLANT SURVEY

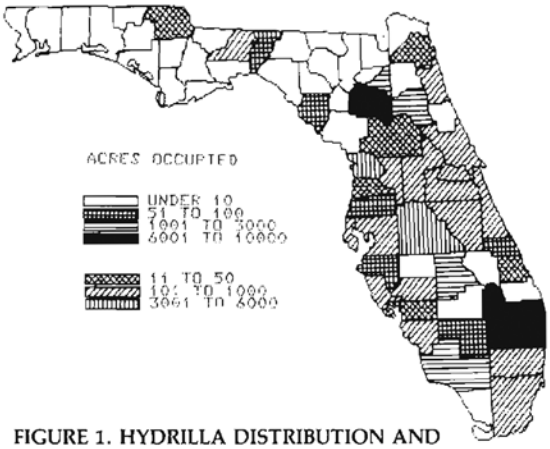



FIGURE 1. HYDRILLA DISTRIBUTION AND ABUNDANCE BY COUNTY

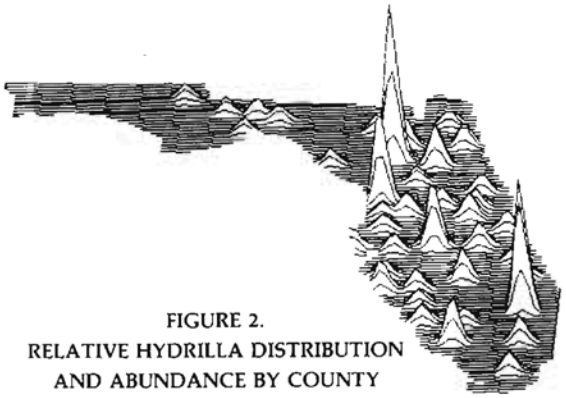
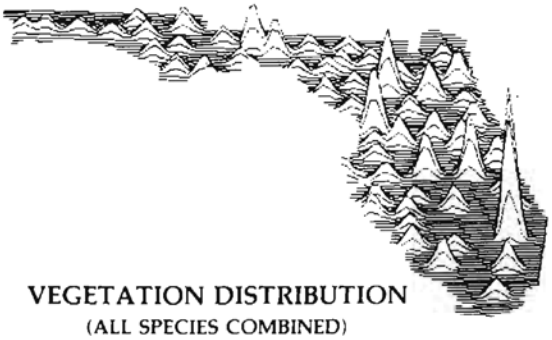
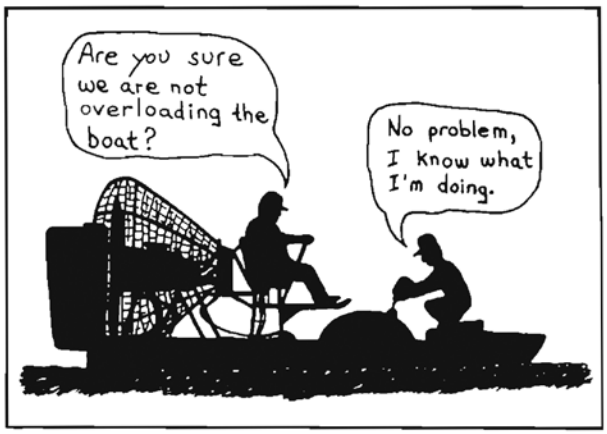


FIGURE 2.
RELATIVE HYDRILLA DISTRIBUTION AND ABUNDANCE BY COUNTY



VEGETATION DISTRIBUTION
(ALL SPECIES COMBINED)

## WEED LYIN'





**From the Editor:** In the attempt to name our new cartoon series only a couple of suggestions were received. I've given it the name "Weed Lyin' " — I feel it's 95% accurate.

**2023 MidSouth Aquatic Plant Management Society Scholarship Opportunity**

The MSAPMS is seeking applications for the 2023 student scholarship to be awarded at the annual meeting Oct. 24-26 in La Grange, GA (https://msapms.org/). We request that the successful applicant attend the meeting and give a presentation of academic progress and results as they are available. One scholarship of $2,500 will be awarded to a qualified graduate or undergraduate student applicant enrolled and studying aquatic plant science or other relevant research.

To apply, the Scholarship Committee should receive the following information by August 15th, 2023:

1. A cover letter which includes the applicant's previous, current, and future relationship to the aquatic plant management industry, and a comment on the importance of the proposed research to aquatic plant management.

2. Copies of unofficial or official transcripts of undergraduate and any graduate work completed to date (these transcripts may be those issued directly to the student by the institution);

3. A letter from the student's major professor or advisor recommending the student for the scholarship, indicating that the student is currently enrolled and in good standing;

4. One letter of recommendation, other than the major professor;

5. A copy of the proposed research plan
   - For graduate applications, proposals approved by the graduate committee are preferred but not mandatory.

All submissions may be made with either hardcopy, addressed as below, or electronically (in PDF format) via e- mail.

To enter an application or request more information, contact:

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# The Invasion of Exotic Aquatic and Wetland Plants in Florida: History and Efforts to Prevent New Introductions[1]

By
Don C. Schmitz
**Aquatic Biologist, Florida Department of Natural Resources**
**Bureau of Aquatic Plant Management**
**Tallahassee, Florida**

## Introduction

By 1950, the number of exotic (non-native) plant introductions into the United States was estimated to be at least 180,000 (Klose, 1950). Some 1,800 exotic plant species have escaped into the wild (Ripley, 1975), and a large portion has become naturalized (Morton, 1976; Austin, 1978). Particularly susceptible to exotic plant invasions because of its semi-tropical climate, Florida has been referred to as "a biological cesspool of introduced life." This paper will focus on the history of exotic aquatic plant introductions into the United States, and the present rules and regulations invoked by Florida and the federal government to prevent new introductions from occurring.

In 1988, 517,438 hectares (1,278,589 acres) of freshwater lakes, rivers, and canal systems were surveyed in Florida to evaluate the distribution and coverage of aquatic plant species (Nall and Schardt, 1989). The survey detected 137 aquatic species covering 140,973 hactares (348,344 acres). Twenty-two species were exotic and covered nearly 37,000 hectares (91,427 acres) or 26 percent of all species observed (Table 1). The submersed African species, hydrilla, comprised 16 percent of all aquatic species or 62 percent of all the exotic aquatic species observed; wetland species were not surveyed. However, it was estimated that nonsurveyed melaleuca (*Melaleuca quinquenervia*) and Brazilian pepper covered greater than 10,000 hectares (24,710 acres), each (Center and Balciunas, 1988; Habeck, 1989).

TABLE 1. Exotic aquatic and wetland plants found in Florida. All aquatic plants and estimated water surface area occupied are from the Florida Department of Natural Resources (FDNR) aquatic plant survey of the state's waters in 1988. All wetland plant survey estimates are compiled from sources other than the FDNR survey.

| AQUATIC PLANT SPECIES | HECTARES INFESTED |
|---|---|
| *Hydrilla verticillata* | 22,635 |
| *Panicum repens* | 4,654 |
| *Salvinia minima* | 2,147 |
| *Eichhornia crassipes* | 1,428 |
| *Braclziaria mutica* | 1,793 |
| *Alternanthera philoxeroides* | 1,154 |
| *Pistia strafiotes* | 1,099 |
| *Ludwigia spp.** | 755 |
| *Myriophyllum spicatum* | 427 |
| *Colocasia esculenta* | 293 |
| *Hygrophila polysperma* | 121 |
| *Egeria densa* | 79 |
| *Ceratopteris spp.*** | 61 |
| *Najas minor* | 54 |
| *Najas ancistrocarpa* | 36 |
| *Myriophyllum aquaticum* | 27 |
| *Pennisetum purpureum* | 5 |
| *Limnophila sessiliflora* | 3 |
| *Nasturtium officinale* | <1 |
| *Ipomoea aquatica* | <1 |
| *Potamogeton crispus* | <1 |
| *Hydrocleis nymphoides* | <1 |
| **WETLAND PLANT SPECIES** | |
| *Melaleuca quinquenervia*[1] | >10,000 |
| *Schinus terebinthifolius*[2] | >10,000 |
| *Mimosa pigru*[3] | >20 |

*Survey estimate comprising *L. octavalis* (native) and *L. peruviana* (exotic).
**Survey estimate comprising *C. pteroides.* (native) and *C. thalictroides* (exotic).
[1]Area Infested estimated by Center and Balciunas (1988).
[2]Area Infested estimated by Dr. Dale H. Habeck, University of Florida.
[3]Area Infested estimated by Robert Kipker, FDNR.

These "biological pollutants" have caused extensive ecological, and resource management problems in Florida's waterways. Their introduction and spread have hindered navigation, flood control, and recreational activities such as fishing and water sports, and their expansive growth has displaced native wildlife habitat. Aquatic plant management programs are now necessary to control many of these aggressive exotic aquatic and wetland plants. Since 1980, the cost of aquatic plant management programs to public agencies and private individuals in Florida has been approximately $90 million.

## History of Aquatic and Wetland Plant Introductions

Because water lettuce (*Pistia stratiotes*) was first described by John and William Bartram during their early explorations of Florida in 1765 (Bartram, 1942), it was thought to be native to Florida. However, Cordo et al. (1981)

[1]*Reprinted from the Proceedings of the National Conference on Enhancing the States' Lake and Wetland Management Programs, 18-19 May 1989, Chicago, IL, R. Kirschner, Editor, 400 W. Madison, Chicago, IL 60606. USEPA, Northeastern Illinois Planning Commission and North American Lake Management Society, Sponsors.*

has suggested that water small bundles of plants sent from St. Louis, Missouri, to Tampa, Florida, that were discarded into a canal in the early 1950s. By 1967, hydrilla was established throughout Florida and was rapidly expanding its range into other southeastern states. Only the female biotype of hydrilla was known to exist in the United States during the 1960s and 1970s. But in 1982, hydrilla plants obtained from a Washington, D.C., aquatic plant nursery produced both male and female flowers, confirming that the monoecious biotype was in this country. The monoecious hydrilla that is now established in the nor thern states greatly increases the potential for genetic diversification through sexual reproduction, which could lead to even greater expansion of this noxious weed (Steward et al. 1984).

Another exotic wetland plant species that poses a significant threat to south Florida's wetland communities is catclaw mimosa (*Mimosa pigra*), This native of Central and South America now occupies three distinct south Florida locations, one dating back to 1953. This shrub has long, sharp thorns and forms dense stands along waterbodies that can block access to people and wildlife. Because the species has sensitive leaves that fold on touch, its introduction into Florida may have been as an escape from ornamental cultivation.

Other exotic aquatic plants that have escaped from cultivation and are now established in Florida's waterways include: elephant ear (*Colocasia esculenta*), a native of tropical Asia introduced by th U.S. Department of Agriculture in 1910 (Greenwell, 1947); water primrose (*Ludwigia peruviana*), which is commonly found in Central and South America; watercress (*Nasturtium officinale*), a native of Europe that has been introduced and cultivated throughout the United States as an ingredient of salads; and a number of species (*Hydrocleis nymphoides, Najas minor, Najas ancistrocarpa*, and *Potamogeton crispus*) that are probably related to dumps of home aquaria into Florida water ways.



## Regulations to Prevent the Introduction of New Aquatic Weeds

William Mclane (1969), who owned and operated an aquatic plant nursery in south Florida from the late 1940s to the early 1970s, first proposed the establishment of rules and regulations regarding the im portation of exotic aquatic plants. In 1969, the Florida State Legislature enacted a State Statute (section 403.271) that prohibited the impor tation, transportation, and cultiva tion of aquatic plants without a permit from the Department of Pollution Control (now the Florida Department of Environmental Regulation). In 1973, the controlling authority was transferred to the Florida Department of Natural Resource's (FDNR) Bureau of Aquatic Plant Research and Control (Goldsby et al. 1976), now the Bureau of Aquatic Plant Management, from which the program has evolved to its present status. In 1984, legislation was introduced that revised section 403.271 by authorizing the permitting and inspection of all persons involved with the aquatic plant business. A violation of Florida's rules can result in a second degree misdemeanor charge.

**Flashback 1990** — *Looking at Aquatic Plant Management through the Years.*

Chapter 16C-52 of the Florida Administrative Code (F.A.C.) states the specific regulations governing aquatic plant importation, transportation, cultivation, possession, and retail sales. This rule provides for annual permitting of persons who use aquatic plants for business purposes and scientific research. The Florida Department of Natural Resources has established a prohibited aquatic plant list (Table 2) that consists of a number of species from 18 different genera. The major provisions of FDNR's regulatory program are:

- Exotic aquatic plant species may not be planted in the state's waterways.
- Permittees are required to notify the Bureau of Aquatic Plant Management within seven days after importing plants from abroad, giving a complete botanical listing of species received.
- Permittees who cultivate aquatic plants must have secure and adequate quarantine facilities to avoid accidently introducing exotic plants to adjacent waterways.
- All permitted culture facilities, wholesalers, and retail outlets are subject to inspection, and all prohibited aquatic plants can be seized without compensation to the owner.
- Violations can result in the suspension or revocation of the permit or a misdemeanor charge of the second degree.

The U.S. Department of Agriculture's Animal and Plant Health Inspection Service (USDA/ APHIS) has been charged with administering the Federal Noxious Weed Act of 1974 (U.S. Code Serv. 1985). This responsibility includes the identification of actual or potential noxious weeds, prevention of their entry into the United States, and early detection and eradication of incipient infestations. According to Part 360.100 Definitions (Federal Noxious Weed Regulations), section 3 of the Federal Noxious Weed Act of 1974 defines "noxious weed" as

> any living stage (including but not limited to seeds and reproductive parts) of any parasitic or other plant of a kind, or subdivision of a kind, which is of foreign origin, is new to or not widely prevalent in the United States, and can directly or indirectly injure crops, other useful plants, livestock, or poultry or other interests of agriculture, including irrigation, or navigation or the fish or wild-life resources of the United States or the public health.

USDA/ APHIS has designated 17 aquatic plant species as Federal Noxious Weeds. (FDNR's prohibited aquatic plant list contains a larger number of species because the department believes that a larger number of exotic species could invade and infest south Florida's unique, semitropical waterways.)

Incoming plant shipments from other countries are first inspected at an USDA/ APHIS inspection station for agricultural pests and plants that are listed as federal noxious weeds. All federal noxious weed species that are intentionally or accidentally imported are destroyed. The Florida Department of Natural Resources has an informal agreement with the USDA/APHIS Miami plant inspection station (where the majority of tropical aquatic plants enter the United States) to monitor shipments for plants listed as FDNR-prohibited aquatic plant species. Under this agreement,

TABLE 2. The list of aquatic and wetland plant species that are listed as federal noxious weeds (USDA/ APHIS) and FDNR prohibited aquatic plants.

| USDA/APHIS NOXIOUS WEEDS | FDNR PROHIBITED LIST |
|---|---|
| *Azolla pinnata* | *Alternanthera philoxeroides* |
| | *Cabomba aquatica* |
| *Eichhornia azurea* | *Eichhornia spp.* |
| *Hydrilla verticillata* | *Hydrilla spp.* |
| *Hygrophila polysperma* | *Hygrophila polysperma* |
| *Ipomoea aquatica* | *Ipomoea aquatica* |
| *Lagarosiphon major* | *Lagarosiphon spp.* |
| *Limnophila sessiliflora* | *Limnophila sessiliflora* |
| *Mimosa pigra* | *Mimosa pigra* |
| *Monochoria hastata* | *Monochoria hastata* |
| *Monochoria vaginalis* | *Monochoria vaginalis* |
| | *Nachaniandia alternifolia* |
| | *Pontedoria rotundilolia* |
| *Sagittaria sagittifolia* | |
| *Salvinia auriculata* | *Salvillia spp. (except S. minima)* |
| *Salvinia biloba* | |
| *Salvinia herzogii* | |
| *Salvinia molesta* | |
| *Sparganium erectun* | *Sparganium erectum* |
| *Stratiotes aloides* | *Stratiotes aloides* |
| | *Trapa spp.* |
| | *Vossia cuspidata* |
| **PROPOSED SPECIES TO BE ADDED** | |
| | *Crassula helmsii* |
| | *Ipomoea fistulosa* |
| | *Melaleuca quinquenervia* |
| | *Schinus terebinthifolius* |

the USDA/APHIS notifies FDNR if a species cannot be identified or a FDNR-prohibited plant species has been imported. All FDNR-prohibited aquatic plants are seized or destroyed.

Past FDNR inspections have resulted in the seizure and/or eradication of a number of federal noxious weed species. Giant salvinia (*Salvinia molesta*) is an aggressive water fern that has caused severe problems wherever it has been intro-duced (Nelson, 1984). This troublesome weed has been found in two aquatic plant nurseries in Florida that apparently received contaminated plant shipments from Sri Lanka.

A native of southeast Asia, water spinach (*Ipomoea aquatica*) has become Florida's most problematic federal noxious weed species. This plant is cultivated as an edible vegetable by Asian immigrants for personal use and for sale in oriental food markets throughout the United States. This vine-like species can grow in a wide range of habitats and is quite aggressive because of its prolific growth rate. The FDNR has seized and destroyed many water spinach infestations in south and central Florida drainage ditches and ponds, but many aquatic plant managers believe it is only a matter of time before this species becomes established here.

Another federal noxious weed, the anchored water hyacinth (*Eichhornia azurea*), was seized at a private residence after the species was obtained from a mail-order aquatic plant nursery located in Ohio. The federally listed *Lagarosiphon major*, a plant species very similar to hydrilla, and the floating weed, water hyacinth, can also be easily mail-ordered from aquarium and aquatic garden supply companies.

Although water hyacinths are not listed as a federal noxious weed species, a federal law (Chapter 825, Public Law 874) prohibits the inter- state shipment of water hyacinth plants and also alligatorweed and water chestnut (Trapa natans). This law is administered by the U.S. Department of Justice, rather than the USDA/ APHIS, but it is doubtful that this law has ever been enforced since its enactment in 1956.

According to section 2803(a) of the Federal Noxious Weed Act,

> No person shall knowingly move any noxious weed, identified in a regulation promulgated by the Secretary [of the USDA], into or through the United States or interstate, unless such movement is authorized under general or specific permit from the Secretary and is made in accordance with such conditions as the Secretary may prescribe in the permit and such regulations as he may promulgate under this Act to prevent the dissemination into the United States, or interstate, of such noxious weeds.

A number of federal noxious weeds are presently sold as ornamentals and/ or vegetables and are freely shipped from state to state. Although section 2803(a) of the Federal Noxious Weed Act grants authority to the USDA to stop the interstate spread of federal noxious weeds, the USDA/APHIS is interpreting the legislative intent, Senate Report No. 93-1313 (93rd Congress), as overriding the Act itself. In the Senate Report, "the restriction on interstate movement [of noxious weeds] would apply only to movements from areas quarantined under section 5 of the bill." To date, no quarantines have been enacted under the Federal Noxious Weed Act.

Because of the failure of the Federal Noxious Weed Act of 1974 and/or the USDA/ APHIS to stop the interstate commerce of federal noxious aquatic weeds, waterways in Florida and in other states are at risk. It makes no economic or biological sense to prevent the importation of federal noxious weeds into the United States and then allow commercial sales of these same plants from state to state. A consistent policy is needed to prevent federal noxious weeds now in this country from becoming naturalized.

Florida has a very active program to prevent new exotic aquatic plant introductions from occurring that uses permits and inspection of aquatic plants at retail, wholesale, and farming establishments. However, Florida cannot regulate plant species shipped here from another state via U.S. mail or commercial freight carriers. It is up to the USDA to properly administer the Federal Noxious Weed Act of 1974, or Florida, as well as other states, will be infested with new exotic aquatic plant populations.

## Acknowledgments

I am grateful to Andrew J. Leslie, Greg Jubinsky, Larry E. Nall, and Jeff D. Schardt of the Florida Department of Natural Resources and Dr. David Hall of the University of Florida for assistance in this research project.

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*Photo 1. Alternanthera philoxeroides* (Alligatorweed)

# Successful Biocontrol Insects to Control Alligatorweed

**By Charles E. Ashton**
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Alligatorweed (*Alternanthera philoxeroides*) was introduced into the United States from South America in the late 1800s and became problematic in the southeastern United States. This sprawling emergent plant formed dense floating mats which once grew across many narrow rivers and canals (photo 1). In 1959, cooperative efforts on biological control of aquatic plants were initiated between the U. S. Army Corps of Engineers and the Agricultural Research Service, U. S. Department of Agriculture. Overseas searches began for potential biological control insects to control alligatorweed in the 1960s. An extensive process of overseas surveys and research, screening and quarantine was involved prior to releasing insects in the United States. This process produced three insects: the Alligatorweed flea beetle (*Agasicles hygrophila*), the Alligatorweed thrip (*Amynothrips andersonii*), and the Alligatorweed stem borer ((*Vogtia*) *Arcola malloi*). The flea beetle, the thrip and stem borer were released in Florida in 1965, 1967 and 1971, respectively. These insects have been successfully established in most of the southeastern United States and successfully control alligatorweed. Three years after the introduction of the alligatorweed flea beetle in Florida, the U.S. Army Corps of Engineers Jacksonville District stopped herbicide spraying for alligatorweed in Florida. The insects have not eliminated alligatorweed in Florida waters. As alligatorweed populations increase in the spring, the populations of the biocontrol insect increase and their feeding keeps the plant from becoming a problem. Unfortunately, alligatorweed is more cold tolerant than the biocontrol agents. The beetles will not survive freezing weather, so beetles do not overwinter in cooler climates. In these areas, aquatic plant managers would typically have to rely on herbicides or other methods to control alligatorweed.

In 1980, a freeze in Northern Florida depleted the alligatorweed flea beetle population to such an extent along the St. Johns River that alligatorweed populations began to be a problem again along the River. The Jacksonville District sent staff to South Florida to collect and repopulate the St. Johns River with alligatorweed flea beetles. In a short time, the insects brought the problem weed back under control. Due to


*Photo 2 (above). Adult alligatorweed flea beetle*

*Photo 3 (top right). 1965 Ortega River, Jacksonville*

*Photo 4 (right). 1966 Ortega River, Jacksonville*

the success of this effort, it was determined that it may be possible to expand alligatorweed biological control efforts into colder climates by introducing alligatorweed flea beetles in the spring. In 1981 a program was established to provide alligatorweed biocontrol insects to states where the insects did not overwinter. The collection and distribution of the alligatorweed flea beetles was the primary focus of this effort.

### Biocontrol Insects

The adult alligatorweed flea beetles are black with yellow stripes (photo 2). The adults have well developed flight muscles and travel to new areas in search of food. All life cycles feed on alligatorweed. A female can lay approximately 1000 eggs in her lifetime. The entire life cycle including adult, egg, larvae, pupae, and adult is completed within 30 days. In 1965 the beetles (photo 3) were released on the Ortega River in Jacksonville, Florida and by 1966 the alligatorweed had been controlled (photo 4).

The adult alligatorweed thrips are shiny and black (photo 5). They exist in two forms, a short-winged and a long winged form. Only the long winged form is capable of flight. A female deposits an average of 200 eggs in her lifetime. The larva feed by piercing young plant leaves producing a characteristic distortion and curling of the young leaves. The total generation time of the insect is approximately 28 days. The adults can live up to four months. The thrips are established in most alligatorweed beds in the collection areas but only limited numbers are collected with sweep nets. Although we have permits to collect and ship these insects to other states recently, no efforts have been made to collect them.


*Photo 5. Adult alligator-weed thrip*


*Photo 6. Adult alligator-weed stem borer*


*Photo 7. Alligator-weed thrip larva*


*Photo 8. Larval damage to alligatorweed*

The alligatorweed stem borer is a moth and in the adult form ranges from ½ to ¾ inch in length (photo 6). It is dull brown in color and is seldom observed in the wild. Females lay eggs on the upper leaves of alligatorweed and lay from 200 to 300 in their short lifetime (6-8 days). The eggs hatch in several days and larvae bore into the plant stems. The larva continues feeding and each larva (photo 7) may bore into several stems prior to developing into a pupa and adult. The life cycle is completed in about 39 days. The larva feeding inside the hollow stem stops the flow of nutrients to the upper portions of the plant causing the stems and leaves to die and appear wilted (photo 8). The stem borer appears to be the most cold tolerant of the alligatorweed biocontrol insects.

U.S. Army Corps of Engineers established the Aquatic Plant Control Operations Support Center (Center) located in the Corps of Engineers Jacksonville District to serve as the Corps-wide center of expertise in the operational aspects of aquatic plant management. Providing alligatorweed biocontrol insects to public agencies with alligatorweed problems is one of the services that the Center provides. The U.S. Army Corps of Engineers, Engineer Research and Development Center (ERDC) laboratory in Vicksburg, Mississippi funds the project through the Federal Aquatic Plant Control Program. Currently the Center holds permits from the U.S. Department of Agriculture Animal and Plant Health Inspection Service (USDA-APHIS) to collect, ship, and field release these insects in Alabama, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Texas and Puerto Rico. Permits for insect release in the continental U.S. are issued for a period of 10 years while permits for Puerto Rico are issued on a yearly basis.

Adult alligatorweed flea beetles are collected in May along the St. Johns River by Center staff utilizing sweep nets while running airboats through beds of alligatorweed (photo 9). The insects are sorted from other bugs, packed in Styrofoam cups with alligatorweed, and then packed in coolers with a small amount of ice, to be air expressed to their destinations. Each cup contains approximately 300 alligtorweed flea beetles and each cooler can hold a maximum of 32 cups. The collection is made on Monday and Tuesday and shipped on Wednesday. The shipments arrive on Thursday, which allows two days to distribute the insects in the field. State and county agencies, universities, and other federal agencies receive the shipments and utilize them to control alligatorweed on their properties or distribute them to other individuals as needed.

The U.S. Department of Agriculture, Agricultural Research Service at the Beltsville Agricultural Research Center in Maryland keeps records on the beneficial non-quarantine insects that are transferred among the states. The APCOSC began the alligatorweed flea beetle collection and distribution project in 1981. During this time, the Center has distributed approximately 800,000 alligatorweed flea beetles to 8 southeastern states and Puerto Rico (figure 1). During this 23-year period, flea beetles were not distributed in 5 years because of lack of beetles or funding problems. In 1981, 1983, and 1984, 27,000 alligatorweed thrips were also collected and distributed. The number of beetles distributed over the years has been based on requests from aquatic plant managers in the field. No collection was made in 2002, due to funding problems. In the last 5 years excluding 2002, an average of 52,000 alligatorweed flea beetles were distributed to the southeastern United States and Puerto Rico.

In 2004 the Center shipped insects to Alabama, Georgia, Mississippi, North

*Photo 9. St. Johns River*

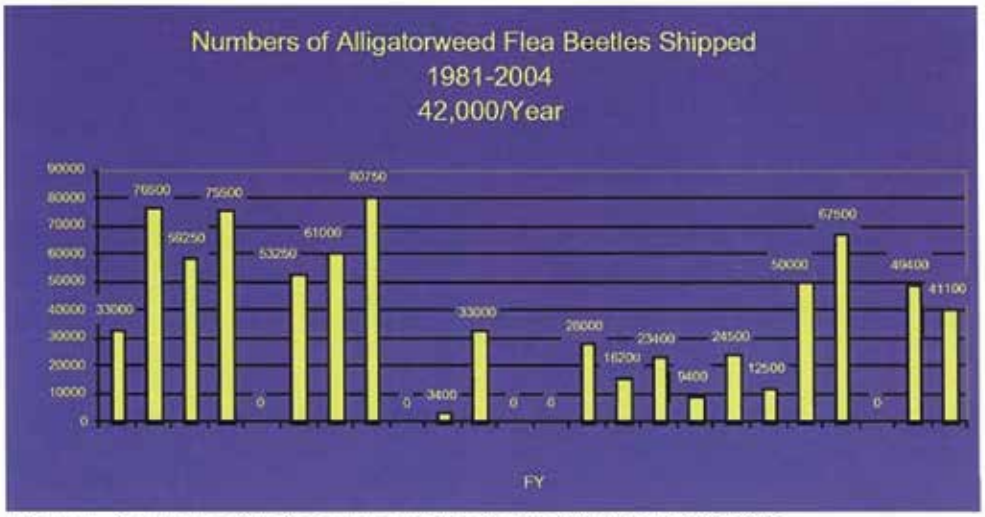


*Figure 1. Numbers of Alligatorweed Flea Beetles Shipped, 1981-2004*

Carolina, South Carolina, and Puerto Rico. In South Carolina, the Center works with Clemson University. For the last two years, Dr. Jack Whetstone has released flea beetles in the Georgetown Canal in Georgetown, South Carolina. This 26-rnile long canal supplies water to a paper company and serves as a drinking water supply for the city of Georgetown. In the past, the city had to continually harvest alligatorweed from the canal by mechanical means. Since the introduction of the flea beetles, the need to harvest alligatorweed in the canal has been significantly reduced. In Alabama, the Center provides flea beetles to the Alabama Fish Center, which in turn supplies them to individual fish farmers to control alligatorweed in their ponds. In Mississippi, Alabama, Georgia and Texas, insects are provided to National Wildlife Refuges, county agents, water control districts and State Wildlife, Fisheries and Parks. These agencies report good results with the flea beetles and reductions in the use of herbicides.

In the past, the Center had only shipped flea beetles to Puerto Rico. However this year, Center staff has been working with Dr. Edwin Abreu with the University of Puerto Rico to provide stem borers to assist with the control of alligatorweed on the island. The literature indicates that the best way to collect and ship alligatorweed stem borers is by collecting larva in the wilted sterns of alligatorweed. To determine the percentage of viable larva in wilted stems, 40 wilted stems of alligatorweed were collected and examined in the field. Of the 40 stems collected 20 larva and 2 pupa were found (55%). The wilted stems of alligator weed are collected in the field, placed in coolers with a small amount of ice, and shipped to Dr. Abreu in Isabela, Puerto Rico. Dr. Abreu harvests the larva and pupa from the stems to establish a laboratory colony for later field release. In the current year, the staff has collected and shipped 689 wilted stems (3 coolers full) of infected alligator weed to Puerto Rico.

The introduction of the three-alligatorweed biocontrol insects into Florida has successfully controlled alligatorweed in the state. Neither the Corps of Engineers nor the State of Florida expends funds for spraying alligatorweed. This project gives aquatic plant managers the option of utilizing biocontrol insects instead of herbicides to control alligatorweed in colder climates. In areas where alligatorweed flea beetles do not overwinter, the release of the beetles in May generally allows them to control alligatorweed for the remainder of the growing season. In the future, the project will be expanded to include the addition of the alligatorweed stem borers.

If you have a problem with alligatorweed and need biocontrol insects contact the APCOSC at E-mail charles.e.ashton@saj02. usace.army. mil. Provided the project is funded, the Center will be happy to help .

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## Acknowledgements

I would like to thank the U.S. Army Corps of Engineers, Engineer Research and Development Center laboratory for providing funding and photographs.

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# A Manager's DEFINITION of Aquatic Plant Control

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## Defining Aquatic Plant Control:

During the past few decades demand for access and use of U.S. surface waters has increased. This is evident in freshwater systems where human activities have expanded. These uses include real estate, recreation, irrigation, hydropower, potable water, navigation, and efforts to conserve environmental attributes such as fish and wildlife habitat. Aquatic plants are a natural and important component of many freshwater systems, and resource managers consider a diverse assemblage and a moderate level of aquatic vegetation to be beneficial for numerous ecosystem functions. Nonetheless, an overabundance of aquatic plants, particularly invasive non-native plants, can impair freshwater systems, requiring some level of aquatic plant management to conserve water body uses and functions. These aquatic plant management activities routinely take place on water bodies ranging in size from small private ponds to large public multi-purpose lakes and reservoirs.

With increasing demands and values associated with surface waters has come a greater need for aquatic plant control. Nonetheless, the term "control" can take on many meanings depending upon the type and amount of use of each water body, the species of plants present, the responsibilities of resource managers, and the objectives of various stakeholder groups associated with the water body. A quick review of reference materials provides the reader with dozens of descriptions and synonyms for "control", and yet for various reasons none of these efforts would provide a meaningful definition for aquatic plant management. The Aquatic Plant Management Society (APMS) looks to address this deficiency by providing an aquatic plant manager's working definition of aquatic plant control.

While the terms aquatic plant control and aquatic plant management are often considered synonymous, many resource managers consider control efforts as being operational in nature, and management as a process more aligned with program goals and objectives.

The APMS defines aquatic plant control as **techniques used alone or in combination that result in a timely, consistent, and substantial reduction of a target plant population to levels that alleviate an existing or potential impairment to the uses or functions of the water body.**

The above definition best applies to management techniques that directly target a reduction in plant biomass. It is recognized that some management strategies seek to impact factors such as plant reproductive capacity (e.g., production of flowers, seeds, tubers, etc.) or nutrient availability, and while these techniques are often recognized as a valuable component of an integrated management program, physical reduction of plant biomass may not result for many years. Moreover, in our definition, the use of the term "substantial" may seem ambiguous; however, we feel there is an inherent problem with using quantitative guidelines (e.g., a 70 percent biomass reduction results in acceptable control) to define what is in most cases a series of qualitative field observations by the aquatic resource manager and stakeholders to determine the success of the management activity. Aquatic resource managers should always consider if the proposed management technique has a successful track record, and know the limitations of the potential strategy. Claims that a product or technique can provide control should be supported by peer-reviewed literature, experiences from other resource managers with similar management objectives, or current research and demonstration efforts.

No single definition of aquatic plant control can cover each specific contingency therefore good communication on the front end is a key. **The resource manager and stakeholders must first establish expectations for the amount and duration of plant control prior to the initiation of a control activity, and then implement a management strategy to meet these expectations.** This definition and the attached white paper are intended to address factors that relate directly and indirectly to aquatic plant control. Numerous variables influence aquatic plant control operations and many of these parameters, including water body uses, environmental conditions, and available management tools are presented in Appendix 1, along with the influences they may have on the planning or outcomes of aquatic plant control operations. The white paper and Appendix may be useful to

managers responsible for conserving identified uses and functions of public waterways, and who must explain to stakeholders the reasoning behind management plan selection and the ultimate results.

## Linking Management Decisions to Aquatic Plant Control Expectations: Factors that Influence Decisions and Outcomes

Aquatic plants have been controlled in U.S. surface freshwaters under organized programs for more than a century, so it is natural to ask why it is necessary to provide a definition of aquatic plant control at this point in time. In questioning a number of managers, researchers, and other stakeholders, it became obvious that opinions on what constituted acceptable control of an aquatic plant population were widely varied. While agricultural managers have been using terms such as "weed free periods" and "crop yield reductions" to define the economic benefits of weed control in cropping systems, aquatic plant managers have a different focus than their terrestrial counterparts. Agricultural weed managers usually attempt to control a broad-spectrum of weeds in order to enhance one or more crop species in a fairly controlled environment with a specific function. Aquatic plant managers usually try to control one or two weeds (usually invasive exotic species) to conserve or enhance perhaps dozens of desirable plants as well as multiple uses of aquatic systems. In essence, an agricultural definition of "weed control" does not encompass many of the issues associated with aquatic plant management.

In developing a manager's definition for control, it was initially tempting to utilize the language of research to provide a quantitative definition. Both the amount and duration of plant control can be readily quantified within the framework of an experimental study or demonstration project. Nonetheless, many experimental studies result in destructive sampling of the target plants at a given point in time (e.g. 90 percent reduction at 8 weeks after treatment), and they often don't allow us to determine if even better control or subsequent recovery would result at a later point in time. While this efficacy information can be very useful to managers regarding the expected performance of a specific management technique, the uses, functions, and environmental conditions can vary widely among water bodies and within water bodies through time. This will influence not only the level of management that may be attempted, but also the outcomes of each control operation. While research projects utilize methods that allow for quantification of control, the vast majority of aquatic plant control operations are ultimately judged by fairly subjective visual observations and qualitative means (e.g. the target plants are near the bottom, difficult to find, and the current level of control is rated as good). Therefore, plant control or lack thereof is largely based on whether or not the resource manager and stakeholder expectations have been met.

As noted above, there are numerous issues that either directly or indirectly influence aquatic plant control and management strategies. Before selecting control tools or developing management strategies, three key elements should be addressed that will ultimately influence the manager's decision making process.

## Native vs. Non-native, vs. Invasive Aquatic Plant Control:

The National Invasive Species Council defines an invasive species as: "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health".

While there are major distinctions between invasive exotic and native species, the main objective of this white paper is to clarify the term "control" and as such will not make significant distinctions between managing invasive exotic species and nuisance growths of native plants. Whether a plant is a native or exotic, it can cause problems for given water uses (e.g., water conveyance, access). Nevertheless, two key distinctions between nuisance native and invasive plants deserve further discussion. First, problems associated with nuisance native vegetation are typically site specific while invasive plants can impair uses and functions of waters across a broad spectrum of conditions and on a regional scale. The vast majority of large-scale aquatic plant control efforts in the U.S. target invasive species. These plants have the potential to spread and dominate new ecosystems and they also have demonstrated the ability to become established in relatively stable aquatic systems. The philosophy behind invasive plant management programs often is to reduce the potential for spread within and among water bodies by reducing the plant biomass to the greatest extent practicable. The second distinction involves early detection and rapid response (EDRR) programs. These efforts are typically unique to invasive exotic species. A significant and costly multi-agency effort may be initiated to control a very small infestation; however, given the potential negative properties of many invasive exotic plant species, these front-end efforts are viewed as necessary and cost-effective.

## Efficacy vs. Control

It is tempting to define aquatic plant control in terms of an expected percent reduction in coverage or biomass of a target plant population. Some regulatory agencies (e.g., California EPA, Canada Pest Management Regulatory Agency) require that herbicide manufacturers prove the efficacy of their products prior to registration. In this regulatory scenario, a product must reduce a target pest population by greater than 70 or 80 percent to provide efficacy. Within the discipline of aquatic plant management, numerous techniques can provide both a rapid and significant reduction in a target plant population (>70 percent), but these results may only be sustained for a few weeks or months. Therefore, depending upon when the efficacy of a management technique is measured, one assessment may suggest that control was achieved, while a subsequent assessment conducted weeks, months, or a season later may lead to the conclusion that

the management effort failed to provide any level of control.

If resource managers and stakeholders have agreed to implement a strategy to provide an entire season of biomass reduction and the target plants recover within one or two months, then by our definition, control has not been achieved. In contrast, some methods may result in slow initial impact on a target plant population, but may ultimately provide one or more seasons of control. To complicate matters, many stakeholders fail to grasp that an aquatic plant problem may require more than one treatment or strategy. It is incumbent upon resource managers to understand the strengths and weaknesses of the various management techniques and then convey this information to the stakeholders. If expectations are not defined properly, the stakeholder may lose confidence in the management program. When managers do not establish clear expectations, they are often questioned if control was achieved. Attempting to assess aquatic plant control when clear expectations were not established on the front end is one of the biggest challenges in coming up with a meaningful definition or even assessment of control.

## Environmental Controls

Managers must be careful not to confuse slow-acting control methods with natural variations in plant populations. While it is often tempting to link a prior control effort with the large-scale decline of a target plant population, environmental events (e.g. droughts, floods, hurricanes, seasonal senescence, etc.) often are largely responsible for these declines. If empirical data do not exist to support a cause and effect relationship between a control effort and plant biomass decline, managers should avoid making claims that can not be supported by evidence. Some managers rely on environmental events (e.g. flooding events that scour submersed plants or move floating vegetation, and prolonged periods of high dark water that prevent light penetration for submersed plants) to provide control. While this can be effective, in order to be considered an aquatic plant management technique, there should be some level of predictability associated with the environmental event. From a management perspective there is a big difference in relying on routine seasonal flooding events to control a given plant population versus relying on 100-year floods or droughts to provide plant control.

## Levels of Aquatic Plant Control

At the most basic level there are three possible aquatic plant control approaches: 1) no attempt to control, 2) control efforts to eradicate a plant species, or 3) some level of intermediate control that is either incomplete or temporary.

## No Attempt to Control

Despite its connotation, the "no control" option is a valid management decision whose potential outcomes must be considered by managers and explained to stakeholders. Factors that influence a manager not taking active control measures may include:

**Plant species** – Is the plant invasive? Is it a native plant impairing water body uses or is it just unwanted by stakeholders?

**Size of infestation** – Is this a pioneer infestation consisting of a few plants? Is it an established, but stable, population? Is it an established population or starting to approach problematic thresholds?

**Plant location** – Is the infestation in an isolated location? Is the location conducive to spreading the pest plant by fragmentation, flow, etc? Are there important nearby water bodies that are prone to becoming infested?

**Plant biology** – Is there a likelihood of a rapid population expansion? Would "no control" permit the plant to produce viable seed or vegetative propagules that could make later control efforts more difficult and expensive?

**Exploitation** – Is the plant species providing an ecological service (e.g. nutrient uptake, food source for waterfowl, habitat for fisheries, etc.)

**Managerial will** – Managers may be under pressure to not control a plant because it provides benefits (perceived or real) to a user group. Stakeholders may oppose control because they are not familiar with proposed methods.

**Managerial experience** - Inexperienced resource managers are often uncomfortable with making aquatic plant management decisions (especially on a large-scale). Until a manager understands the issues and situation, the "no control" option may be viewed as the safest and least controversial.

The consideration of these factors and others may justify a "no control" decision. There are consequences associated with all management decisions and "no control" is not exempt. As previously addressed, plant reductions related to environmental factors could be included within the realm of the "no control" option. While environmental events such as floods, droughts, freezes, or severe algae blooms can be quite effective in controlling aquatic plants, these events are not typically predictable and they are not initiated by managers. Nonetheless, the fact that some managers tend to rely on seasonal or weather events to provide effective control suggests the term "no control" may be a misnomer in these situations.

## Eradication

Much like defining control, eradication has proven to have numerous meanings to various managers, researchers, and stakeholders. In a strict sense, eradication means the complete and permanent removal of all viable propagules of a plant population. This is confounded when a population is removed and then reintroduced at a later time. Some plants may be eradicated following single management efforts (e.g. removal of water hyacinth *(Eichhornia crassipes)* plants prior to seed set) while

others such as hydrilla may requires years of intense surveillance and management. Eradication efforts are typically employed when a region, state, or watershed is threatened with a new introduction of an invasive species that has potential for significant economic or environmental impact. Based on efforts by various resource management agencies to date, aquatic plant eradication programs are characterized by:

- sustained and multi-year efforts to insure elimination of the plant population;
- small-scale efforts to control relatively few plants,
- control costs on a per acre basis can be quite high;
- the overall impact of repeated control efforts on the infested water body is continually weighed against the regional threat posed by the invasive plant;
- control efforts may eventually be reduced; however, vigilant monitoring remains a key to success.

## Temporary Control

Outside the realm of eradication, all other control efforts are temporary. Temporary control is essentially an acknowledgement that one hundred percent control is either not an economically viable management objective or is not physically achievable. Temporary control is a continuum that can be represented by the short-term reduction of target plants following mechanical harvesting or spot treatments with contact herbicides, to many years of control that may result from grass carp *(Ctenopharyngodon idella)* stocking for submersed plants, or decades of suppression of alligatorweed *(Alternanthera philoxeroides)* by the alligatorweed flea beetle *(Agasicles hygrophila)*. Thus, temporary control results when the aquatic plant manager has made the decision that eradication is not a viable endpoint and some level of target plant persistence is acceptable in the management strategy for a given water body.

Temporary control is achievable using a variety of methods. Managers should evaluate each proposed method and the integration of various methods in terms of meeting specific control objectives.

## Maintenance Control

Maintenance control is applied on a lake-wide or regional scale over time, usually to reduce and contain invasive species. Once established, invasive aquatic plants can be extremely difficult, if not impossible, to eradicate. However, managing invasive plants at some prescribed level that does not impair the uses and functions of the water body can reduce environmental and economic impacts. As the term implies, maintenance control indicates that a conscious decision has been made to actively control an aquatic plant problem with the added understanding that a long-term commitment to management rather than eradication is the goal. Simply stated, maintenance control involves routine, recurring control efforts to suppress a problem aquatic plant population at an acceptable level.

Maintenance control encompasses a continuum of control objectives. On one extreme, the goal of maintenance control may be to reduce and sustain a plant population at the lowest feasible level that technology, finances, and conditions will allow. This strategy has proven effective in managing established populations of highly invasive aquatic plants. By managing water hyacinth (*Eichhornia crassipes*) at low levels through frequent small-scale control operations, there is a corresponding reduction in the overall management effort, especially herbicide use and management costs. There also are environmental gains, such as reductions in sedimentation, and dissolved oxygen depressions. At the other end of the spectrum, maintenance control operations can be applied just prior to plant populations impairing the uses or functions of the water body. This strategy entails allowing plants to grow to the brink of problem levels, and therefore may be best employed in controlling slow growing or otherwise non-invasive plants.

Paradoxically, there is often more stakeholder support for crisis management (allowing plants to reach some problem or impairment level) than maintaining invasive species at low levels. This may be related to stakeholders being unaware of invasive plant growth potential. It also may be related to the public's perceptions of control methods — for example, not understanding that less herbicide may be needed to maintain plants at low levels rather than waiting for an obvious problem to develop.

*While the examples of grass carp and alligatorweed flea beetle describe multi-season impacts, it must be recognized that the basis for this extended control is the continued presence of adequate populations of the management tool (i.e. the carp or the beetle). If the carp numbers are reduced below a certain threshold (predation, sportfishing, flooding, escape from the system), the target plant will generally re-colonize the aquatic system. Likewise, a severe winter can have adverse impacts on biological control organisms, and this may allow the target plant population to grow back to nuisance levels. The principle of maintaining a continuous pressure on the target plant is an important concept that is often not discussed when describing maintenance control provided by grass carp or biocontrol organisms. Maintenance control is often used to describe only ongoing herbicide programs, yet it is the integrated use and continuous pressure provided by grasscarp, biocontrol organisms, and chemical control tools that best describe a maintenance control approach.*

## Adaptive management –

Since maintenance control represents a long-term commitment, it must also encompass a strategy known as adaptive

management. Uses and functions of water bodies change through time, as do conditions within water bodies and among plant populations. Examples include target and non-target plant growth stages, water temperature, depth, clarity, and flow. All change several times during the year and can require different control strategies or different expectations for control outcomes. Therefore, integrated management plans for each aquatic plant control operation must account for and adapt to these changes.

## Communicating Control Expectations to User Groups

Many stakeholders view aquatic plant management endeavors as a one-time control effort with no further need for additional management. This does not reflect the reality of the discipline of aquatic plant management. The vast majority of management programs require a sustained effort over multiple years to keep unwanted vegetation under control. For example, while grass carp can provide long-term control of hydrilla, this result is due to their continuous presence and feeding on existing biomass and propagules. Carp can sustain control for many years, yet removal of the carp due to natural losses or on purpose will typically result in the recovery of the target plant. Likewise, a single treatment with fluridone herbicide may remove or reduce a target invasive plant such as Eurasian watermilfoil (*Myriophyllum spicatum)* within a system for one to several years. Upon discovery of new plants, many stakeholders are dismayed that the treatment did not eradicate the problem. In some cases these plants may have recovered from dormant seed or they may have been introduced from a nearby system that was not managed. Aside from the use of an effective classical biological control organism (highly selective) or high stocking rates of grass carp (non-selective), user groups must be informed about the importance of maintaining continuity in an aquatic plant management program. Single small-scale efforts that don't address the problem at an adequate scale often lead to claims that "we tried that and it didn't work." A lake full of hydrilla *(Hydrilla verticillata)* or Eurasian watermilfoil may require whole-lake management efforts. The control may last one or two seasons or even longer, but experience suggests that these invasive plants will ultimately return at some level.

One of the bigger challenges facing aquatic resource managers relates to the promotion of unproven and often costly technologies that are packaged as environmentally friendly approaches to aquatic plant management. As noted earlier, claims of a product or device providing "control" should be supported by published or ongoing research, or by another reputable resource manager who has successfully applied that technique or strategy and met similar control objectives.

## APPENDIX A

### Parameters that Influence Aquatic Plant Control Decisions and Outcomes

Aquatic plant management is a complex discipline that blends predictable sciences of chemistry and hydrology with variable parameters of biology and meteorology for application in venues with boundaries defined by human values and economics. Before aquatic plant control activities are initiated, one of the first and most important steps is to identify the various uses and functions of the water body. Identifying uses clarifies environmental and economic values of the water body that may be at risk. It also helps in selecting management tools and strategies that are compatible with, and will help to conserve, the various uses and functions of the water body.

After the uses and functions are identified, a management objective must be developed for the water body that considers these uses as well as concerns of the various stakeholders with interests in the water body. Management objectives are fairly straight forward for waters with relatively few uses or an emergency plant problem. Conflicts in developing objectives arise more frequently when there are many shared uses, multiple stakeholder groups, and an unclear vision if plants, that currently may be enhancing an identified use, may in time impair this or other uses. After management objectives are developed, managers must list all of the potential control tools and select the best tool or combinations that will achieve the stated objective.

There are direct and indirect environmental and economic costs associated with aquatic plant management activities. Responsible resource managers must understand these consequences and choose options that are proven effective and compatible with the current conditions at the site of interest. This information can be obtained through peer-reviewed literature, from direct experience, or through consulting with reliable sources with successful experiences controlling similar plant problems under similar conditions.

Table 1 lists various parameters to consider in developing an aquatic plant control program. Many of these considerations or constraints may influence both the scope of the program and the level of control achieved. While immediate and complete removal of a plant problem may be a desired goal or outcome, in practice, the control process may take months and may be temporary in nature; and therefore, will need to be repeated on a routine basis. Water body and plant conditions are constantly changing as are tools available to manage plants. Rarely can one person keep track of all of these changes or become an expert in each control tool; therefore, except for the most basic control situations, aquatic plant management experts should be consulted and stakeholders informed about impending aquatic plant control operations. Paramount in this communication is conveying to the non-technical stakeholder why particular methods were chosen and what are the anticipated or expected outcomes of selected (and perhaps rejected) control options, and a receptiveness of stakeholders to respect the multiple uses and functions that may be associated with each water body and to review control tools and options based on their potential for achieving management objectives rather than from a personal preference or bias.

## **Flashback 2009 —** *Looking at Aquatic Plant Management through the Years.*

| Parameter | Consideration/Constraint | Influence | Plant type |
|---|---|---|---|
| **Water uses and functions** | identify uses, values or functions of each water body to determine which if any may be at risk from invasive aquatic plants or nuisance growths of native and non-native plants - control tools and management strategies must be compatible with water body uses - water uses and conditions change and must be considered during the planning for each control operation | the uses of each water body must be identified and prioritized in order to develop management objectives - management objectives and water uses influence the tools and strategies best suited for aquatic plant control which in turn influence the spatial extent and duration of control | E = emergent<br>S = submersed<br>F = floating<br>Plant types are listed if their control is a primary consideration or influenced by this control consideration |
| Navigation and access | river channels or boat ramps blocked, areas of lakes inaccessible | frequent inspections and rapid response are necessary to sustain commercial navigation in rivers and canals - frequent inspections and control as necessary to conserve recreational access and navigation | E, S, F |
| Transportation | floating plant masses jam against bridges and may cause structural damage or erosion around pilings | frequent inspections and rapid response are necessary to prevent damage associated with aquatic vegetation, especially tussocks and floating islands | E, S, F |
| Flood control | plant masses can block or impede water flow in river channels, canals, lake outfalls, or flood control structures | frequent inspections and control of invasive plants that may impact flood control to the lowest feasible level - control native and non-invasive plants as necessary to conserve flood control | E, S, F |
| Potable water | plants clog water intakes | frequent inspections and control of plants as necessary to prevent disruption of water supply - herbicides must have potable water tolerance, set-back distance, or concentration limit | S, F |
| Irrigation | plants clog water intakes, impede water flow in ditches, canals, and rivers | ensure herbicides are compatible with irrigated crops, may need to treat when crops not in field, find alternate irrigation supply -notify homeowners of any lawn or ornamental plant watering restrictions after herbicide use | E, S, F |
| Livestock watering | plants do not usually impact ability for watering livestock from water bodies | if herbicides used, may need to remove livestock from water body shoreline, find alternate watering source | E, S, F |
| Downstream uses and needs | plant masses prevent water releases for downstream uses like drinking, irrigation, wetland restoration, estuaries | control plants to provide downstream water - herbicides must be compatible with downstream uses - coordinate control with water releases - frequent releases may dilute or draw off herbicide concentrations | E, S, F |
| **Recreation** | identify and assess recreational uses within the system | aquatic plants may enhance or hinder recreational activities within a water body that may be seasonal or year-round | |
| Boating | plants can restrict access and boating activities | select control methods and frequency to accommodate types and amounts of boating - inboard/outboard motor, sailing, canoe/kayak, rowing shell, etc. | E, S, F |
| Fishing | plants can block access to fishing areas - plants provide habitat to support fisheries but at high densities and cover can impair fish and wildlife habitat | manage invasive plants to conserve or enhance native plants - select herbicides that are compatible with fishery – try to time control to minimize impacts with bedding and increased activities like tournaments, weekends, holidays, etc. | E, S, F |
| Hunting | plants can block access to hunting areas - plants provide habitat and food source, especially for some waterfowl | manage invasive plants to conserve or enhance native plant habitat - plan control to minimize impacts with hunting | E, S, F |
| Swimming | plants can cover swimming areas, increase danger of entanglement and drowning | select control method compatible with swimming or control during low or no swimming periods | E, S, F |
| Skiing | plants can impede boat operation and increase danger of entanglement and drowning | keep designated ski / boating areas free of aquatic plants | S, F |
| Wildlife viewing | plants can block access to wildlife viewing areas and view of wildlife | work with wildlife management agencies to ensure access to wildlife areas is acceptable - keep designated areas open for boat access | E, S, F |
| **Fish and wildlife management** | identify and assess wildlife uses and needs within the system - while moderate levels of plants may provide essential habitat or forage, too many plants may cover nesting, bedding and forage areas | aquatic plants and control operations may enhance or hinder wildlife management activities within a water body that may be seasonal or year round | |
| Endangered species, including habitat and forage/prey | plants may provide essential habitat for endangered species - conversely, plants can cover nesting, bedding and forage sites as well as impair habitat for forage animals - ex: in Florida, waterhyacinth may outcompete native plants essential for Everglades Kite nesting as well as cover their prey (apple snails) causing them to abandon nests | understand types and seasonality of endangered species as well as forage/prey habitat requirements, select control tools and timing compatible with endangered species | E, S, F |

**Flashback 2009** — *Looking at Aquatic Plant Management through the Years.*

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|---|---|---|---|
| Fishery | moderate levels of diverse plant communities are generally viewed as favorable for many sport fish populations - monocultures of nuisance or invasive plants can crowd out beneficial native plants, cover bedding sites, stunt or eliminate some fish populations, reduce dissolved oxygen leading to fish kills | select control methods compatible with fish management objectives for water body - ex: do not drawdown during spawn; repeated harvesting may reduce young of year sport fish, ensure herbicide is compatible with primary fish management objective, avoid formation of extensive surface mats of submersed or floating plants and large submersed plant treatments with contact-type herbicides during hot water/low oxygen periods | E, S, F |
| Waterfowl hunting | plant monocultures can crowd out or cover beneficial native plants | if possible, control plants well in advance of or after hunting season | E, S, F |
| Non-game wildlife | plant monocultures can crowd out or cover beneficial native plants or cover nesting and foraging sites | identify areas or species of concern with wildlife management agency and select control tools and timing compatible with non-game species managed in the water body | E, S, F |
| Habitat | plant monocultures can crowd out or cover beneficial native plants | control invasive or nuisance plant populations to conserve or enhance diverse beneficial native plant assemblages | E, S, F |
| Nesting / foraging | plant monocultures can cover fish bedding sites, interfere with rookeries, cover or exclude prey or forage animals and plants | control invasive or nuisance plant populations to conserve nesting and foraging sites, ensure control tools are compatible with important forage plants and animals | E, S, F |
| Vegetation planting project | invasive and nuisance plant growth can cover or crowd out newly planted vegetation | prevent invasive or nuisance plants from covering revegetation projects, select control tools and timing that are compatible with planted species | E, S, F |
| **Mosquito control** | invasive floating plants and surface mats of submersed plants are ideal mosquito breeding sites | control invasive and nuisance plant mats, especially in quiescent waters in urban areas to reduce mosquito habitat | S, F |
| **Control feasibility** | various parameters influence whether or not a plant can be effectively controlled including; available tools, water body physical and chemical conditions, and plant susceptibility and growth stage | list and consider all control tools that have been proven successful in the water body in question or in similar waters and conditions - integrate the best tool or tools compatible with water body uses, functions, and conditions, that meet management objectives into the control program | |
| **Potential for control** | | | |
| Available methods | list all plant control tools that have been demonstrated effective in controlling plant(s) in question - demonstrated through documentation, contact with experienced managers that have effectively applied that control strategy | integrate tools into control plan that have been demonstrated to be effective - if tool is new, unproven, experimental, etc., approach implementation as operational research and convey to stakeholders the level of control anticipated and level of confidence in achieving control | E, S, F |
| Biological | usually refers to releasing an animal species including fish, arthropods, or pathogens to suppress or control target aquatic plants to some extent | effectiveness may vary from suppression to complete control so target plant susceptibility and management objectives must be clearly evaluated and conveyed to stakeholders | E, S, F |
| Fish – grass carp | generalist feeder that may control target and non-target plants - prefer some plant species over others - sterile, triploid chromosome variety available - mobile river fish that may need to be contained with physical or electric barrier - may control plants for up to a decade - may require permit from fish and game agency - extremely difficult to remove and determine population size in system after stocked (easier to add more if needed than to remove after stocking) | test to ensure that only sterile triploid carp are released - ensure target plant is susceptible to grass carp, stock at the lowest feasible level - consider controlling target plants with other methods first to reduce biomass - install containment strategy - identify non-target susceptible plants - develop integrated strategy to augment control - stock 10"-12" fish in cooler months to reduce losses from predation, heat stress, and low dissolved oxygen - stocking rate can change significantly, ex: if water levels increase or decrease after stocking or sudden natural declines in vegetation (shading, etc.) can cause "overstocked" situation | S, F |
| Arthropods | most classical biological control is conducted with insects - agents must be approved by the USDA as well as state regulatory agencies prior to release to ensure host specificity - agents may reproduce in self-sustaining populations or may need additional releases to sustain sufficient levels to suppress or control plants | impacts from insects may range from no observable control to decimation of target plant depending on insect species, plant type and climate at release site - predation from native animals (birds, fish, wasps, etc.) may influence the biocontrol population size and therefore the level of stress, suppression, or control achieved | E, S, F |
| Pathogens | some plant pathogens, especially fungi can stress aquatic plants - commercially available pathogens (bioherbicides) are under research evaluation | naturally occurring outbreaks may increase efficacy of herbicide treatments, ex: water hyacinth control in some Florida waters | E, S, F |
| Chemical herbicides | chemical herbicides must be registered for aquatic use by the USEPA and state regulatory agency - permits may be required from state or local governments before using registered herbicides | sites and maximum rates are regulated by the federal and state label - susceptible plant species and lower than maximum use rates are determined through laboratory and operational research | E, S, F |
| Contact/systemic | herbicides fall into two general categories, faster acting contact type herbicides that the kill the portion of the plant to which they are applied, and slower acting systemic type herbicides that translocate within the plant killing the entire plant including the roots | faster acting or contact type herbicides may be more conducive to controlling submersed plants in flowing waters - slower systemic herbicides may be more suited to large-scale treatments to minimize oxygen consumption during plant decomposition | E, S, F |

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| Liquid/pellet formulation | herbicide formulations fall into two basic formulations; liquid or aqueous, and solid pellets, flakes, wettable powders, or granules | liquid formulations are usually less expensive and are a better choice in waters with thick soft sediments where pellets can sink, diminishing effectiveness - pellets applied in slow flowing waters with firm substrates sustain prescribed concentrations for longer periods | E, S, F |
| Plant growth regulators | PGRs do not kill, but rather suppress growth of target aquatic plant | herbicides at low rates may provide some plant growth regulation - may lead to increased resistance in plants if not killed - application of this control strategy not well developed | S |
| **Mechanical** | | | |
| Harvester | removal of plant mass from water body - may control non-target plants and animals - various designs, sizes, and hauling capacity available – may provide immediate control of small scale plant problems | may fragment and spread target plant - must find disposal sites - removes target and non-target plants and animals - more efficient harvesters may harvest larger fish and wildlife that cannot escape path - efficiency may be increased with barges to shuttle plants to disposal site – may create turbidity in shallow waters | E, S, F |
| Barge mounted hoe/dragline | removal of dense mats of plants and floating islands | removes dense masses of vegetation and other material from canals and river channels as well as bridges and flood control structures - may fragment and spread target plant - must find disposal sites - may remove target and non-target plants and animals | E, S, F |
| Shredder | various designs are available to shred floating masses of herbaceous and woody plants and floating masses or islands of sediments | used for emergency restoration of access, navigation, or flood control attributes as well as around bridges - generates fragments that may spread invasive plants - controls all plants and animals in control area - may require additional shredding or harvesting of materials that float back to the surface - may generate temporary turbidity in immediate control area - drops mater on bottom - not advisable for repeated use at boat ramps, navigation channels, residential shorelines, etc. | E, S, F |
| Rotovator | underwater apparatus or arm extending from barge with rotating tines to tear plants from sediments | generates fragments and may spread invasive plant infestation - may need to harvest uprooted plants - disturbs sediments and may generate turbidity | E, S |
| **Cultural/Physical** | | | |
| Barriers | passive devises to cover target plants, or to contain plant fragments, turbidity, herbicide-treated water - may be highly labor intensive to install/remove | may be used in small areas where other options are less practical | E, S |
| Benthic | fabric laid over plants on substrate - must anchor to bottom - place over live plants or control plants to substrate and place barrier to control re-growth | evaluate potential impacts to target and non-target plants and animals - may need to clean barrier to prevent plant growth on top | E, S |
| Curtains | vertical barrier in the water column to minimize water exchange from one site to another - can either be manufactured curtain to prevent water exchange to contain herbicides, or a strip of plants left on the edge of harvest or shredding sites to contain fragments or turbidity | prevent or reduce herbicide dilution and turbidity in flowing or open waters | E, S |
| Benthic rollers | devise usually anchored to a piling or dock to roll over plants and sediments | may be effective on small scale - needs power source and frequent monitoring | E, S |
| Drawdown | water control structure must be available - reducing water levels to accommodate aquatic plant control must be compatible with other uses and functions of the water body - consider ability to refill water body after drawdown | drawdowns need to last for several months - must be complete to desiccate plants - best applied in winter to include impacts from freezing - compatible with prescribed fire for emergent plant control - try to avoid during fish spawn, waterfowl hunting, endangered species nesting foraging - partial drawdowns during growing season may allow invasive or nuisance submersed plants to colonize into deeper waters expanding the problem - incomplete drawdowns may allow wetland plants like cattail or willow to reach nuisance levels | E, S, F |
| Desiccation | extreme drawdown must be of sufficient duration to dry target plants and preferably sediments - not appropriate during wet or growing season | plants that produce underground tubers (hydrilla) or extensive seed bank (water hyacinth) are not well suited to control by drawdown - floating islands may develop upon re-flooding and may need to be controlled | E, S, F |
| Freezing | freezing enhances desiccation and amount of control | drawdown needs to expose sediment to reduce insulating effect from water - conversely, summer drawdowns can increase spread of invasive (torpedograss) or native plants (willow) can expand to nuisance levels | E, S, F |
| Prescribed fire | planned burning of emergent vegetation to reduce standing crop - burning must be compatible with surrounding land use | reduces standing crop and stimulates re-growth in some species - be prepared to follow up with other methods including herbicides upon re-flooding – may not be practical in urban areas or near high traffic highways | E |

**Flashback 2009** — *Looking at Aquatic Plant Management through the Years.*

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|---|---|---|---|
| Flooding | flush floating plants or mats of plants out of system or into upland areas, - increase water level to shade and stress submersed plants | raising the water level to flush and strand floating plants or mats of plants into uplands is an option in waters with flood control structure and few to no houses or structures along shoreline - other flooding methods include lowering water levels to treat submersed plants, then re-flooding to reduce light and further stress plants - some emergent plants (torpedograss) can be controlled by dewatering, burning, and re-flooding to suppress re-growth | E, S, F |
| Dredge – barge mounted | large-scale dredging operation that removes rooted plants and sediments - sediments returned to water column or pumped to settling basin | may miss plants - may fragment and spread plants - may increase turbidity | S |
| Dredge – diver assisted | hand-held suction devise controlled by underwater diver using snorkel or SCUBA - dislodge plants by hand and place into suction lift to screen plants onshore or on attending barge | labor intensive - effective in small areas where other methods are not practical - may cause or may be impeded by siltation / turbidity | S |
| Dyes | artificial dyes like natural tannins color water, reducing light penetration to control or suppress submersed plant growth | may provide submersed plant and algae suppression in small areas where water flow, volume, and exchange are low | S |
| Hand pulling | removing plants by hand - includes tossing rakes or hand-held cutting blades to sheer plants | immediate control - labor intensive - may be suitable for new infestations around boat ramps, docks, trash rakes at water intakes, pumps, etc. - may use rakes and cutting blades to clear small areas of plant material - creates fragments that may spread plants to other areas | E, S, F |
| Shearing - chains, etc. | includes any of a number of devises that are dragged through rooted stands of plants including chains pulled by hand or steel bars towed by boat or barge | labor intensive - disturbs sediments - creates fragments and turbidity - may need to clear obstructions - used in some canal systems where most plants may be considered undesirable and substrate habitat is a low concern | E, S |
| **Waterbody parameters** | | | |
| **Hydrology** | | | |
| Water depth | water depth can influence the cost and duration of control - water control structures can give the flexibility of reducing and increasing water depths to accommodate control | re-growth of submersed plants to the surface is faster in shallow waters - do control costs, methods, etc. warrant short term control? - control of submersed plants with herbicides requires treating much or all of the water column - shallow water should be less costly to treat than deep water - increasing the water depth after a submersed plant herbicide treatment reduces light penetration enhancing the amount and duration of control | E, S |
| Water volume | important for herbicide control since effectiveness of many herbicides is dependent upon sustaining a prescribed concentration | reducing water volumes before herbicide treatments for submersed plant control can save money and increase efficacy - increasing water volume before use of herbicides to control submersed plants can dilute concentration and reduce or negate control efficacy | S |
| Water flow | static vs. moving water can play an important role in selecting control methods | important in determining pelletized vs. liquid formulation herbicides - dilution from flow may be too great to apply herbicides, especially slow acting systemic compounds - flow may dictate urgency of control, ex: to keep floating plants from clogging flood control structures or jamming against bridges - keeping flow unimpeded may impact ability to contain grass carp with conventional physical barrier | S, F |
| Springs / sinkholes | related to flow | groundwater may dilute or dissipate herbicides | S |
| Tidal influence | tides can raise or lower water levels and volumes, can flush herbicides, and regulate plant growth | may dilute herbicide concentrations by adding water volume at high tide or flush herbicides out of treatment area as tide recedes - depending on salt content, may preclude use of some herbicides not registered for use in brackish or marine waters - may restrict access for herbicide spray boats, harvesters, barges, etc. due to low (grounding) or high (bridge clearance) water level - invasive plants may not reach problem level if salt content sufficiently high - ex: hydrilla in brackish water - may favor invasive species tolerant to low salinities - ex: Eurasian watermilfoil | S |
| **Water chemistry** | | | |
| Dissolved oxygen | oxygen is needed to sustain aquatic life and decompose organic sediments and detritus - warmer water holds less dissolved oxygen than cooler water | check oxygen level prior to herbicide use - slow acting or systemic herbicides or treating smaller areas with contact type herbicides can reduce amount of plant decomposition and demand on oxygen to avoid stressing or killing fish - try to conduct large-scale plant management in cooler months before plants reach peak biomass (more oxygen / less decomposition) | S, F |

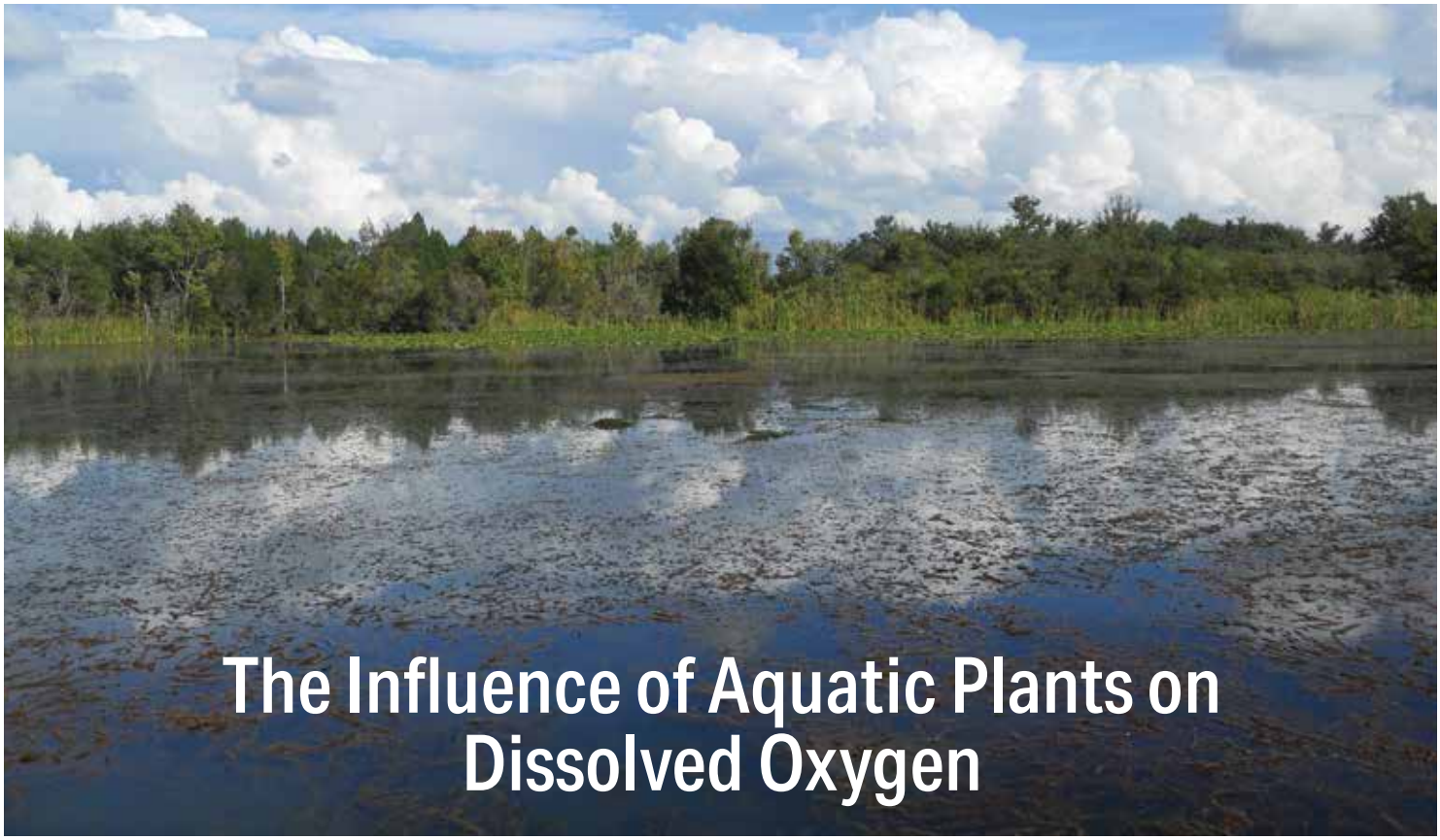
| | | | |
|---|---|---|---|
| pH, alkalinity, and hardness | these parameters may be important in determining invasiveness of plants in certain waters - ex: water hyacinth and hydrilla do not grow as well in low pH waters - pH, alkalinity, and hardness modify performance of certain herbicides | low alkalinity and pH increase copper toxicity to fish - high pH decreases efficacy of flumioxazin herbicide for submersed plant control - hard water binds with glyphosate and reduces efficacy | S |
| Nutrient content | nutrient content in aquatic macrophytes and in the sediments may be re-suspended in the water column after controlling aquatic plants - nutrients are released from decomposing plants and in shallow waters, sediments may be stirred by waves and water currents | nutrient content may be a concern when planning large-scale management - some nutrients are released by decomposing plants - removing plants from the system to remove nutrients may not be cost-effective since aquatic plants are mostly water - sediment nutrient re-suspension may be significant after the calming effects of plant cover is removed | S, F |
| Water transparency | water transparency affects the amount of and depth to which light penetrates the water column to stimulate submersed plant growth and growth of new emergent plant shoots | generally, submersed plants grow faster in waters with higher transparency with all other factors being equal - conversely, lower transparency can retard growth of submersed plant shoots | S |
| Color / tannic content | highly colored or tannic water limits light penetration and can suppress submersed plant growth | submersed plant recovery after control can be retarded in highly colored or tannic waters - anticipate increased submersed plant control duration | S |
| Turbidity / suspended particles | turbid water limits light and suppresses submersed plant growth | submersed plant recovery after control may be retarded in highly turbid waters - suspended clays and organics can neutralize diquat and fluridone herbicides | S |
| Algal type and concentration | some algal blooms can suppress submersed plant growth either through light attenuation or perhaps allelopathy with blue-green blooms | treating large areas of submersed plants during a planktonic algae bloom may perpetuate or enhance the bloom | S |
| **Sediment characteristics** | | | |
| Composition - sand, clay, organics | sediment type plays an important role in plant growth as well as control, especially chemical options | clay sediments inactivate diquat herbicide, high levels of organic sediments can adsorb fluridone herbicide | S |
| Sediment depth / location | check sediment type and thickness prior to herbicide treatments | thick soft sediment layers can reduce or negate pelletized herbicide formulation efficacy - harvesting in shallow waters above flocculent sediments may result in turbidity problems | S |
| Potential for re-suspension | extensive plant cover, especially submersed plants, can retard organic sediment decomposition or allow suspended particles to settle out of flowing water forming thick flocculent layer | diquat herbicide is inactivated by suspended clay particles - high suspended organic particle content can reduce fluridone herbicide efficacy - removing calming effect of plants (after control) may allow water flow or waves to agitate sediments, especially in shallow waters, re-suspending sediments and associated nutrients - result may be increased turbidity or algae bloom - agitation from harvester paddle wheels can increase turbidity in shallow waters with flocculent sediments | S |
| **Plant physiology** | | | |
| Plant origin/growth characteristics | problem plants in a proposed control area should be characterized as native or exotic, and if exotic, they should be characterized as either a nuisance under the conditions present in the water body, or an invasive species in that region | the invasiveness and extent of the plant in the region influences the intensity of control - ex: a newly discovered plant that may be invasive in waters across the region may trigger eradication efforts - a native plant that interferes with boat ramp access may be beneficial throughout the rest of the water body triggering only local control | E, S, F |
| Native plant | a plant species that evolved in the general region where it is now found | a diverse assemblage of native plants is generally viewed as favorable - native plants do not generally impair natural waters, they may present problems to various uses and functions of the water body on a local scale - problems associated with native plants are often generated by watershed alterations including stabilized water levels and increased nutrient content - plants native to a region can cause problems in man-made waters like shallow canals or aqueducts where presence of any plant species may be considered undesirable or problematic | E, S, F |
| Exotic / alien | a plant that has been transported to a region in which it did not evolve | exotic plants do not necessarily cause problems in the ecosystems in which they have been introduced - causes of problems may be similar to those associated with native plants and therefore may be localized | E, S, F |
| Invasive | a plant that is non-native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health – even if an invasive plant species does not cause problems in one waterbody, it may serve as a contamination source for adjacent waters that may be more conducive to invasion | newly discovered populations of invasive plants should be considered for eradication or containment - delays may allow spread within infested waters or to additional waters - invasive plants may not be invasive in all cases - ex: water milfoil may cause problems in clear, shallow, stabilized waters, but may not be problematic in deep or turbid lakes or reservoirs with widely fluctuating water levels | E, S, F |

**Flashback 2009** — *Looking at Aquatic Plant Management through the Years.*

| | | | |
|---|---|---|---|
| Plant growth stage | plants are susceptible to various control methods based on current weather and growth conditions | most herbicides need actively growing plants to be effective - new growth is generally easier to control with herbicides than mature plants with high starch reserves and larger rhizome / root mass | E, S, F |
| Target plant / non-target | it is important to understand the growth stage of target plants as well as commingled non-target plants | consider cost-effective control measures that selectively control target plants while conserving or enhancing non-target species - evaluate cost-effectiveness of proposed control - ex: controlling a new infestation of hydrilla or Eurasian watermilfoil in two feet of water in an attempt to eradicate may be cost-effective - controlling widely dispersed and established hydrilla in two feet of water where re-growth to the surface may take 1-2 months may not be cost-effective management | E, S, F |
| Plant susceptibility | plants must be susceptible to control tools to avoid wasting valuable time and money | evaluate effectiveness of control tools through literature reviews or contact with managers with similar problems and conditions - plant susceptibility may change from one control event to the next related to such parameters as plant growth stage or water conditions | E, S, F |
| Target plant / non-target | prior to initiating aquatic plant control in systems where a diverse native plant community is desired, it is important to identify non-target plants to develop control programs that conserve or enhance these species | impacts to non-target plants can be reduced through selection of control methods, timing of control, using lowest feasible herbicide rates, and controlling target plants, especially invasive plants, before they become widespread and require large-scale control efforts - ex: stocking sterile grass carp early after an infestation of susceptible plants or reducing plant biomass prior to stocking allows the lowest number of fish to be released lessening non-target plant control | E, S ,F |
| Potential for re-growth | | | E, S, F |
| Target / non-target | control operations may be expensive - evaluate the potential for re-growth for proposed control methods or strategies | consider cost-effective control measures that selectively control target plants while conserving or enhancing non-target species - evaluate cost-effectiveness of proposed control - ex: controlling a new infestation of hydrilla or Eurasian watermilfoil in two feet of water in an attempt to eradicate may be cost-effective - controlling widely dispersed and established hydrilla or EWM in two feet of water where re-growth to the surface may take 1-2 months may not be cost-effective management | E, S, F |
| **Climate** | | | |
| Weather | daily weather conditions<br><br>seasonal weather conditions | rain may wash off herbicides before they are effective - treat early in day during summer months in thunderstorm prone areas - check weather report prior to herbicide applications for wind and rain forecast - several cloudy or rainy days after a large submersed plant treatment with contact herbicides may result in substantial dissolved oxygen reductions<br><br>use caution applying systemic herbicides requiring 2-3 months of contact in areas impacted by tropical or seasonal monsoonal weather - take advantage of winter dieback by controlling plants before they become a problem in spring or summer | E, F, S<br><br>S |
| Light intensity | an important plant growth factor along with temperature | some herbicides' primary breakdown pathway is via photolysis; efficacy may be reduced in the summer or in shallow clear waters - consider with water transparency for predicting submersed plant growth along with herbicide selection and treatment timing - light intensity triggers tuber production in hydrilla | S |
| Water temperature | temperature influences plant growth and the amount of dissolved oxygen in the water column as well as microbial activity important for decomposing plant material and degrading some herbicide compounds | warming winter and spring temperatures can trigger plant growth, important for herbicide uptake especially in submersed plants - warmer water holds less dissolved oxygen than cooler; important for planning size of herbicide treatment and mode of action (fast acting contact vs. slower systemic) | S, F |
| | | | |
| Other considerations | in addition to physical parameters, there are human values to consider when deciding the level of aquatic plant control to attempt on a water body | these influences do not necessarily reflect the level of control that may be achieved, but rather the will of stakeholders to commit to attempting some level of control effort | |
| Cost | value judgment - does the anticipated outcome of controlling or not controlling plants justify expenditure? | the benefits of control must justify control expenditures - control must meet reasonable management objectives, including duration of control, restore or conserve uses and functions of water body, protect public health and safety, etc. | E, S, F |

| | | | |
|---|---|---|---|
| Anticipated amount of control | aquatic plant control is complex and many stakeholders have a rudimentary understanding of available tools and realistic control expectations - the public usually expects control to resolve impaired uses or functions of water bodies - responsible aquatic plant managers and researchers must clearly convey to stakeholders why they select or support control options as well as the anticipated amount and duration of control | management objectives should address anticipated extent of control - control includes the level of impact to the standing crop as well as underground roots, rhizomes, tubers etc. that influence ability of the plant to recover; therefore, control also includes the degree of impact to the problem-causing plant, the time to alleviate impaired uses, and the expected amount of time control will last; i.e. time until water uses may again be impaired | E, S, F |
| Spatial – acres, % of water column | control area includes the coverage of plants to be controlled, expressed in acreage, square meters, etc. - also includes the percent of the water column in which plants are controlled, expressed as percent volume infested - can also include the below ground portion controlled (runners, roots, corms, tubers, etc.) | control using different tools or applied to different plant species provides variable results - managers must select tools that provide a level of control that satisfies management objectives and convey this reasoning or expectations to stakeholders | E, S, F |
| **Duration** | | | |
| Time to achieve control | depending on the method(s), the amount of time to achieve control may be immediate or may take months or longer, if achieved at all | control methods may provide immediate relief of a problem (ex: harvesting adjacent to flood control structures or bridge pilings) or take months (ex: systemic herbicides, biological controls) | E, S, F |
| Length of control in time | the applied control method(s) as well as environmental parameters impact the duration of control achieved - ex: control may be achieved in a matter of a few days to a few weeks, but plants may re-grow to problem levels within a month | control may last a few days to several years depending on method and water body conditions - ex: a summer contact type herbicide treatment of hydrilla or torpedograss growing in 1-2ft of water may only last a few weeks before plants refill the water column while a winter fluridone treatment in 12-15 feet of water may prevent hydrilla from growing back to the water surface for 18-24 months | E, S, F |
| Suppression | includes reducing plant vigor as well as flowering, seed production | many biological controls as well as plant growth regulators stress plants but by themselves may not provide a level of control that meets management objectives or stakeholder expectations | E, S, F |
| **Water body values at risk** | assess various uses of water bodies and estimate economic and environmental costs as well as impacts to human health if plants are controlled or not controlled | assists in establishing management objectives as well as level of control and choosing control options | E, S, F |
| **Alternative water body** | if plant control cannot be achieved in a water body, identify any alternative waters to serve the uses and functions | this is a temporary solution while eradication or management efforts are being devised or applied in a water body - access to the infested water body may be closed during eradication efforts or control delayed in infested waters while higher priority waters are managed, especially if other nearby waters are available - efforts should be made to resume use of water body as soon as possible | E, S, F |
| **Contractor / equipment availability** | ensure availability of contractor and equipment to address all anticipated control possibilities | have back-up labor and equipment contractors available - securing contracts can take time which may be critical for eradication or in emergency situations – large-scale control operations or operations in waters with multiple uses and functions may have very narrow windows of opportunity to implement | E, S, F |
| **Control history in similar waters** | apply control tools or management strategies with proven or demonstrated effectiveness and compatibility with uses and functions of system | monitor efficacy of each control event - determine causes of poor or no control and avoid repeating - for new infestations look to successes or failures with various control options in waters as similar as possible to proposed control site | E, S, F |
| **Coordinate with stakeholders** | control operations should be developed with stakeholders that have expressed interest in understanding the intricacies of aquatic plant control - the public should be notified through some means of any use restriction of impending herbicide control operations | stakeholders may view aquatic plant control and control tools from a single or less than holistic perspective - education and outreach efforts are important in addressing public concerns | E, S, F |
| **Support – verbal, financial, in-kind** | important tiebreaker for waters of equal importance when factors such as funding, technology, contractor availability, or cost/ benefit ratios are insufficient to implement control projects in all water bodies - especially for lower priority uses or waters | work with all stakeholders to clarify management objectives - in low priority management waters, if support is high, then elevate to higher priority than equal priority waters where support is low or stakeholders oppose control | E, S, F |
| Public | level of verbal support from homeowner or public or private stakeholders or associations | for equally ranked control project priorities, public support may elevate control projects, especially above projects where there is no support or open stakeholder opposition to control | E, S, F |
| Agency – federal, state, local | level of verbal, financial, or in-kind service support for controlling aquatic plants | external funding or services may elevate a control project to a higher priority above otherwise equally evaluated projects with no external assistance | E, S, F |

**Flashback 2013 —** *Looking at Aquatic Plant Management through the Years.*



# The Influence of Aquatic Plants on Dissolved Oxygen

## By Erin Bradshaw Settevendemio

There are four essential elements needed by living organisms on Earth: light, nutrients, water, and oxygen. For the foreseeable future, sunlight is in great supply, adding up to about 274 million gigawatt-years of energy per year. Nutrients are found in all living organisms as well as organic soils, and are continually recycled through our ecosystems. As most of us know, 70% of the earth is covered in water, supporting great numbers of organisms across the globe. It seems odd, then, that oxygen is comparatively in such little supply. Our atmosphere is composed mostly of nitrogen, with oxygen constituting only 20% to support life on our planet. Furthermore, this is the availability of oxygen for *terrestrial* organisms; the amount of available oxygen in aquatic environments is approximately 13,500 times *less*, rarely exceeding 0.0015%, or 15 ppm. This relatively low amount of oxygen in water has caused important influences on the evolutionary biology of aquatic organisms such as submersed aquatic plants (macrophytes) and fish. For instance, submersed macrophytes lack the waxy cuticle layer commonly found on terrestrial species, facilitating the diffusion of gases across the plant epidermal layer; many fish species living in low dissolved oxygen (DO) environments are morphologically evolved for surface breathing or have rudimentary lungs.

### Factors That Influence Dissolved Oxygen

As major producers and consumers of DO, autotrophs have substantial influence over the biological community in our fresh waters. Autotrophs are organisms which use sunlight energy to produce sugars, proteins, and fibers. Examples of aquatic autotrophs include macrophytes, phytoplankton, and algae. During the process of photosynthesis in our aquatic environment, oxygen is a by-product that is released to the surrounding water. However, in the absence of sunlight, these organisms switch gears and consume oxygen (respire) and release carbon dioxide as a by-product, sometimes resulting in a depletion of DO concentrations (hypoxia).

There are a number of other factors that influence DO concentrations in the aquatic environment. For instance, water circulation by wave action can increase DO, while stagnation can lower it. The benthic sediment type and organic layer buildup can also lead to DO consumption by bacteria as dead and dying plants are broken down. Finally, DO is negatively correlated with temperature, which causes a decrease in DO as temperature increases. Combined with the natural daily fluctuation of DO caused by plants, these factors ultimately result in compounding effects. Impacts can be severe in late summer, lowering DO to levels unsuitable for many aquatic fauna such as fish and invertebrates (DO <2.0 ppm).

## How Hydrilla Impacts Dissolved Oxygen

Hydrilla (*Hydrilla verticillata*) is a fast-growing, dense aquatic weed found extensively in Florida and throughout the United States. This species provides beneficial habitat for invertebrates and fish species; however, it can also negatively impact water quality. Hydrilla exhibits high complexity due to abundant stem production and branching near the water surface, contributing to a high biomass. This thick floating mat results in very limited water circulation. In addition, the surface mat dramatically decreases sunlight transmission through the water column, limiting DO production via photosynthesis. In late summer when temperatures are high, these combined factors may result in hypoxic conditions.

In a study conducted during the summer of 2012 on Sandmine Lake in Lake County, Florida (Figure 1), dissolved oxygen, temperature, and hydrilla density were monitored in dense hydrilla beds to evaluate how water quality is impacted by the growth of this aquatic weed during summer months. Although our hypothesis was confirmed and we did find complete hypoxia (hypoxia extending through the entire water column) in dense hydrilla beds, we did not find a direct correlation with biomass density or temperature. Biomass was consistently very high throughout summer ($\geq$3.5 kg/m$^2$ dry weight), and temperature peaked in July; however, we did not see hypoxia until August and September. According to our hypothesis, we would have expected to see hypoxia in July when hydrilla density was high and temperature was at a maximum. However, hydrilla density was not significantly higher and temperature was actually lower in September than at the beginning of the summer season (Figure 2).

## Hydrilla Isn't The Whole Story

These results suggest that other factors which influence DO may contribute significantly to the occurrence of hypoxia in dense hydrilla beds. By late summer, day length is decreasing and gradually limiting the time period in which the plants are able to produce oxygen, while increasing the time period of oxygen consumption. The decrease in day length also results in plant senescence; the increase in released nutrients from dying plants promotes filamentous algal blooms on top of dense hydrilla mats, which can also substantially influence dissolved oxygen concentrations.

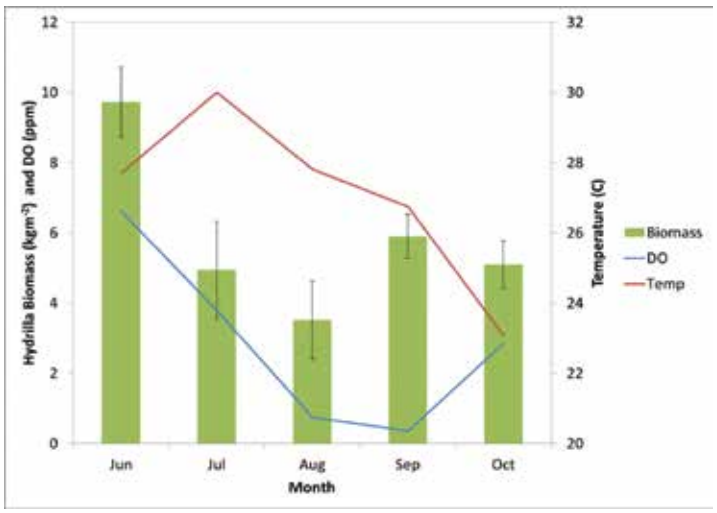



**Figure 2. Hydrilla biomass (kg/m2), dissolved oxygen (mg/L), and temperature (°C) at Sandmine Lake, June – October 2012.**

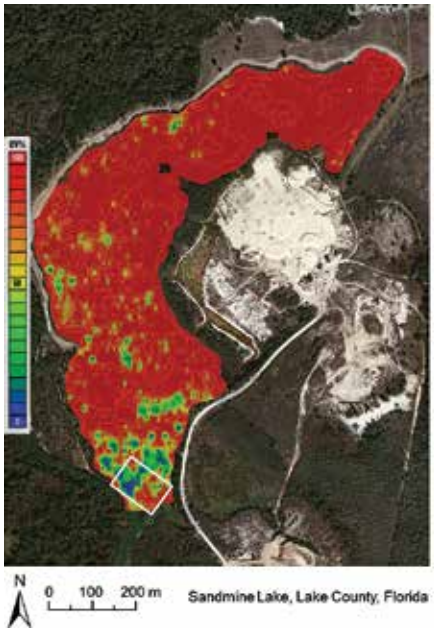



**Figure 1. Sandmine Lake was constructed at a former sandmine operation in the Lake Norris Conservation Area. Its depth ranges from 2–9 meters. Hydrilla coverage is substantial throughout the year, particularly when coupled with mild winters. This map shows surface-matted hydrilla coverage on Sandmine Lake during March 2012. The white box represents the primary sampling area from June through September 2012.**

Although we did find hypoxia in dense hydrilla beds, it was limited to a portion of the day and only at a certain time of year. We did not see fish kills during our sampling periods, even when severe hypoxia (DO <1.0 ppm) extended throughout the water column. Although fish kills do occur occasionally, they are usually caused by compounding factors such as overcast skies, increased water circulation due to wind, and turbidity, which combined with warm temperatures and nightly plant respiration can result in fish kill events. It is also clear that treatment with herbicides during late summer would be hazardous to fish communities, given the additional depletion in dissolved oxygen due to plant senescence.

Our results show that dissolved oxygen dynamics in dense hydrilla are not very different from other submersed aquatic macrophytes, including native species evaluated in other studies. Furthermore, macrophytes such as hydrilla or coontail (*Ceratophyllum demersum*) are probably of better habitat quality for invertebrates and fish compared with floating-leaved species which have lower complexity, prevent wind mixing and light penetration, and can cause prolonged hypoxic events.

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# Distinguishing dreams from reality when using eDNA to detect aquatic invasive plants in lakes

**walpa.org/waterline/september-2020/distinguishing-dreams-from-reality-when-using-edna-to-detect-aquatic-invasive-plants-in-lakes/**


**LAUREN KUEHNE AND JULIAN OLDEN, FRESHWATER ECOLOGY AND CONSERVATION LAB, UNIVERSITY OF WASHINGTON**

The hope and promise of using environmental DNA (eDNA) — where water samples are analyzed for presence of a species' DNA — is alluring, and with good reason. Finding the proverbial needle in a haystack is infinitely easier than detecting a fish, invertebrate, or aquatic plant in a lake or river. Unless it's very abundant, chances are you will miss it! Consequently, tools that can simplify this process, reduce the cost of surveying, or just improve chances of detection are greatly needed. The stakes are even higher in the context of monitoring for invasive species, which require considerable effort and money to manage and control. Aside from prevention, early detection is the best defense, making eDNA a promising and potentially useful tool. In several studies, eDNA has proved equally or sometimes more sensitive than traditional sampling methods, elevating its use to monitor species of high concern such as Asian carp and zebra mussels.

In 2017, we embarked on a research project to assess whether eDNA could be used to detect invasive aquatic plants in lakes. Given that so few studies had been done for plants, we had to start with basic questions:

- "Did it matter if plants were actively growing, or if they were dying off?"

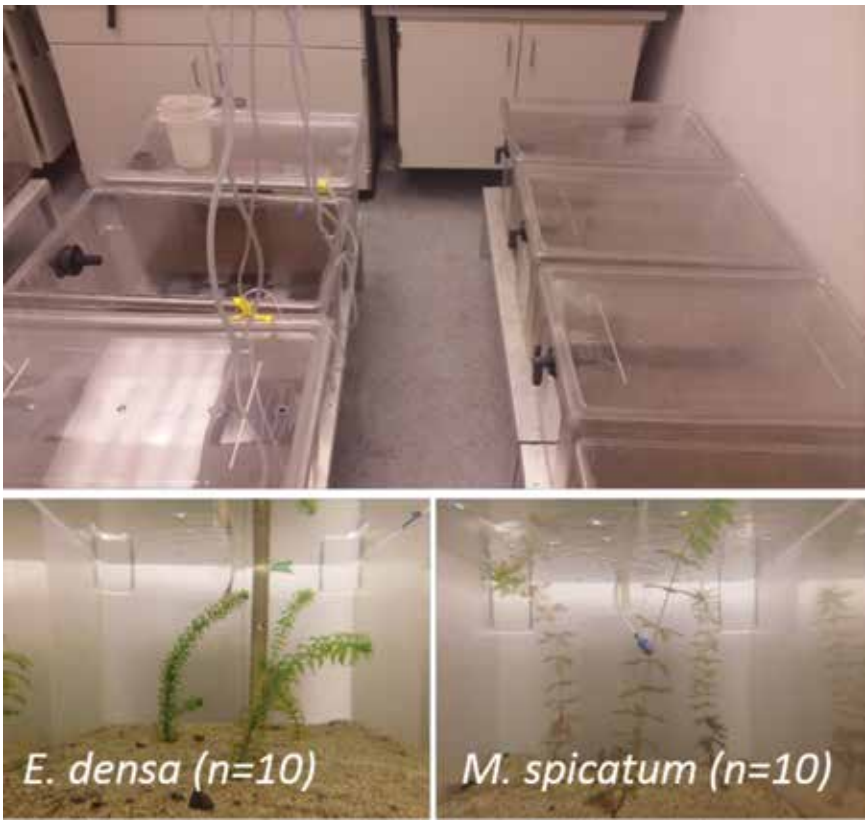


**Figure 1. Mesocosm study where tanks with Brazilian elodea (*Egeria densa*) and Eurasian milfoil (*Myriophyllum spicatum*) were sampled as plants grew and senesced over a 10-week period.**

- "Did detection using eDNA differ between plant species?"
- "How important is it to be close to a plant patch to get a detection?"

The million-dollar question, of course, was "How abundant did plants need to be for eDNA detection to work?"— if the answer was "very," then using eDNA for early detection and rapid response would be problematic.

Supported by a Washington State Department of Ecology Aquatic Invasive Plants Management grant, we implemented the study using both laboratory and field surveys. This combined approach offered the precision and replication afforded by lab conditions to help identify processes, combined with field sampling to allow for a critical real-world reality check. To evaluate how growth stage and species impacted detection using eDNA, we grew two aquatic invasive plants (Brazilian elodea and Eurasian milfoil) in mesocosms over 10 weeks (Figure 1). We collected two one-liter samples from each tank in each week, and partners at the U.S. Geological Survey Western Fisheries Research Center ran assays that they developed for each species. Next, we identified nine lakes in Western Washington that had one or both species present, and varied in plant abundance from those with just a few plant patches up to heavily infested, where plants were present along most of the shoreline (Figure 2). In August, when plant biomass was at its peak, we collected three one-liter samples at four stations in each lake, while mapping presence and abundance of the plants during a visual lake survey. Three of the lakes were also sampled in June and October to assess the importance of sampling timing to detection. Finally, in three lakes, we sampled discrete plant patches, starting at the center and moving outward; this was intended to help answer how important proximity was to detection.

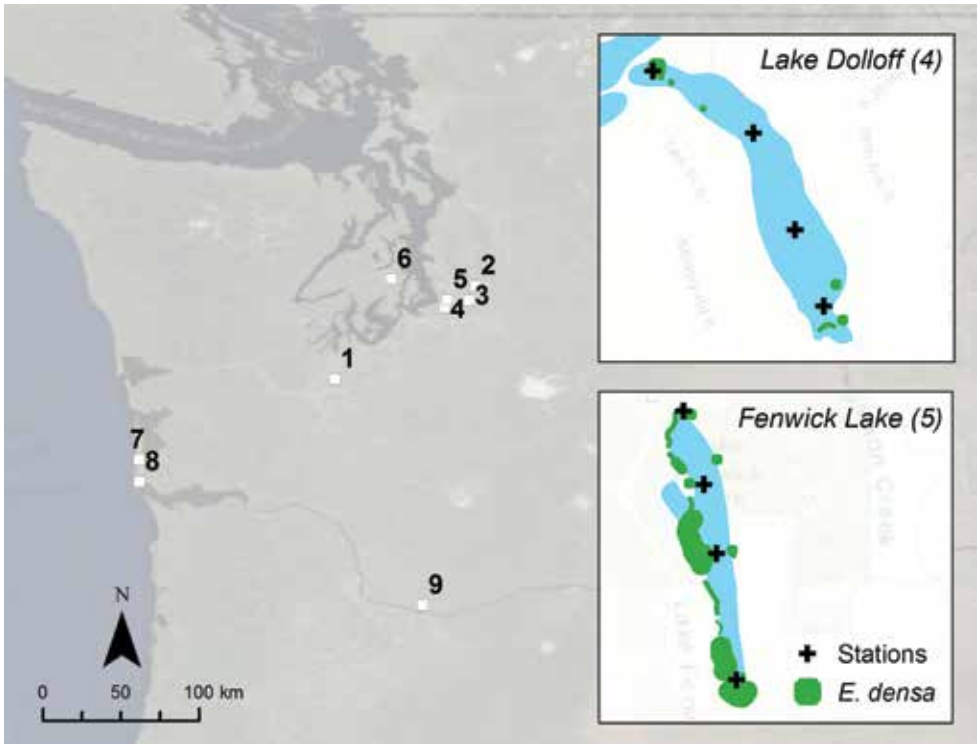


**Figure 2. Study lakes in Western Washington with E. densa and/or M. spicatum. Examples of lakes with low and high plant abundance based on visual surveys are shown in insets. From Kuehne et al. 2020 (1)**

Our results were surprising in many ways. First, although we were able to detect both species using environmental DNA in both laboratory and lake sampling, detection was low compared to what might be expected in a study with animals. Furthermore, as plants grew over the first half of the lab study, detection did not improve reliably, even though there was more biomass in the tanks. The factor that did improve detection was when we turned the lights off after week 5, and plants started senescing. Concentration of eDNA measured in samples was consistently lower for Eurasian milfoil than for Brazilian elodea.

Our field sampling results were highly consistent with the lab results. Based on sampling at four stations, detection using eDNA was reliable only at the highest levels of plant abundance, when plants were effectively found along a majority of the lake shoreline (Figure 3). As in the lab, eDNA concentrations of Brazilian elodea increased by an order of magnitude during fall, when plants were beginning to senesce. And, as in the lab portion of the study, concentrations and detection of milfoil were typically lower than Brazilian elodea, indicating that species may vary considerably in how well eDNA will detect them. Finally, our distance-from-patch sampling showed that being close to patches (and thus the source of eDNA) is important, particularly when overall plant abundance in the lake is low. For example, in a lake with relatively low Eurasian milfoil abundance, the only positive detection was at the edge of the plant patch, even when samples from the center of patches were zero.

Overall, our study showed that much work remains before environmental DNA can be used to detect aquatic invasive plants in lakes. Two of the primary reasons for using eDNA— early detection and evaluation of plant abundance (e.g., following eradication efforts)—are confounded by the problem that detection did not correspond well with plant abundance and was largely unsuccessful unless plants were very abundant. Detection did improve in the fall, indicating that future research might focus on senescence periods. It's also very important to remember that

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fewer than ten aquatic plant eDNA studies have been done to date, meaning the application of this technique for plants is still in its infancy. We believe this study offers a cautionary tale in considering eDNA as a "silver bullet" for early detection of plants, but is also an important base from which to systematically examine ways to improve detection in the future.

*All results, assays, and data from this study are available online (see sources 1-3 below). You can also email the author for more information related to this work at* lauren.kuehne@gmail.com

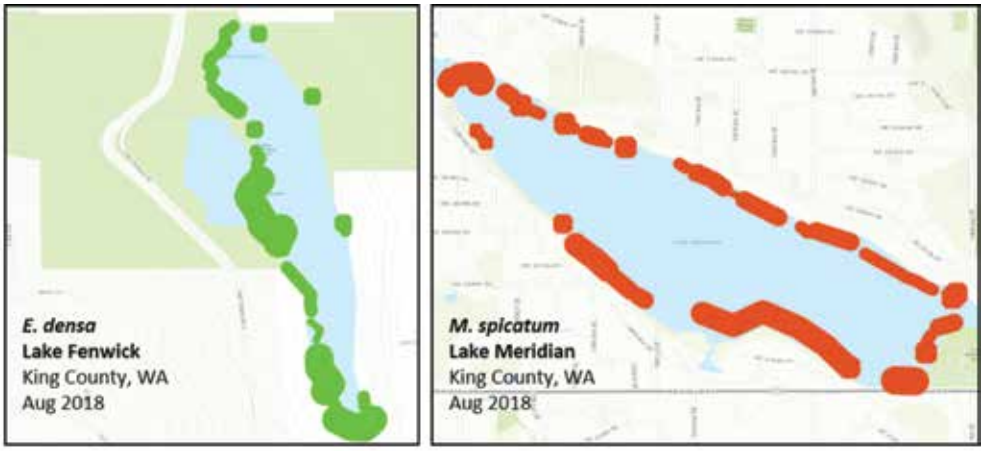


**Figure 3. Examples of mapped abundance of Brazilian elodea (green)and Eurasian milfoil (red) in two high abundance lakes where eDNA wasreliably detected based on sampling at four stations.**

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1. Open Access article of main study and results: Kuehne, L. M., Ostberg, C. O.,Chase, D. M., Duda, J. J., & Olden, J. D. (2020). Use of environmental DNA to detect the invasive aquatic plants Myriophyllum spicatum and Egeria densa in lakes. Freshwater Science , 39 (3), 000-000. https://www.journals.uchicago.edu/doi/full/10.1086/710106
2. Assay for Brazilian elodea: Chase, D.M., L.M. Kuehne, J.D. Olden, and C.O.Ostberg. 2020. Development of a quantitative PCR assay for detecting Egeria densa inenvironmental DNA samples. Conservation Genet. Resour. (2020) DOI: https://doi.org/10.1007/s12686-020-01152-w.
3. Online depository of all laboratory and field sampling data. Ostberg, C.O., Kuehne, L.M., Chase, D.M., Duda, J.J., and Olden,J.D., 2020, Detection of invasive aquatic plants Myriophyllum spicatum and Egeria densa in lakes using eDNA, field and mesocosm data: U.S. Geological Survey data release, https://doi.org/10.5066/P90BVKTO https://www.sciencebase.gov/catalog/item/ 5e386582e4b0a79317df566a

## Regional Updates

### TAPMS UPDATE

- The Texas Aquatic Plant Management Society Annual Conference will be held on November 15-17, 2023 at the Mesquite Convention Center in Mesquite, TX.
- There will be a tour of John Bunker Sands Wetland Center provided on November 15th at 1 pm.
- We are seeking deserving college students currently enrolled in relevant academic programs and who are interested in applying for the $1,500 David Allen Bass Scholarship.
- Interested individuals should check our website with for the latest information: https://www.tapms.org/

# Calendar of Events

**July 24-27, 2023**
**63rd Annual Meeting of the Aquatic Plant Management Society**
Hyatt Regency
Indianapolis, IN
https://apms.org/2023-annual-meeting/

**October 9-11, 2023**
**South Carolina Aquatic Plant Management Society Annual Conference**
Ocean Drive Beach and Golf Resort
North Myrtle Beach, SC
http://scapms.org/meetings.html

**October 16-19, 2023**
**47th Annual Florida Aquatic Plant Management Society Annual Training Conference**
Hilton St. Petersburg Bayfront
St. Petersburg, FL
https://fapms.org/conference/2023-conference/

**October 24-26, 2023**
**42nd MidSouth Aquatic Plant Management Society Conference**
LaGrange, GA
https://msapms.org/conference/

**November 13-17, 2023**
**International Aquatic Plants Group**
Antwerp, Belgium
www.international aquaticplantsgroup.com

**November 15-17, 2023**
**Texas Aquatic Plant Management Society Annual Conference**
Mesquite Convention Center
Mesquite, TX
https://www.tapms.org

**February 26-29, 2024**
**44th Annual Midwest Aquatic Plant Management Society Conference**
Hyatt Regency Downtown
Columbus, OH
https://www.mapms.org/conferences/2024-conference/

**March 18-22, 2024**
**Western Aquatic Plant Management Society Annual Conference**
Las Vegas, NV
https://wapms.org

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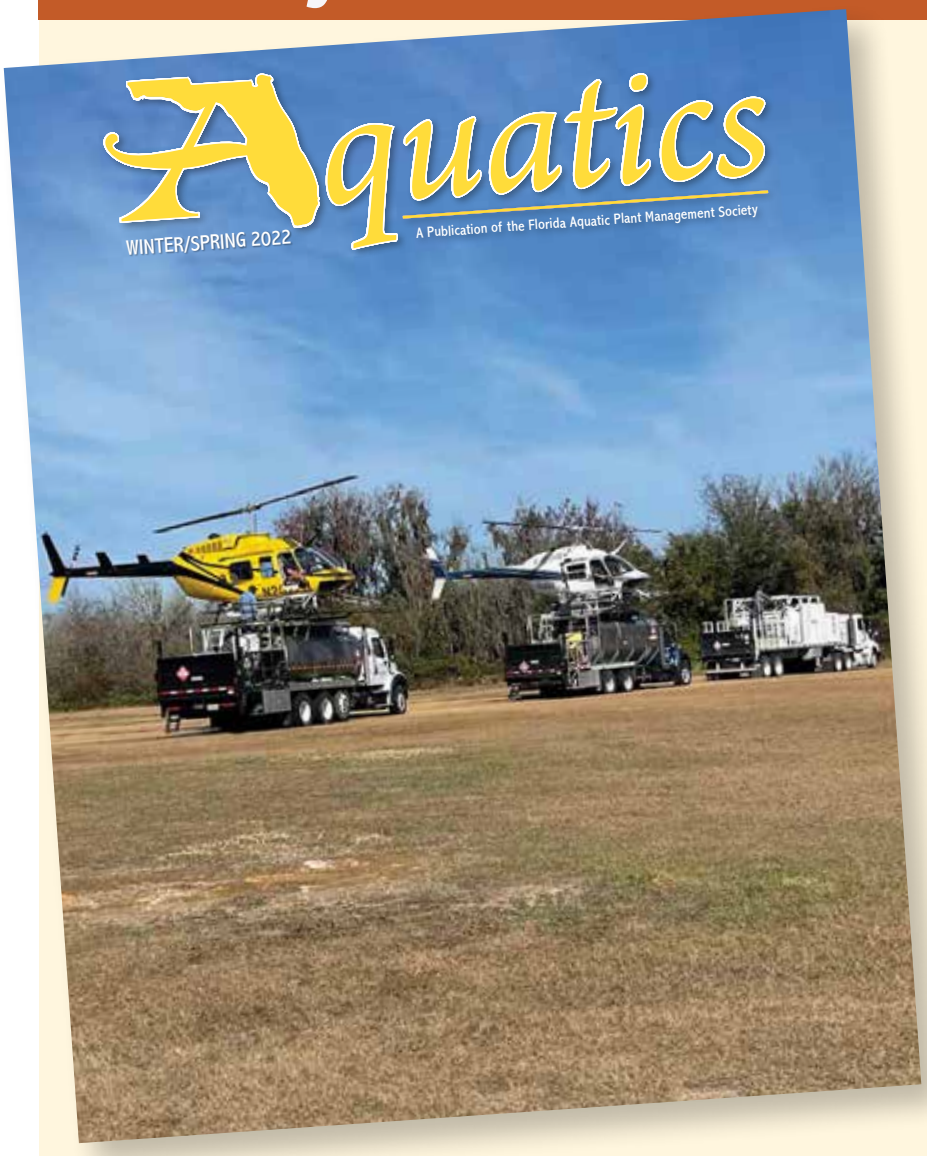


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