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Ecological Effects of Exotic and Native Aquatic Vegetation

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Final report

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Abstract: This report documents a study of environmental conditions and habitat quality of replicated pond ecosystems dominated by populations of exotic plants or mixed communities of native aquatic plants. Study ponds were similar in depth, size, and shape, as well as in (initial) water and sediment composition. The study design called for two phases, the first to evaluate developing plant communities, and the second to evaluate mature plant communities. This report details first year results of developing plant communities.

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Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 33186. The APCRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Research and Development Center (ERDC) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation Number 96X3122, Construction General. Robert C. Gunkel, Jr., EL, was Manager, APCRP. Program Monitor during this investigation was Timothy R. Toplisek, ERDC.

Principal Investigator for this study was Dr. R. Michael Smart, Lewisville Aquatic Ecosystem Research Facility, Ecosystem Processes and Effects Branch (EPEB), Ecology and Environmental Engineering Division (EEED), EL. The report was prepared by Dr. Smart and Dr. Gary Owen Dick, Joe R. Snow, David R. Honnell, Dian H. Smith, and JoEtta K. Smith, all assigned to EEED under an Intergovernmental Personnel Act Agreement with the Institute of Applied Science, University of North Texas, Denton, TX. The report was reviewed by Chetta Owens (ASCI) and Dwilette McFarland (EEED).

This investigation was performed under the general supervision of Mark Farr, Chief, Aquatic Ecology and Invasive Species Branch; Dr. Tim Lewis, Chief, Ecosystem Evaluation and Engineering Division; and Dr. Elizabeth Fleming, Director, EL.

COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
hectares	1.0 E+04	square meters

1 Introduction

The work unit involves a study of environmental conditions and habitat quality of replicated pond ecosystems dominated by populations of exotic plants or mixed communities of native aquatic plants. Study ponds were similar in depth, size, and shape, as well as in (initial) water and sediment composition. The study design called for two phases, the first to evaluate developing plant communities, and the second to evaluate mature plant communities. This report details first year results of developing plant communities.

Objectives

Specific objectives during the first phase were to document water quality and ecological conditions associated with newly established exotic and native plant communities. The research reported herein examined key water quality parameters and populations of fish, other vertebrates, invertebrates, and plankton associated with developing exotic and native plant communities. Sample collection and field observations were periodically conducted for each pond as plant communities developed over a full annual cycle; after one year, ponds were drained and fish removed for measurements. Ponds were compared to identify ecological differences (e.g., differences in water quality, fish population sizes, etc.) that may have occurred relative to dominant plant species. Similar research under the same work unit authority is being conducted on well-established communities of exotic and native aquatic plants.

These studies should provide documentation of possible beneficial aspects of native aquatic plant communities, as well as (possible) adverse water quality and habitat conditions associated with mono-specific populations of exotic species. Harmful water quality and ecological effects on aquatic ecosystems by exotic species require clear demonstration in order to justify continued aquatic plant management efforts.

Background

Aquatic plants are a desirable component of lake and reservoir systems, and often enhance uses of water resources. Aquatic plants improve water clarity and quality (James and Barko 1990) and reduce rates of shoreline erosion and sediment resuspension (James and Barko 1995). Further, aquatic plants provide valuable fish and wildlife habitat (Dibble et al. 1996a; Killgore et al. 1989; French 1988) and serve as a food source for waterfowl and other aquatic wildlife. Native aquatic vegetation also helps prevent spread of nuisance exotic plants (Smart et al. 1994): this role has been of primary interest to the Aquatic Plant Control Research Program (APCRP).

Unfortunately, not all aquatic plants are the same. Most native North American species exhibit growth forms that are beneficial to fisheries and other aquatic wildlife but do not interfere with the use of water resources. On the other hand, introduced species such as hydrilla (*Hydrilla verticillata* (L.f.) Royle) and Eurasian watermilfoil (*Myriophyllum spicatum* L.), herein referred to as watermilfoil, produce dense surface canopies or excessive biomass that may be detrimental to fisheries and water quality, as well as limit recreational access and clog water intakes of water control and distribution structures.

Water quality

Aquatic plants influence a number of water quality parameters, and in turn the ecosystem in which they are found. Uptake of nutrients and other substances, metabolic by-products, and physical structure all play important roles in how plants affect water quality.

Nutrient uptake

Aquatic plants remove nutrients from the water column and sediments, reducing concentrations of compounds such as nitrogen, phosphorus, and potassium. Nutrient uptake is in direct competition with filamentous and planktonic algae, and several aquatic plant species have been used to manage problematic algal species via competition for these nutrients, as well as light and space (Doyle and Smart 1993). Aquatic plants also take up micronutrients, including metals, and can remove some potentially harmful substances from

the water and sediments (Hutchinson 1975; Kamal et al. 2004; Srivastaval et al. 2008). In these respects, aquatic plants are generally considered good for the environment.

Plant metabolism

Photosynthesis and respiration are metabolic pathways undertaken by plants that alter water chemistry. During photosynthesis, carbon dioxide is removed from the water column, resulting in higher pH. The desired range of pH for fish growth and reproduction is 6.5-9.0, and most freshwater fish are capable of adjusting to moderate shifts in pH typically associated with stands of native vegetation. However, in waters heavily populated by dense stands of aquatic plants (or algae), pH often exceeds 9.0 during peak photosynthetic period, and may exceed 10.0 (Smart et al. 1994). In general, pH above 9.5 is stressful to freshwater fish, with the alkaline death point occurring at pH 11.0 (Wurts and Durborow 1992). Changes in pH affect other compounds in a system as well. For instance, increases in pH (due to photosynthesis) can be accompanied by decreases in availability of iron, phosphorus, etc. (Boyd 1979).

A by-product of photosynthesis is oxygen. Quantities of dissolved oxygen produced by algae and moderate densities of aquatic plants benefit fisheries and other aquatic organisms by replenishing supplies removed from the water during respiration. The desirable range for fish growth and survival begins at 5.0 mg/L (Boyd 1979). At prolonged exposure between 1.0 and 5.0 mg/L, fish may survive, but growth slows and fish become more susceptible to bacterial infections. Extended exposure (several hours) below 1.0 mg/L can result in death, and short-term exposure at levels below 0.3 mg/L kills most fish. In some situations, high rates of photosynthesis can cause oxygen to become supersaturated (concentrations are temperature dependent). Fish exposed to supersaturated conditions (110 percent or greater) may suffer gas bubble disease or other maladies and frequently die (Boyd 1979). Supersaturation of dissolved oxygen is frequently associated with algal blooms or excessively dense stands of aquatic plants.

Plants respire, as do animals. This occurs during day and night, and whether or not photosynthesis is occurring. During photosynthesis, plants produce more oxygen than is used for respiration, resulting in

a net gain of dissolved oxygen in the water column during daylight hours. When photosynthesis is not occurring (at night) or occurs at reduced rates (during cloudy conditions), plants continue to use oxygen, thereby contributing to oxygen depletion. This contributes to typical diel fluctuations of dissolved oxygen concentrations: DO concentrations steadily rise during the day, when photosynthesis produces more oxygen than is consumed, and drops at night, when the principal source of replenishment is exchange between the atmosphere and water.

Fish kills due to oxygen depletion are well known. High temperatures and excessive respiration (often associated with high organic content, and thus high decomposition rates) are frequent culprits contributing to reduction in DO concentrations to levels that can kill fish. Dense algae and plant populations may also cause cyclic DO depletion and fish kills. Although all plants contribute to DO reduction at night or under low-light conditions, depletion to levels dangerous for fish is most likely to occur when metabolic activity has become excessive (high biomass) and temperatures are high, a circumstance commonly associated with fast-growing, exotic species such as hydrilla.

Plant morphology and canopy development

Canopy development appears to exacerbate the problem of DO depletion. In open water, atmospheric exchange often keeps oxygen replenished at levels high enough to avert fish kills, at least near the surface. Fish may swim near the water surface, gasping as a means of utilizing oxygen pouring into depleted waters. However, dense plant canopies may effectively reduce gas exchange, functioning as barriers between water and air. Dense surface mats may also physically prevent fish from reaching the surface to gasp for oxygen. This combination frequently leads to fish (and other organism) kills. In ponds at the LAERF, during hot summer months, fish kills are commonly observed in ponds populated by hydrilla or watermilfoil (dense canopy-forming exotics), but not in adjacent ponds containing native communities (less dense-canopy forming natives).

The canopy may contribute to another dissolved oxygen-related problem for fish. Normally, carbon dioxide released during respiration is utilized in photosynthesis or escapes into the atmosphere. Waters that support fish populations normally contain less

than 5.0 mg/L of free CO₂. However, because the canopy may prevent or slow the process of exchange, CO₂ concentrations may increase in waters infested by dense-canopy forming species (Dick and Smart 1997). While fish can tolerate moderately high levels of CO₂ (10.0 mg/L or more), they can only do so provided DO concentrations are also high. As CO₂ levels increase, so increase the minimum concentrations of DO that fish can tolerate (Boyd 1979).

In a community setting, effects of plant morphology (structure, biomass, etc.) are made more complex by the nature of the canopy formed by many plants growing together. As aquatic plants form a surface canopy, light penetration is attenuated, vertical mixing of water is lessened, and atmospheric exchange of gases is impeded. Canopy structure elicits different effects among species exhibiting different growth architectures. As an example, three common species in this study (watermilfoil, hydrilla, and American pondweed, *Potamogeton nodosus*) are discussed below.

Watermilfoil biomass is generally distributed somewhat equally throughout the water column, although during the summer biomass allocation is greatest in the upper portion of stems; stem densities of this species are moderate compared with other submersed macrophytes (Madsen 1993). The result is formation of a moderately dense surface canopy, or mat, extending down to depths approximately 20-30 cm, with a somewhat open architecture below. Under these conditions, metabolic activities such as photosynthesis occur throughout the water column, although at higher rates near the surface, due to higher biomass and shading of deeper water. While atmospheric gas exchange is limited, mixing of the water column still occurs.

Hydrilla exhibits higher biomass throughout the water column during summer and fall, forming dense surface and subsurface canopies, frequently extending down 50 cm or more. Stem densities of this species are usually high, resulting in a closed architecture throughout the water column. Photosynthesis is limited to shallower depths, atmospheric gas exchange is limited, and mixing of the water column is greatly reduced.

American pondweed biomass is relatively low, with most allocated to the upper portion of stems. This species forms mats of floating surface leaves peppered with open water spaces between leaves, while stem densities are relatively low. This results in a surface canopy that does not extend down into the water column, with an open architecture below. Metabolic activities occur throughout the water column, potentially at higher rates below the surface canopy (floating leaves function terrestrially). Atmospheric gas exchange is less limited than by watermilfoil or hydrilla canopies, and mixing of the water column occurs.

Fisheries

Numerous studies have addressed the importance of aquatic plants to fisheries, usually relative to the absence of vegetation or in comparison with other submersed structure (Dibble et al. 1996b). Structure of most types is considered beneficial for fish, although the value of a particular structure may be limited to a narrow range of fish species and size classes. Aquatic plants are generally deemed good for reproduction and survival of some fish species, most notably popular gamefish such as largemouth bass (*Micropterus salmoides* Lacepede) and sunfishes (*Lepomis* spp.) (Killgore et al. 1989). Plants serve as substrates for epiphytic algae, which in turn serve as food for grazing invertebrates. These grazers serve as food for larger predators, including other invertebrates, and are critical as forage for many fish species, particularly in earlier stages of life. Plants also provide cover for small fishes, increasing survival rates and improving population recruitment (Savino and Stein 1983). Larger fish are in turn attracted to plant beds in search of smaller fish for forage.

The range of vegetative cover (aerial) most often given by biologists for optimal shallow water fishery productivity is 15 to 40 percent (Durocher et al. 1984). Less vegetation (or structure) limits cover and associated food items, potentially leading to increased predation on smaller fishes, reducing year class recruitment. Greater than 40 percent provides more cover, and young-of-year fish are less likely to suffer predation. Excessively high survival of smaller fish can result in intense competition for the food supply (Carlander 1977). Growth may be severely limited, and the fishery can become dominated by a stunted year class. In cases such as that of largemouth bass, young fish may be present in high numbers in dense

vegetation, but may not grow to sizes sufficient to survive their first winters (Fullerton et al. 2000).

Estimated optimal aquatic plant coverage does not take into account plant species included in that coverage. Structure and biology of a particular plant species may greatly influence its benefit to a fishery; stem and leaf densities, depths, palatability to grazers, etc., are all factors that may influence a plant's value (Dibble et al. 1996b). For instance, a stand of white water lily (*Nymphaea odorata*) consists of relatively sparse, thick stems and large, floating leaves (one per stem). This type of structure may be valuable as shade (temperature reduction and visibility for fishes) and cover for larger fish, but small fish remain vulnerable to predation when associating with this plant type. On the other hand, Illinois pondweed (*Potamogeton illinoensis*), a submersed species with branching stems and numerous submersed leaves, provides less value as shade but offers an abundance of cover for smaller fishes.

Species diversity of a plant community most likely plays an important role in its value to a fishery. Monotypic stands of plants offer some benefits to some fish, but certain species or size classes will not be able to utilize the habitat. When one component of a fishery suffers, others may as well. For instance, in a monotypic stand of white water lily, larger fish may find sufficient cover to hide from predators to forage efficiently, but the absence of cover for smaller fish may result in a limited food supply for the larger fish. When food supplies are limited, optimal growth (and productivity) will not be achieved, and the habitat value is less than its potential.

A community of variously structured plant species may be of greater value to the fishery than a monotypic stand, regardless of the plant species. A mixture of floating leaves, subsurface leaves, and stems produces various canopy architectures that provide greater structural benefits for a range of fish species and size classes.

Other aquatic organisms

In open waters, planktonic algae are usually the primary producers. However, in shallower waters, aquatic plants may compete directly with algae for nutrients and light (Boyd 1979). Phytoplankton populations are often suppressed in well-established stands of

aquatic plants, and primary productivity is either dependent upon macrophytes and/or periphyton associated with them. Generally, the presence of macrophytes is beneficial in that it reduces the likelihood of noxious algal blooms. However, when surface canopy density and biomass are excessively high, the extent of suppression may limit diversity of phytoplankton, and in turn organisms that depend upon them for food.

Associations between aquatic invertebrates and plants have been documented (Miller et al. 1989). Many aquatic invertebrates are dependent upon plant community (or periphyton that grows on them) for food and cover, which in turn serve as food for fish and other predators (Carpenter and Lodge 1986). In many cases, fish and other aquatic wildlife are dependent upon these invertebrates for the bulk of their diet; without the plants, there would be fewer (or no accessible) invertebrates; without the invertebrates, there would be fewer (or no) fish. Invertebrate densities and composition have been correlated with plant surface area; those species exhibiting greater surface area typically support greater numbers of invertebrates (Balci 2001, Peets et al. 1994). However, greater numbers of invertebrates may not benefit fish: under these same high plant biomass conditions, excessive cover limits availability of prey items (Crouch 1994).

Numerous species of amphibians (frogs and salamanders) are dependent upon water throughout their lives or during reproduction and development, and aquatic plants may afford cover that benefits sustained population recruitment. Although many are more tolerant of low dissolved oxygen concentrations than fish, larval amphibians in static systems must have access to surface waters in order to gulp atmospheric oxygen: such behavior that may be inhibited by the presence of dense surface-canopy-forming species. Some reptiles are also dependent upon aquatic macrophytes for cover, and in some cases for food. Semi-aquatic turtles of the genus *Trachemys*, for instance, are primarily herbivorous as adults (Ernst et al. 1994), with the bulk of their diet consisting of aquatic vegetation. Research has shown that red-eared sliders (*T. scripta elegans*) feed on native plants as well as hydrilla, but shun watermilfoil as food (Dick et al. 1995).

Other considerations

Aquatic plant communities are important to other aspects of lake and reservoir functions. Again, differences in composition and structure of plant communities influence whether plants are beneficial or detrimental to these functions. Functional and recreational uses of lakes are generally not negatively impacted by moderate stands of aquatic plants. In fact, these uses are often enhanced by improvement in water quality and fisheries brought on by the presence of plants. On the other hand, dense stands of canopy-forming species can cause severe problems for access by boat, swimmers, and other recreational uses. Additionally, large mats of hydrilla, watermilfoil, and the free-floating water hyacinth (*Eichhornia crassipes*) may periodically break free, causing clogs in water intake and water level control structures. These phenomena most often cause lake managers to initiate some aquatic plant control action.

2 Methods

Study site

The study was conducted at the Lewisville Aquatic Ecosystem Research Facility (LAERF) in Lewisville, Texas (latitude 33°04'45"N and longitude 96°57'33"W). The facility is located along the boundary of the Eastern Cross Timbers, Fort Worth Prairie, and Blackland Prairie vegetation regions (Gould 1975, Diggs et al. 1999) of Denton County and is within the Trinity River basin. The LAERF comprises 53 earthen, clay-lined ponds ranging from 0.2 - 0.8 ha and averaging 1 m deep (Figure 1). Ponds were constructed in the 1950's with clay liners overlaid by sandy-loam topsoil, and were used as gamefish production ponds until 1985. Water to the ponds is gravity-fed from Lake Lewisville in Denton County, Texas.

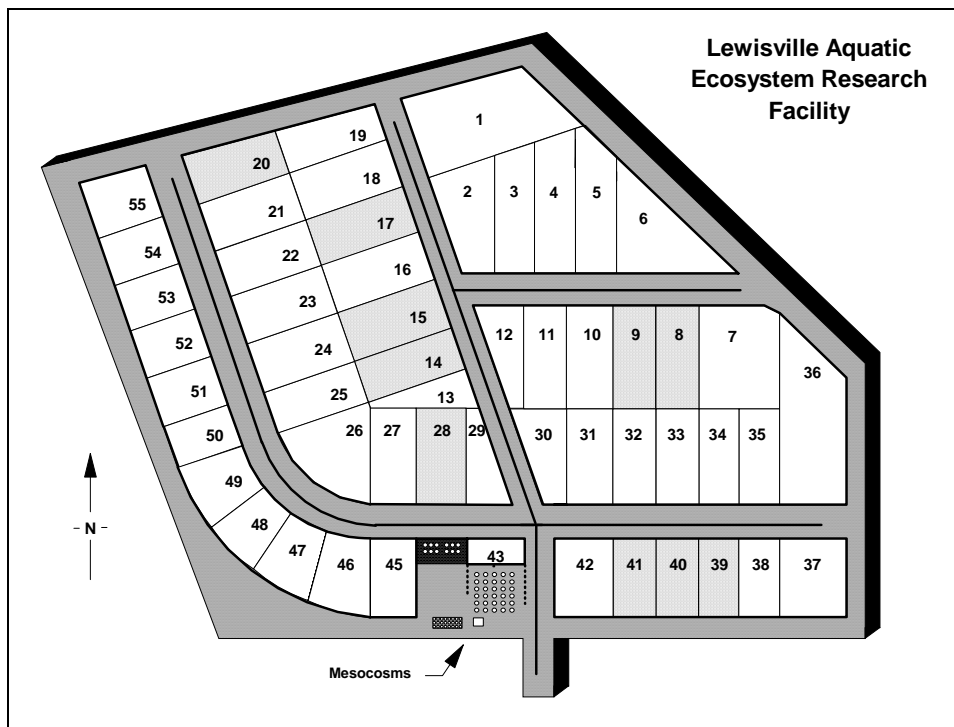


Figure 1. The Lewisville Aquatic Ecosystem Research Facility, Lewisville, Texas is comprised of 55 earthen ponds.

Study design

Three aquatic plant population structures were examined, including one dominated by hydrilla and one dominated by watermilfoil, with

pond margins of both dominated by jointgrass (*Paspalum distichum*). The third population was comprised of a mixed group of native species, including American pondweed (*Potamogeton nodosus*), Illinois pondweed (*P. illinoensis*), wild celery (*Vallisneria americana*), water stargrass (*Heteranthera dubia*), southern naiad (*Najas guadalupensis*), horned pondweed (*Zannichellia palustris*), muskgrass (*Chara vulgaris*), and white water lily. Marginal species in these communities included jointgrass, bulltongue (*Sagittaria graminea*), softstem bulrush (*Scirpus validus*), several spikerushes (*Eleocharis* spp.), tall burhead (*Echinodorus berteroï*), and pickerelweed (*Pontederia cordata*). In most cases, small populations of cattails (*Typha latifolia*) had become established along the margins of ponds by the end of the study.

Plant establishment

Establishment of plant communities began in summer (July) 1999. Ten ponds were prepared to establish plant communities dominated by one of three groups: hydrilla, watermilfoil, or a community of native species. Three replicates of hydrilla (herein referred to as hydrilla ponds) and watermilfoil (herein referred to as watermilfoil ponds), and four replicates of native species (herein referred to as native ponds) were used in the study. Pond preparation included draining, mowing, fertilizing, and rototilling. Wooden piers were constructed and installed to provide access to water 1 m or greater in depth without disturbing the plant communities.

Three ponds (39, 40, and 41) were selected for establishment of watermilfoil based upon having been previously infested with the species and possibly containing viable seed banks. Fertilizer (ammonium sulfate) was added at a rate of 560 kg/ha and rototilled into a depth of 10-15 cm. The ponds were flooded in August 1999, and apical tips of watermilfoil were planted on 3-ft centers over approximately 75 percent of each pond. Native species seed banks were present in these ponds, and LAERF ponds typically become dominated by either southern naiad or muskgrass soon after flooding, with American pondweed eventually becoming the dominant species. In ponds similarly planted with watermilfoil during previous LAERF studies, watermilfoil achieved dominance over native plants by early spring.

Three ponds (8, 9, and 20) were selected for establishment of hydrilla based upon having been previously infested with hydrilla. The presence of hydrilla tubers in these ponds was thought to be sufficient to result in a plant community dominated by hydrilla. Fertilizer (ammonium sulfate) was added at a rate of 560 kg/ha and rototilled into a depth of 10-15 cm. The ponds were flooded in August 1999 to promote sprouting of hydrilla tubers; native species seed banks were present in these ponds. In ponds with hydrilla tuber banks, however, hydrilla usually achieves dominance by early summer.

Four native ponds (14, 15, 17, and 28) were chosen for having not been previously infested with hydrilla or watermilfoil, but containing seed banks of southern naiad, muskgrass, American pondweed, slender pondweed, horned pondweed, bulltongue, and flatstem spikerush (*Eleocharis macrostachya*). Fertilizer (ammonium sulfate) was added at a rate of 560 kg/ha and rototilled into a depth of 10-15 cm. The ponds were flooded in August 1999, and potted plants were installed to diversify and supplement the native community developing from the seedbank. Species additionally planted in native ponds included Illinois pondweed, wild celery, elodea, water star-grass, water hyssop, tall burhead, creeping burhead, pickerelweed, squarestem spikerush (*Eleocharis quadrangulata*), bulltongue, softstem bulrush, and white water lily. Figure 2 provides the planting design for each native pond.

Water management

Water levels were maintained throughout the study period by allowing low flow into each pond, with excess draining through standpipes. Occasional low and high water periods occurred, but none exceeded 20 cm (Figure 3). Water supply outlets were screened to prevent wild fish from being introduced into the ponds, and outflow pipes were screened to prevent escape by exotic plants and stocked fish.

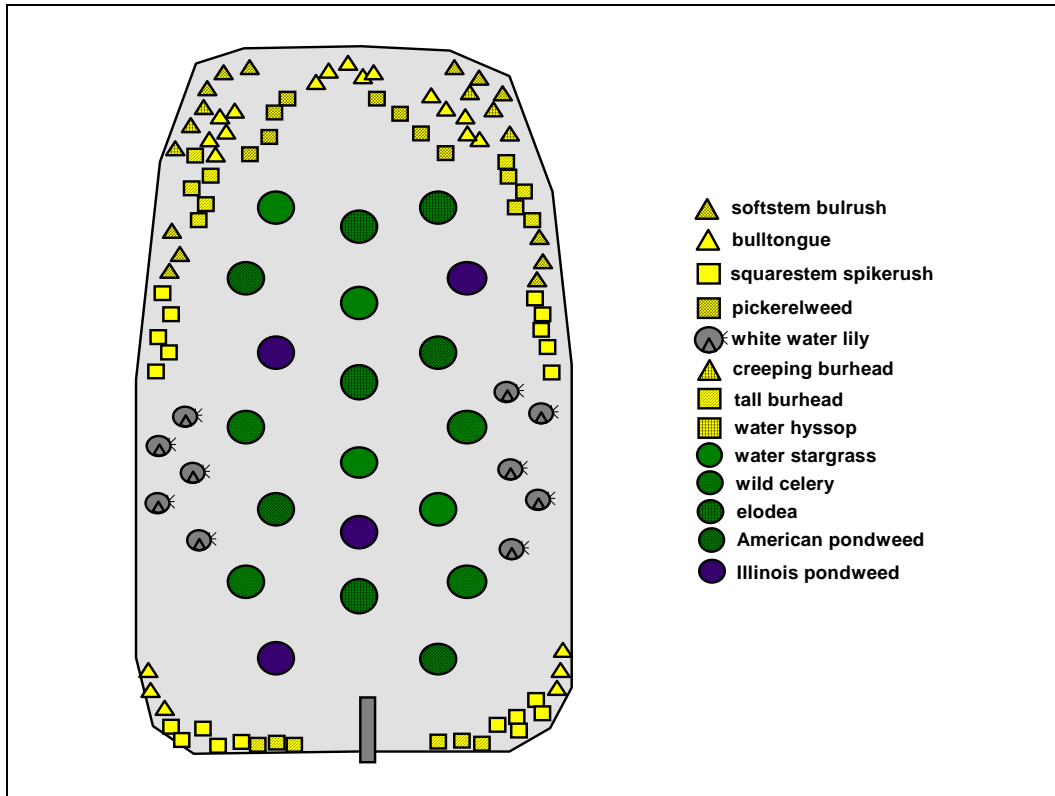


Figure 2. Planting was used to supplement developing native plant communities in four ponds.

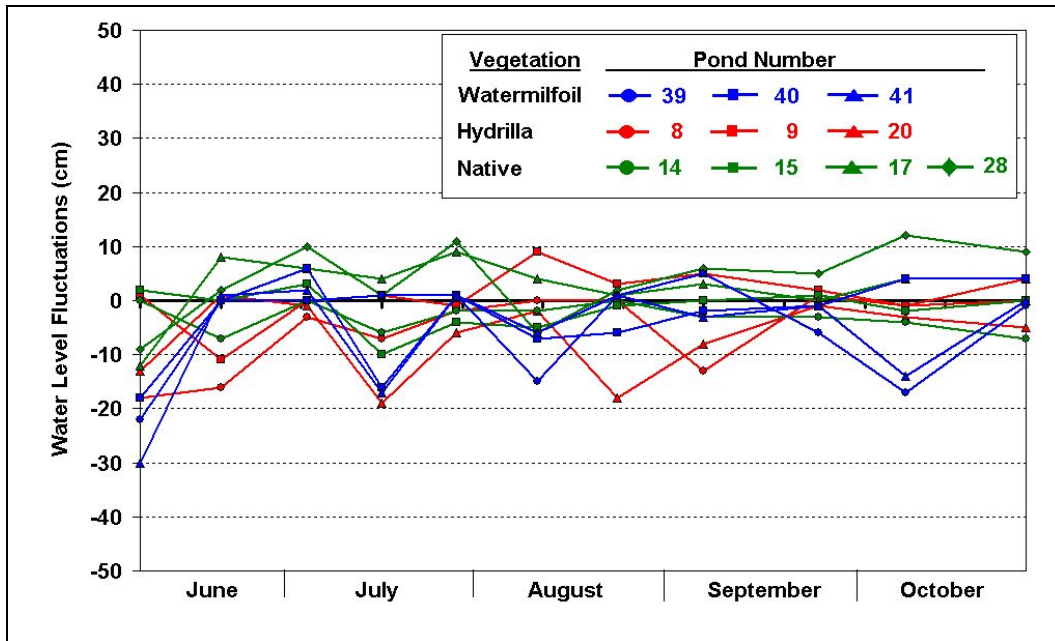


Figure 3. Water levels in study ponds did not vary by more than 20 cm.

Fish population establishment:

Fish were stocked in each pond to evaluate effects of hydrilla, watermilfoil, and native plants on fish community development (Table 1). The Texas Agriculture Extension Agency recommends stocking unfertilized ponds at rates of approximately 60/ha adult bluegills (7.5 cm or greater in length) in the fall or winter, followed by 120/ha juvenile bass in the late spring to early summer. Timing of stocking in this study varied from this recommendation based upon availability of juvenile bass during the fall, which permitted stocking at that time. Northern strain largemouth bass (*Micropterus salmoides*) juveniles were stocked in September 1999 at a rate of 120 per surface ha. The parent stock of these fish was obtained from Lake Lewisville several years prior. Average total length (TL) and weight of these bass at stocking was 72.8 mm and 3.4 g, respectively. Adult (10-cm minimum total length) bluegills (*Lepomis macrochirus*) were stocked at a rate of approximately 15 pairs per hectare. In theory, juvenile bass feed on invertebrates until reaching piscivorous size, when their diet shifts to young-of-the-year bluegills produced the following spring.

Table 1. Pond sizes and stocking rates of juvenile largemouth bass (*Micropterus salmoides*) and adult bluegills (*Lepomis macrochirus*) approximated those recommended by the Texas Agriculture Extension Agency.

Pond	Planted Species	Surface Area (ha)	# Largemouth Bass	# Bluegill Pairs
39	Watermilfoil	0.25	30	5
40	Watermilfoil	0.25	30	5
41	Watermilfoil	0.25	30	5
8	Hydrilla	0.26	33	7
9	Hydrilla	0.26	33	7
20	Hydrilla	0.26	33	7
14	Native	0.26	33	7
15	Native	0.30	38	8
17	Native	0.30	38	8
28	Native	0.30	38	8

Sampling and analyses

Five general parameters were sampled during the study: plant communities, water quality, fish communities, plankton communities, and invertebrate communities. Water quality was monitored biweekly; plants, invertebrates and plankton were sampled every six or eight weeks; fish were sampled at the conclusion of the study, one year after being stocked. Data were also periodically collected on vertebrates (birds, reptiles and amphibians) associated with each pond.

Plant community distribution and canopies

Spatial distribution, species composition, and area coverage of submersed and floating-leaved plants in each pond were monitored over the study period. Six permanent transect locations were established at 20-m intervals along each pond using t-posts installed at the shoreline. Polypropylene ropes, marked at 1-m intervals, were anchored at each position, and all species present throughout the water column were noted along each transect line. Line-transect observations of all species (Madsen 1993) were made at four times during the 2000 season in June (13-16), July (12-13), August (22-24), and October (21-27). These data were used to determine changes in species composition and dominance over the growing season. Dominance was considered to have occurred when frequency of watermilfoil, hydrilla, or native plants exceeded 50 percent.

A final survey to verify spatial distribution of all species was conducted at the end of the growing season using GPS mapping. After draining the ponds, the location of each species or mixture of species was traversed with a hand-held GPS unit, and maps were generated showing plant distribution in each pond. These maps are provided in Appendix A.

Plant canopy characterization

Canopy biomass and volume were compared among the most common species encountered in the study. Watermilfoil, hydrilla, American pondweed, and southern naiad mixed with muskgrass were collected from established plant communities growing in ponds from 70- to 100-cm deep. Quadrats (0.1-m²) were randomly placed on

topped out vegetation (or nearly topped out in the case of the southern naiad-muskgrass composite), and plant material in the top 25 cm of the water column was collected, consistently swirl-dried, and measured for fresh weight. A 2000-L flask was filled to a recorded level, biomass samples were added, and the resultant displaced water was used to ascertain plant material volume. Biomass samples were then dried at 55 °C to constant weight. Dry biomass measurements were made, and compared among species using a one-way analysis of variance (ANOVA) followed by a means separation test (Tukey's, $\alpha = 0.05$). Highest ranks were assigned to species exhibiting highest canopy biomass, and line-transect data were manipulated to reflect dominant species within each interval. Dominance was considered to have occurred when frequency of hydrilla, watermilfoil, or native plants exceeded 50 percent. Spearman rank correlations ($\alpha = 0.05$) were applied to these data to establish statistical grouping of ponds based upon dominant plant species.

Surface canopies can block light penetration and gaseous exchange with the atmosphere, both of which may be ecologically deleterious. Although any surface canopy-producing species may have impacts, those species that produce dense surface canopies (such as hydrilla and watermilfoil) are most likely to cause problems. To characterize differences among plant canopies of different species, percent irradiance was measured at several depths every six weeks by analyzing photosynthetically active radiation (PAR) through the water column and plant canopy with a Licor, spherical quantum sensor. Light transmission data were collected at the surface and at 25-, 50-, 75-, and 100-cm depths.

Water quality

Measurements were made between May 30, 2000 and October 31, 2000. Temperature (°C), dissolved oxygen (DO as mg/L), and pH (units) were monitored hourly on a semi-continuous basis using Hydrolab® datasondes. Datasondes were deployed concurrently in three ponds (one of each vegetation type) and moved every two weeks to a randomly selected pond set (one of each vegetation type). Two datasondes were deployed in each pond to collect data at two depths, 25 cm and 75 cm.

Conductivity ($\mu\text{S}/\text{cm}$), alkalinity (mg/L as CaCO_3), turbidity (NTU), total suspended solids (mg/L), chlorophyll *a* (mg/L), total phosphorus (mg/L), soluble reactive phosphorus (mg/L), nitrate nitrogen (mg/L), ammonia nitrogen (mg/L), sodium (mg/L), potassium (mg/L), calcium (mg/L), and magnesium (mg/L) were measured every two weeks. A single water column sample (from the surface to 15 cm above the pond bottom) was collected from each pond using an integrated sampler (Figure 4). Samples were collected between 9:00 am and 11:00 am from the same order of ponds to reduce variability due to diel fluctuations.

Water was transferred to a bucket and mixed, with temperature, dissolved oxygen, pH, and conductivity ($\mu\text{S}/\text{cm}$) measured; mixed water was then distributed to sample bottles. Samples were processed as either raw water, filtered through 0.45- μ membrane filters, or acidified and put on ice, and analyzed within the periods allotted for hold times (Clesceri et al. 1995) (Table 2). Quality control and quality assurance methods were followed: samples were replicated in the field at a rate of 10 percent, and were split in the laboratory for duplicate analyses at the same rate. Percent recovery was performed on each analysis by means of sample spikes with a known standard concentration.

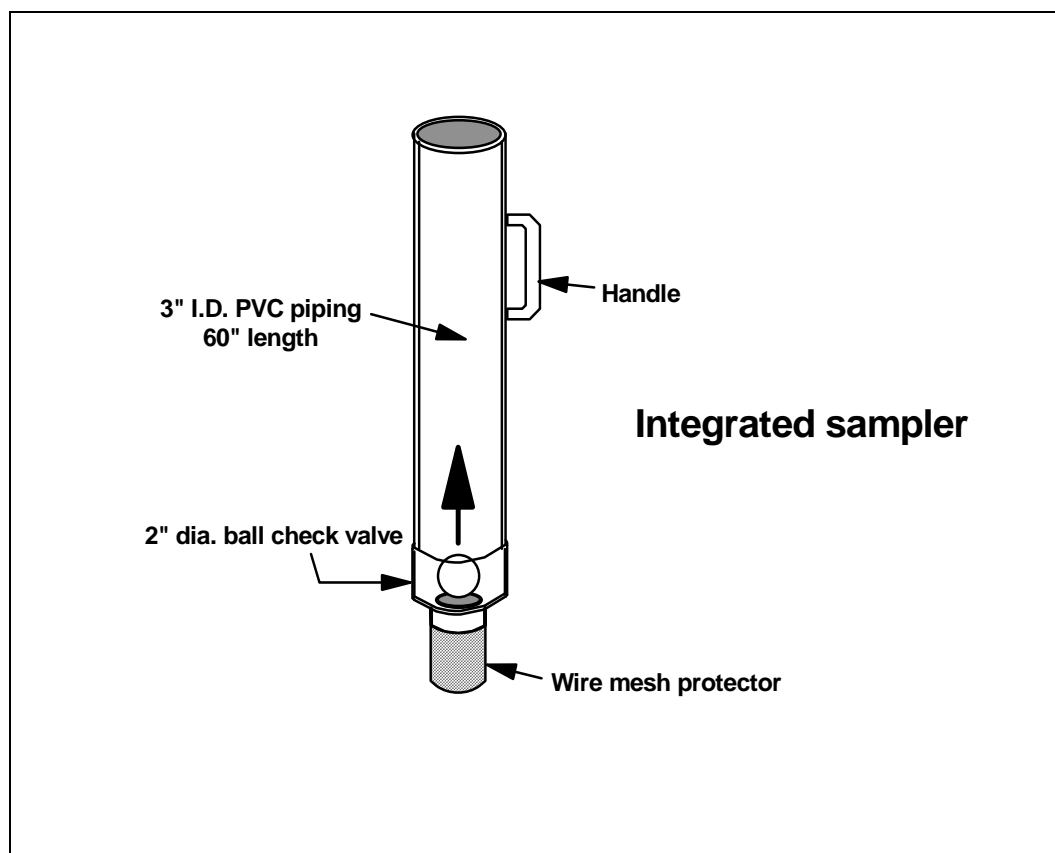


Figure 4. An integrated water sampler was used to collect a column of water from the surface to approximately 15 cm above pond bottoms.

Table 2. Sample preparation, preservation, and analytical methods used for water analysis following *Standard Methods* (Clesceri et al. 1995).

Parameter	Sample Type	Bottle	Preservation	Hold Time	Method
Alkalinity	Raw	Plastic 500-mL	Refrigeration	<24 h	Electrometric titration
Total Suspended Solids	Raw	Plastic 500-mL	Refrigeration	<7 d	Evaporation at 105 °C
Turbidity	Raw	Plastic 500-mL	Refrigeration	<24 h	Nephelometric
Chlorophyll <i>a</i>	Raw	Dark plastic 1L	Refrigeration	<30 d	Spectrophotometric
Total phosphorus	Raw	Plastic 250-mL	Acidification	<48 h	Spectrophotometric
Ammonium nitrogen	Raw	Plastic 250-mL	Acidification	<48 h	Specific ion electrode
Soluble reactive phosphorus	Filtered	Plastic 175-mL	Refrigeration	<48 h	Spectrophotometric
Nitrate nitrogen (NO ₃ -N)	Filtered	Plastic 175-mL	Refrigeration	<48 h	HPLC
Metals (Na, K, Ca, Mg)	Filtered	Plastic 30-mL	Acidification	< 6 m	AA spectroscopy

Plankton

Plankton communities were sampled approximately every six weeks (beginning in June) to ascertain densities for comparison among aquatic plant communities. Three surface grab samples (10 L each) were collected from each pond at the 1-m depth and concentrated to approximately 100 mL by pouring through standard #25 Wisconsin plankton nets. Samples were immediately preserved in Lugol's solution. Each sample was passed through 0.45-millipore membranes for identification (Bold and Wynne 1978, Prescott 1978) and enumeration under dissecting and compound microscopes at low magnification (up to 40X). Microscope calibration and counting techniques (natural unit count) follow those given in Standard Methods (Clesceri et al. 1995). One-way analysis of variance ($\alpha=0.05$) was performed on counts to compare phytoplankton and zooplankton counts among ponds. When differences were detected, Tukey's comparison of means was performed to identify and group statistically similar ponds.

Macroinvertebrates

Macroinvertebrates swimming near or attached to macrophytes were collected on three occasions (early June, late July, and early November) during the study. Samples were collected from four stations within each study pond at 0.5-m depths: a sample consisted of a single 2-m-wide sweep at mid-depth with a D-shaped dip net having a 0.062-m² opening and a 1-mm mesh. Samples were preserved in alcohol and later sorted, identified to a reasonable taxonomic level (Merritt and Cummins 1984; Pennak 1978, Needham and Needham 1962) and counted. One-way analysis of variance ($\alpha=0.05$) was performed on counts to compare macroinvertebrate populations among ponds over time. When differences were detected, Tukey's comparison of means was applied to identify and group statistically similar ponds.

Fish

Ponds were drained and fish harvested at the end of one year (November 2000). Fish were measured for standard length (SL) and weight; relative weights (Wr) of fish were calculated from these data. All largemouth bass and adult bluegills (1 year or older) were

collected from the ponds and measured, providing data to compare survival, growth, and productivity. Young-of-the-year bluegills were counted, and subsets were taken to attain measurements and calculations. One-way analysis of variance ($\alpha=0.05$) was performed on these measurements to compare fish populations among all ponds. When differences were detected, Tukey's comparison of means was applied to identify and group statistically similar ponds.

Other vertebrates

Ocular surveys of birds, reptiles, and amphibians associated with the study ponds were made biweekly beginning in May 2000 and ending November 2000. Species were identified in the field and counts recorded. Statistical analyses were not performed on these data.

3 Results and Discussion

As plant communities developed during the course of the year, differences in water quality and associated populations (planktonic, macroinvertebrate, and vertebrate) became apparent. In several cases, ponds planted for dominance by hydrilla, watermilfoil, or native plants did not support intended communities by the end of the study. These differences are addressed in the following sections.

Environmental conditions

Air temperature averages for June, July, August, September, and October 2000 were 27.5, 30.8, 32.4, 27.0, and 21.0°C, respectively (Figure 5), averaging 2.5°C above normal. A maximum temperature of 44°C occurred on September 4, 2000, while a minimum temperature of 4°C occurred on October 9, 2000. The most significant drop in air temperature occurred on September 24, 2000.

Precipitation averaged 2.0 cm below normal between June and October 2000 (National Weather Service 2000). Rain occurred on 13 days during the month of June, for a total of 15.1 cm, with a maximum of 4.6 cm on June 10 (Figure 6); total rainfall was 7.5 cm above normal for June. No precipitation occurred from July 1 through September 24, 2000. A total of 0.4 cm occurred in late September, and a total of 11.1 cm occurred in October.

Plant communities

After planting in summer of 1999, study ponds were generally developing plant communities consistent with desired experimental conditions. Beginning in spring 2000, line-transect surveys were conducted and the frequency of occurrence of each species observed was tabulated and compared. These data showed dominance by target species in most ponds during and by the end of the study period.

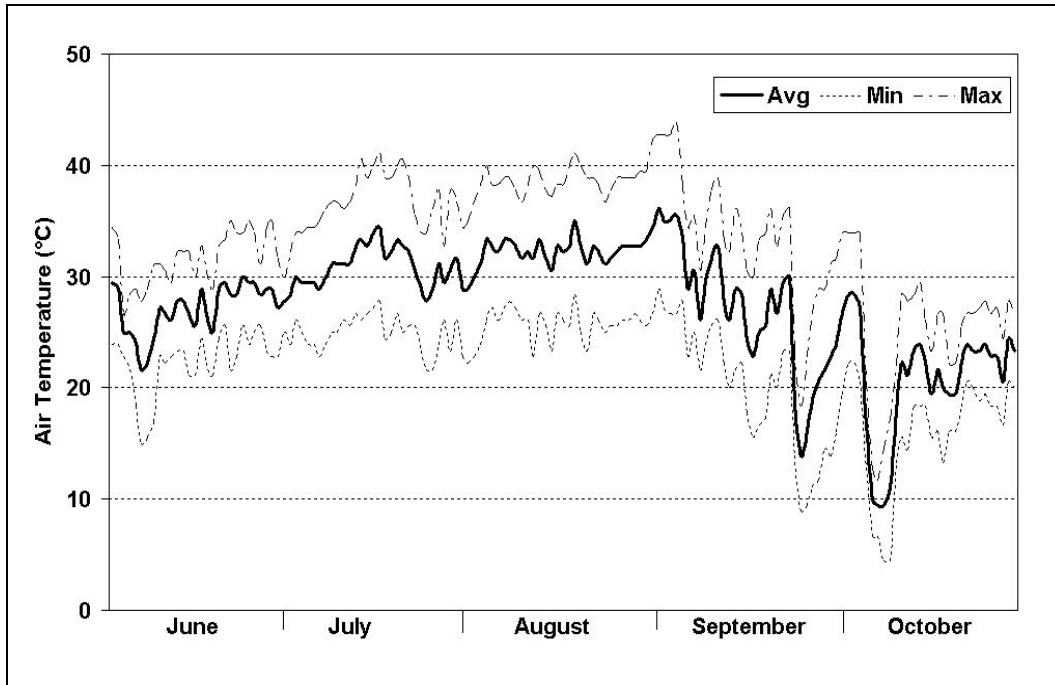


Figure 5. Air temperatures in North Central Texas during the study period averaged 2.5 °C above normal.

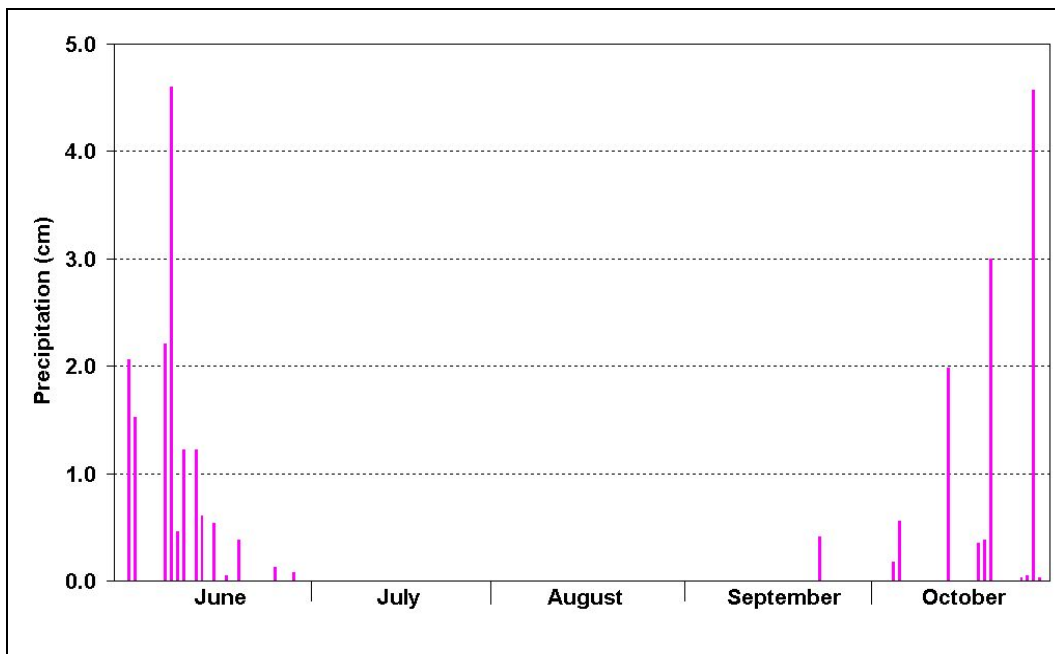


Figure 6. Precipitation in North Central Texas during the study period was typical for the region.

Species composition and dominance

When exotic macrophytes dominate a body of water, they can displace native vegetation, thus reducing species diversity. In hydrilla and watermilfoil ponds, plant communities generally became monocultures of exotics, while some diversity of submersed plants was maintained in native ponds. Species richness among the study ponds was affected by initial planting schemes. Submersed and emergent species in watermilfoil and hydrilla ponds were generally limited to a few species that typically occur in LAERF ponds without deliberate introduction, including American pondweed, southern naiad, muskgrass, flatstem spikerush, and jointgrass. Because native ponds were planted with additional submersed, floating-leaved, and emergent species, diversity was higher. Species richness remained highest among all macrophyte types in the native ponds at the end of the study (Figure 7).

Species dominance was also influenced by planting and incidental species occurring in ponds. As the growing season progressed, canopy development beyond shoreline communities diverged in composition among ponds, thus warranting scrutiny. The following analyses focus on the submersed plant community dynamics in the study ponds.

In ponds targeted for dominance by watermilfoil (39, 40, and 41), the native species southern naiad and muskgrass were observed at high frequencies early in the season (Figure 8). American pondweed was also present in these ponds, with the highest frequency occurring in pond 39. As the growing season progressed, watermilfoil frequency increased in ponds 40 and 41, and by October was the dominant species in those ponds.

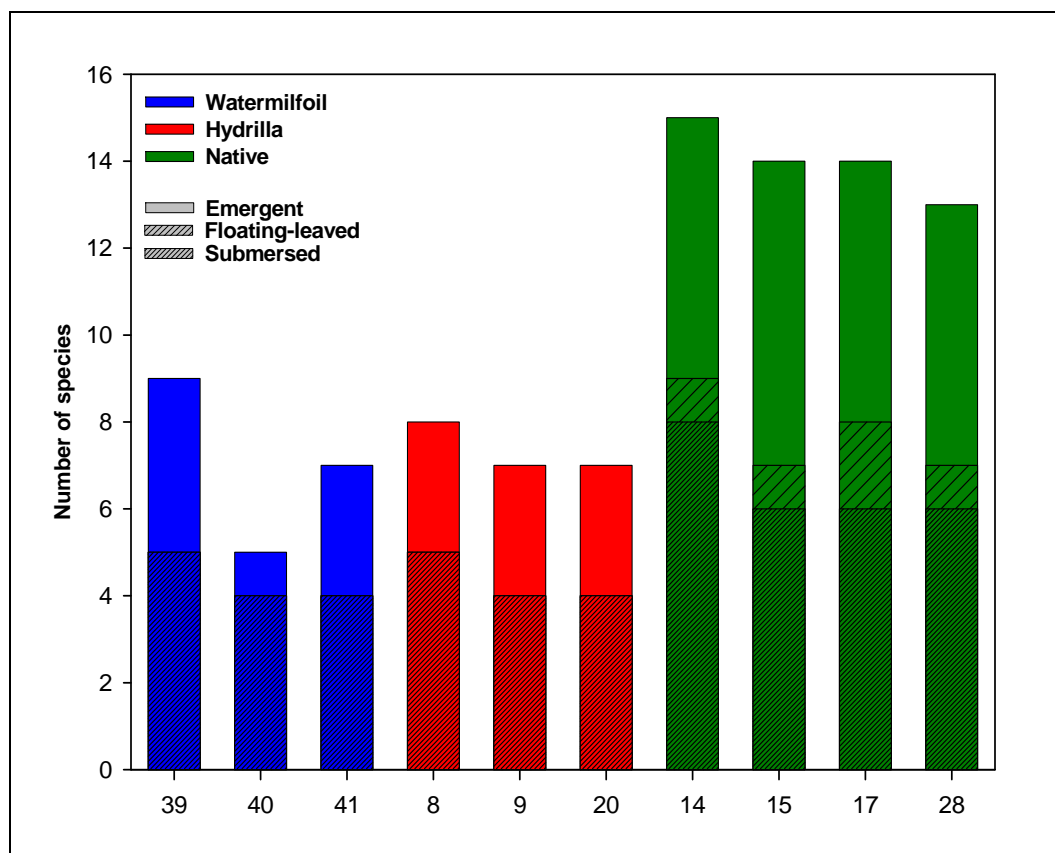


Figure 7. Species richness was highest in native ponds for all vegetation as well as submersed, floating-leaved, and emergent growth forms.

In pond 39, American pondweed frequency increased, and by October, a substantial hydrilla population had developed: by the end of the study, watermilfoil was no longer the dominant species in that pond. American pondweed was expected to occur in all study ponds (growing from seed and tuber banks), but exotics such as watermilfoil and hydrilla that typically out-compete native species (at LAERF) in this case did not. Hydrilla was possibly introduced from an adjacent pond by herons, turtles, or nutria.

In ponds planted for hydrilla dominance (8, 9, and 20), muskgrass and southern naiad were dominant early in the season (Figure 9). However, by October hydrilla had substantially developed in all ponds and achieved dominance. American pondweed generally increased in frequency throughout the season (southern naiad and muskgrass were evidently outcompeted by both hydrilla and pondweed).

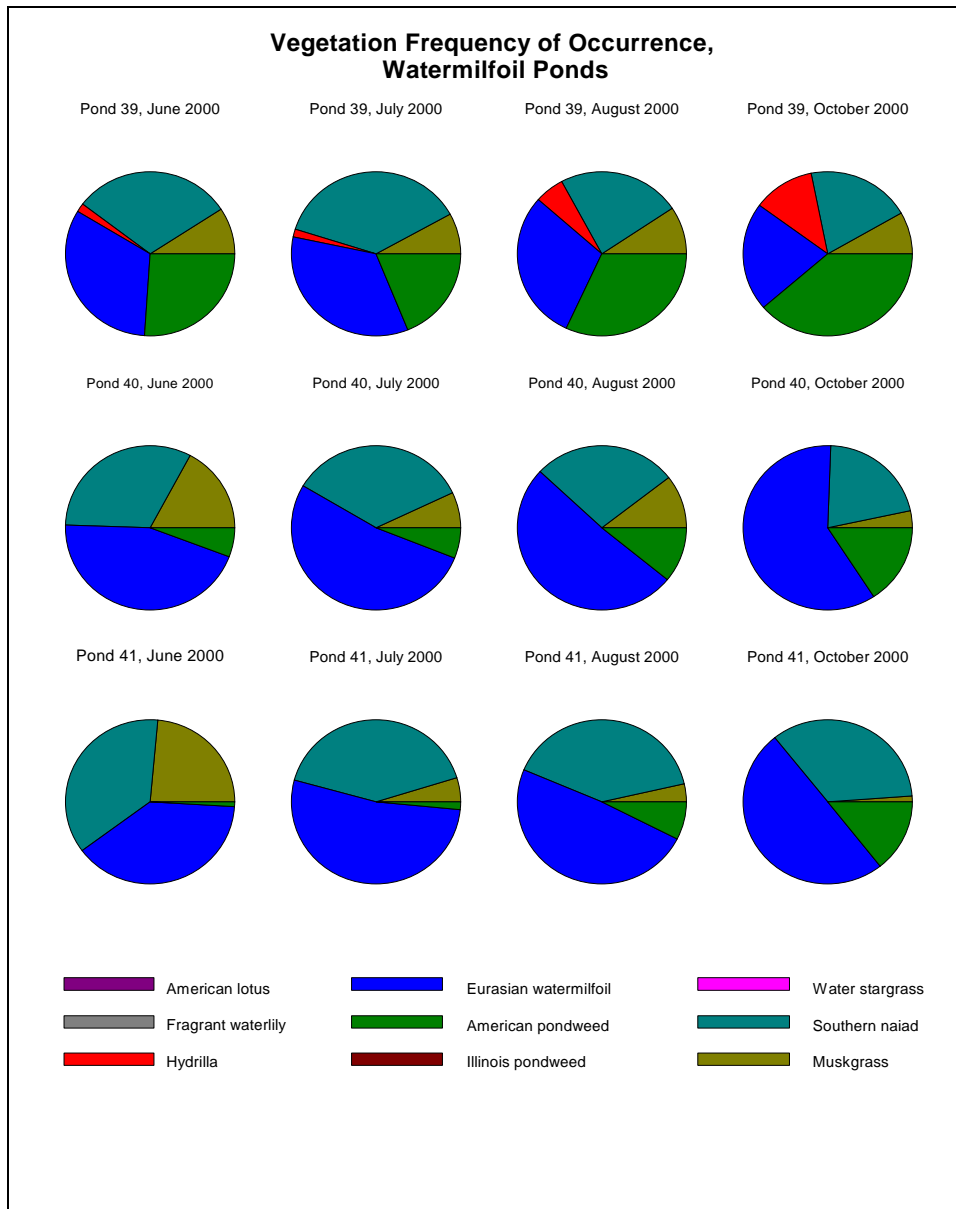


Figure 8 Line-transect frequency of occurrence in Eurasian watermilfoil (*Myriophyllum spicatum*) ponds was measured from June to October 2000. Frequency of occurrence by watermilfoil in pond 39 did not indicate dominance by that species.

Ponds manipulated for dominance by native species (14, 15, 17, and 28), initially exhibited high frequencies of southern naiad, muskgrass, and American pondweed (Figure 10). However, hydrilla had become established in one pond (17). As the growing season progressed, pondweeds (American and Illinois) increased in frequency in most ponds. At the October sampling period, native species clearly dominated ponds 14, 15, and 28. Hydrilla had expanded considerably

in pond 17, particularly in deeper water areas, but had not achieved dominance over native species based upon frequency data.

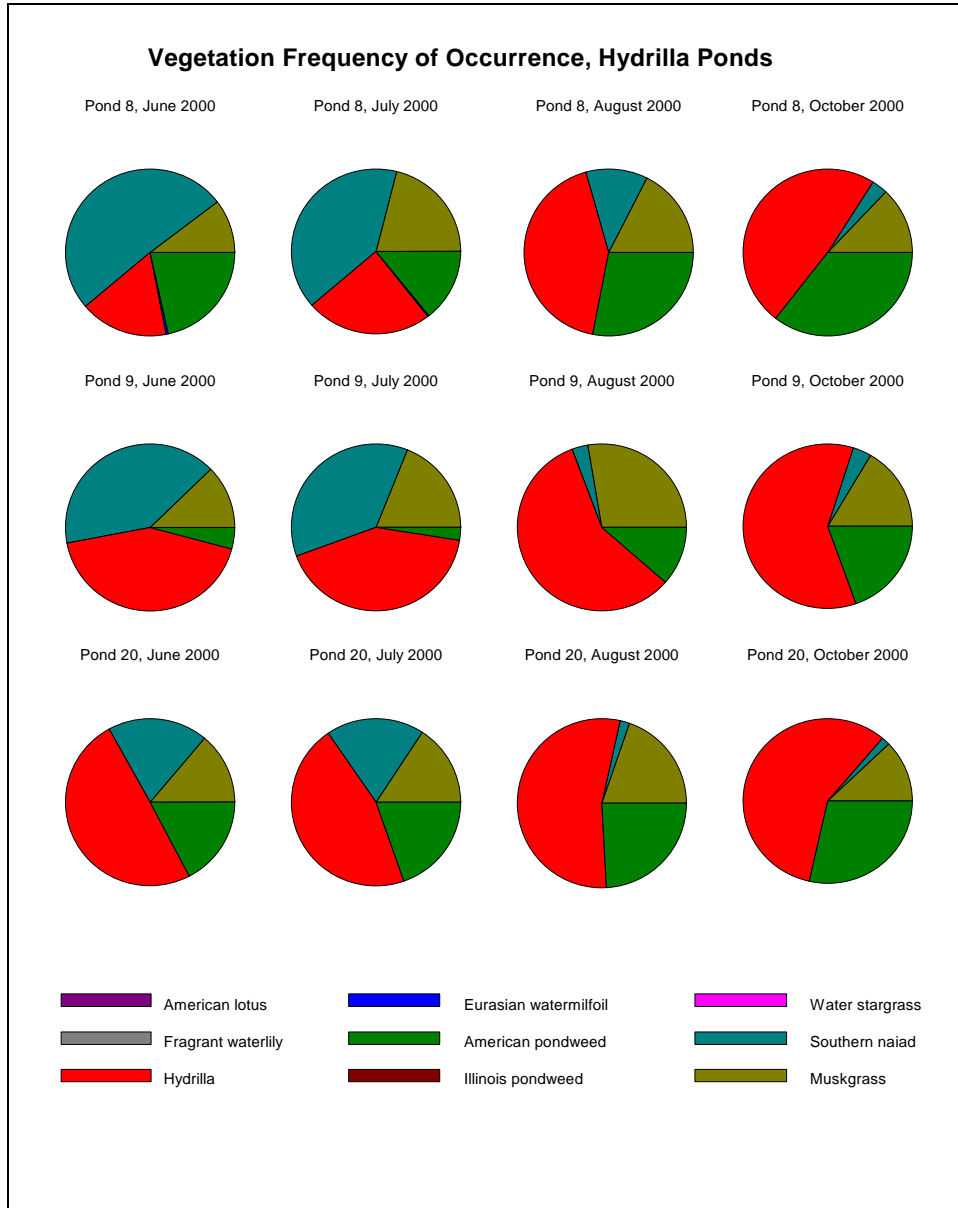


Figure 9. Line-transect frequency of occurrence in hydrilla (*Hydrilla verticillata*) was measured from June to October 2000.

Development of an ecologically dominant plant canopy

Dominance by species frequency does not take into account morphological differences between species, and therefore may not reflect potential biotic and abiotic interactions in aquatic systems. Floating-leaved species, for instance, may be lower in frequency of occurrence

relative to submersed species, but because of their ability to shade out other plants are more likely the ecologically dominant plants.

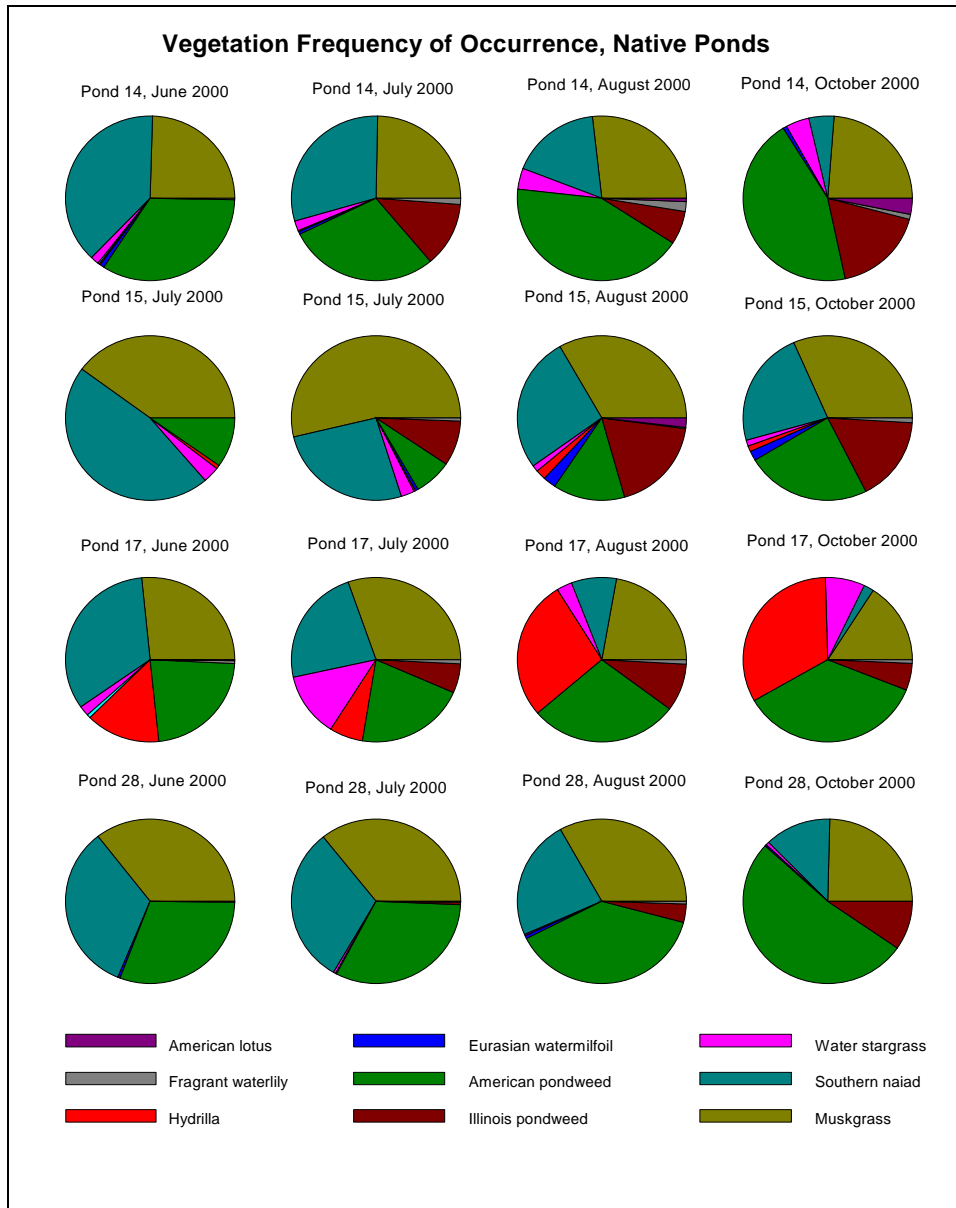


Figure 10. Line-transect frequency of occurrence in native ponds was measured from June to October 2000.

Canopy biomass and volume were compared among hydrilla, watermilfoil, American pondweed, and a southern naiad-muskgrass composite. Fresh weight comparisons (which typify plant architecture in the water column) demonstrated that hydrilla canopies attained the highest fresh weights, followed by watermilfoil (Figure 11). Both species' canopies exhibited significantly higher fresh

weight than native species. The same results were found when plants were volumetrically measured. Although dry biomass measurements showed no significant difference between hydrilla and watermilfoil, both plants exhibited significantly greater biomass than the native plants measured.

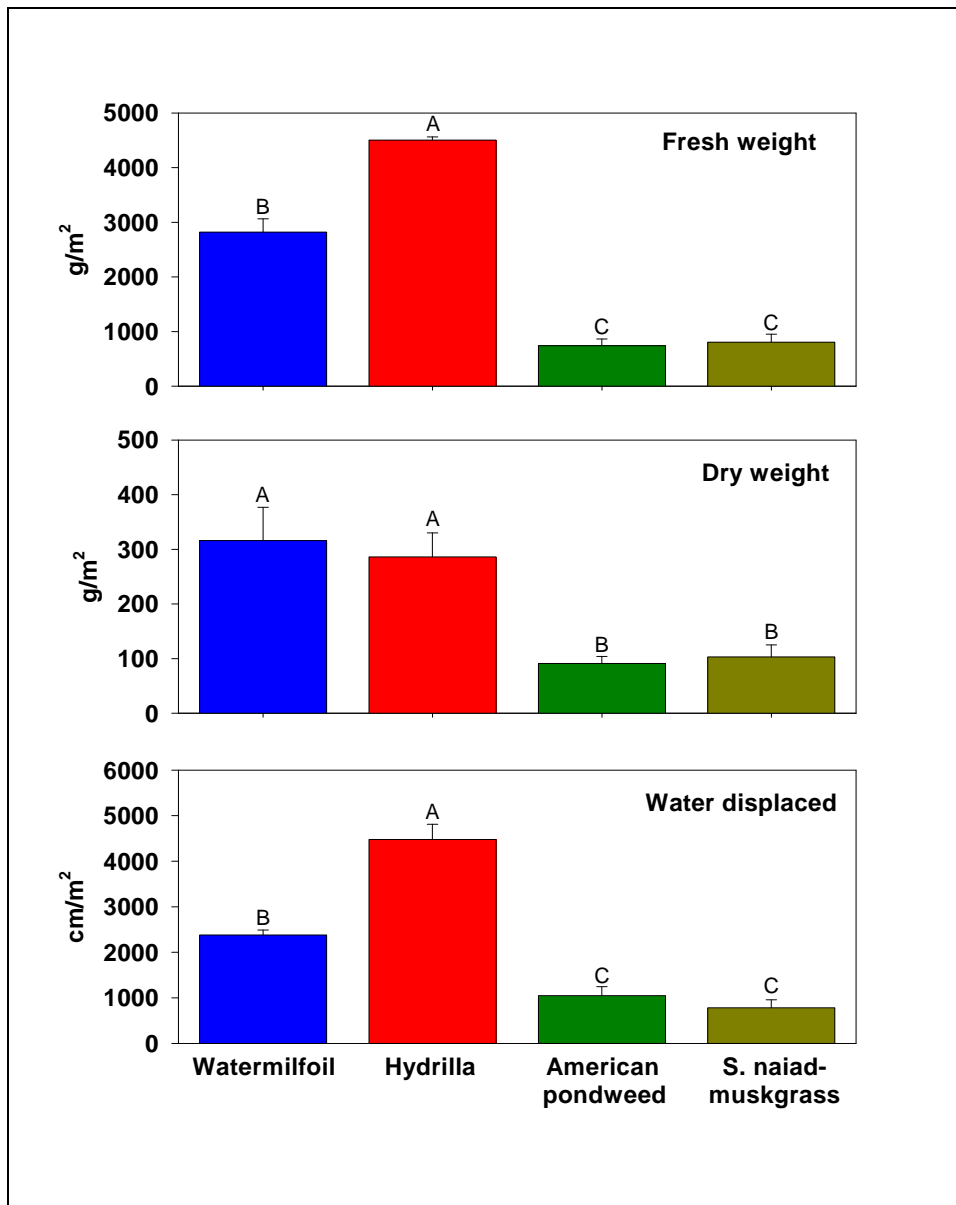


Figure 11. Biomass and volume of common species taken from the top 25 cm of the water column. Letters above bars indicate significant differences ($p > 0.05$).

Frequency of occurrence data were then used to characterize and compare species dominance of the plant canopy by using a ranking scheme based on characteristics that favor a strong surface canopy

effect: plant morphology (e.g., floating-leaved species) and biomass (e.g., hydrilla). Those species with the greatest capacity to dominate other species earned the highest rank, followed by those with lesser surface canopy effects. The order of ranking follows:

1. Hydrilla
2. Watermilfoil
3. American pondweed
4. Illinois pondweed
5. Water stargrass
6. Southern naiad
7. Muskgrass

At each transect, the observed plant assigned the highest rank was counted, while lower ranked species were excluded. By using this method, the likely effects of surface canopy (e.g., disruption of light and oxygen exchange) could be more distinctly characterized than by frequency of occurrence of all plants. This analysis emphasized the effects caused by dominance of disruptive species in ponds that may have had a variety of species present throughout the water column. Considering that hydrilla and watermilfoil exhibit rank growth throughout the water column, by extension, these data help characterize the likelihood of other effects when ponds are overwhelmingly dominated by these exotics.

Canopy dominance in Eurasian watermilfoil ponds

Two of the three ponds planted with watermilfoil exhibited canopy dominance by that species throughout the growing season (Figure 12). In pond 39, hydrilla and American pondweed gained in dominance as the season progressed, and by October, no species exhibited clear canopy dominance in that pond (watermilfoil, 36 percent; hydrilla, 27 percent; natives, 33 percent).

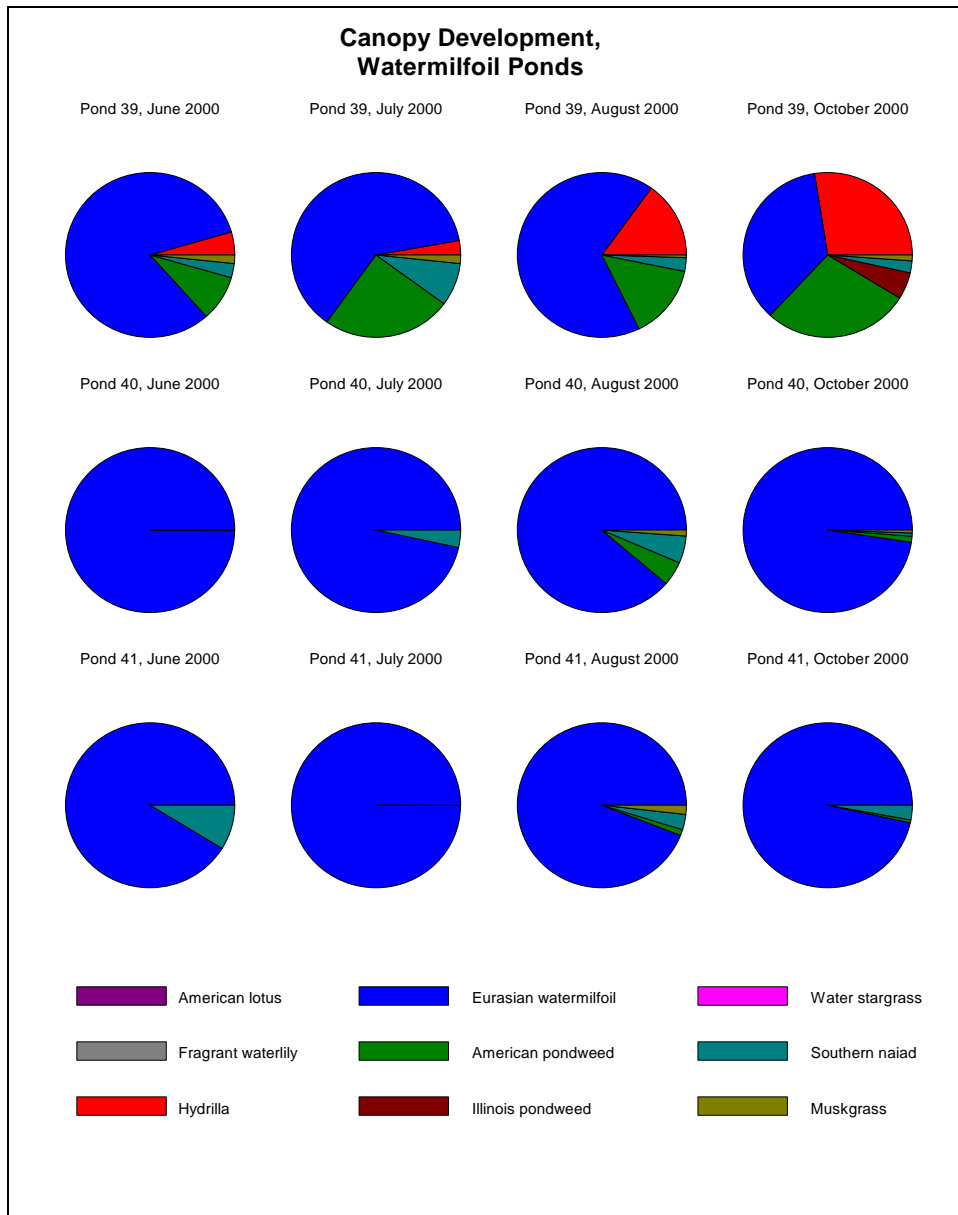


Figure 12. Canopy dominance in Eurasian watermilfoil ponds was measured from June to October 2000. Pond 39 was no longer dominated by a watermilfoil canopy by the end of the study.

Canopy dominance in hydrilla ponds

Ponds manipulated for hydrilla dominance were dominated by that species through much of the study period (Figure 13). Pond 8 was slow to develop a hydrilla canopy in comparison to ponds 9 and 20. However, by August all hydrilla ponds showed well over 90 percent coverage of hydrilla.

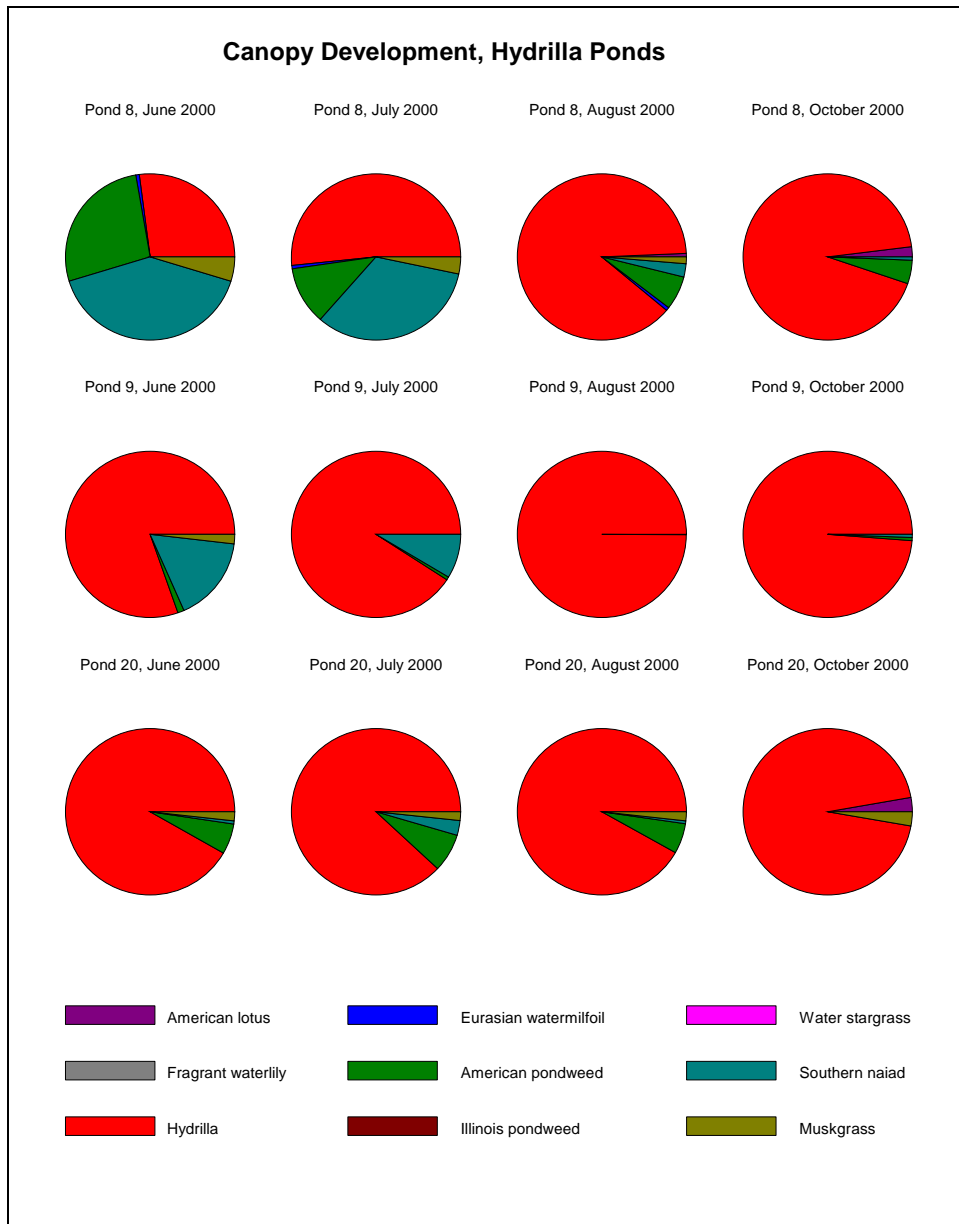


Figure 13. Canopy dominance in hydrilla ponds was measured from June to October 2000.

Canopy dominance in native ponds

Three of the four ponds planted with native plants maintained diverse populations throughout the growing season (Figure 14). Pondweeds (American and Illinois) were the most common canopy-dominant species in ponds 14, 15, and 28 throughout most of the study period. An accidental invasion and subsequent spread of hydrilla in pond 17 shifted canopy dominance to hydrilla by August, and this condition continued through the end of the study.

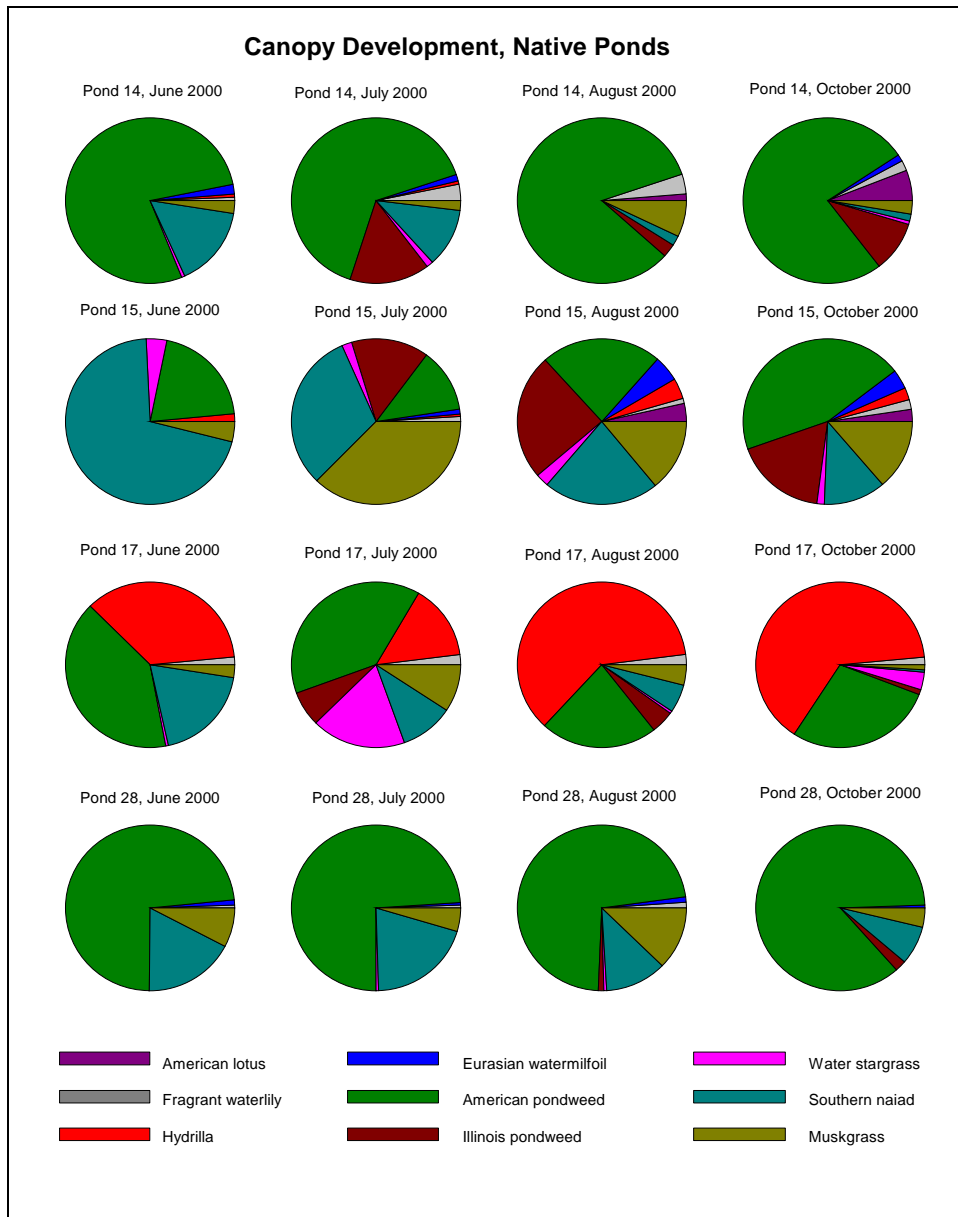


Figure 14. Canopy dominance in native ponds was measured from June to October 2000. Pond 17 was no longer dominated by native species by the end of the study.

Overall, ponds were dominated by target species canopies throughout the study period. Initially (June), two native ponds (15 and 17) and one hydrilla pond (8) were more similar to one another than other native or hydrilla ponds, respectively (Figure 15). By July, all ponds except one native pond (17), in which hydrilla had become well established, were dominated by target species. By August, this same pond was dominated by hydrilla.

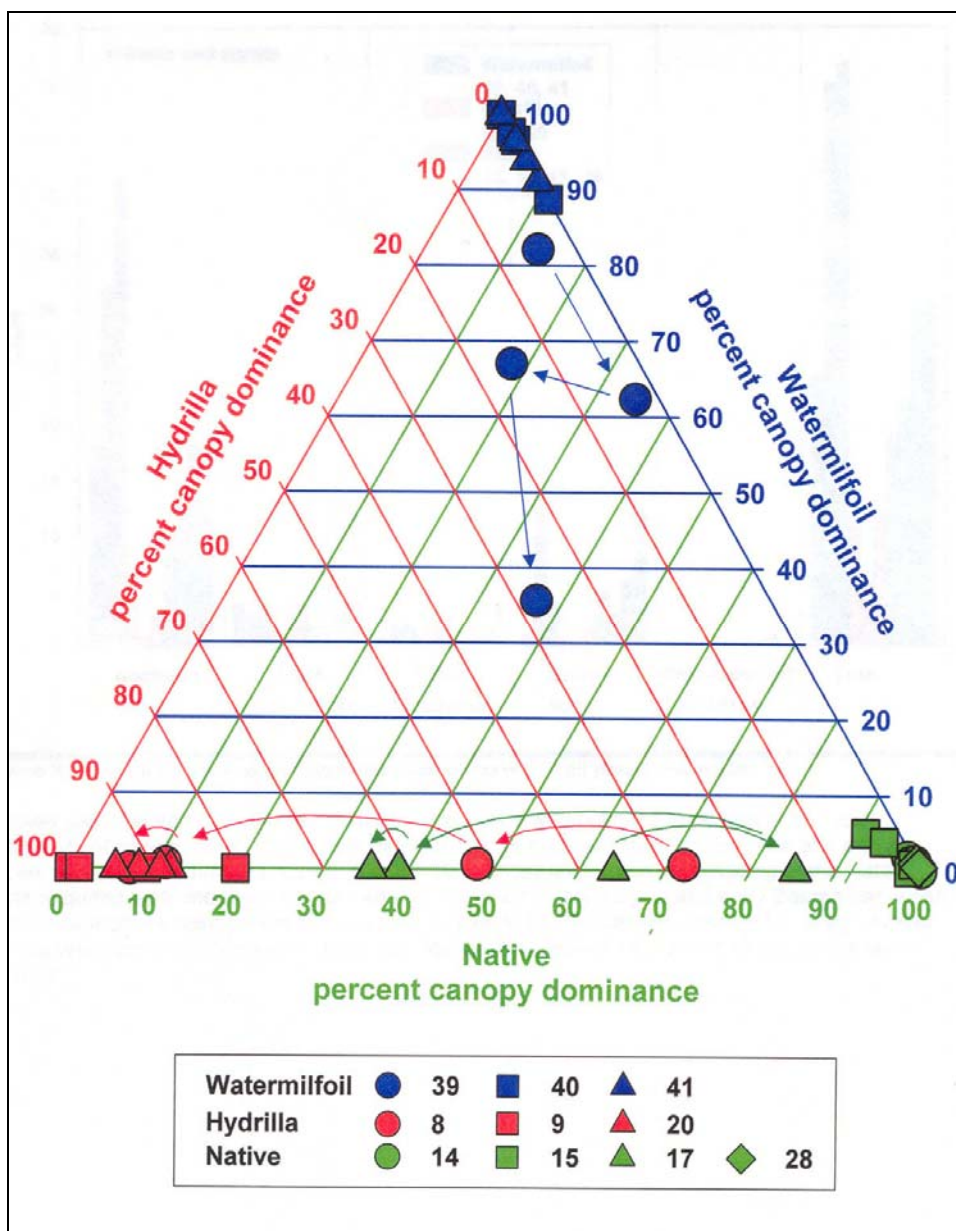


Figure 15. Targeted dominance (50 percent or greater) was achieved in most ponds.

Canopy structure as measured by light irradiance

PAR (photosynthetically active radiation) measurements from all ponds indicated that the lowest light penetration occurred in hydrilla ponds (Figure 16). In early June, before surface canopy development, irradiance in hydrilla ponds was less than half that in native and watermilfoil at all depths measured. Dense subsurface stems were the likely cause for this difference. By mid-August, irradiance in hydrilla ponds was low at all depths, watermilfoil ponds remained high near

the surface, but declined rapidly below 25 cm, while native ponds remained relatively high. Differences between ponds were attributed to canopy development by hydrilla and watermilfoil surface canopies. In contrast, less dense native pond surface canopies permitted greater light penetration.

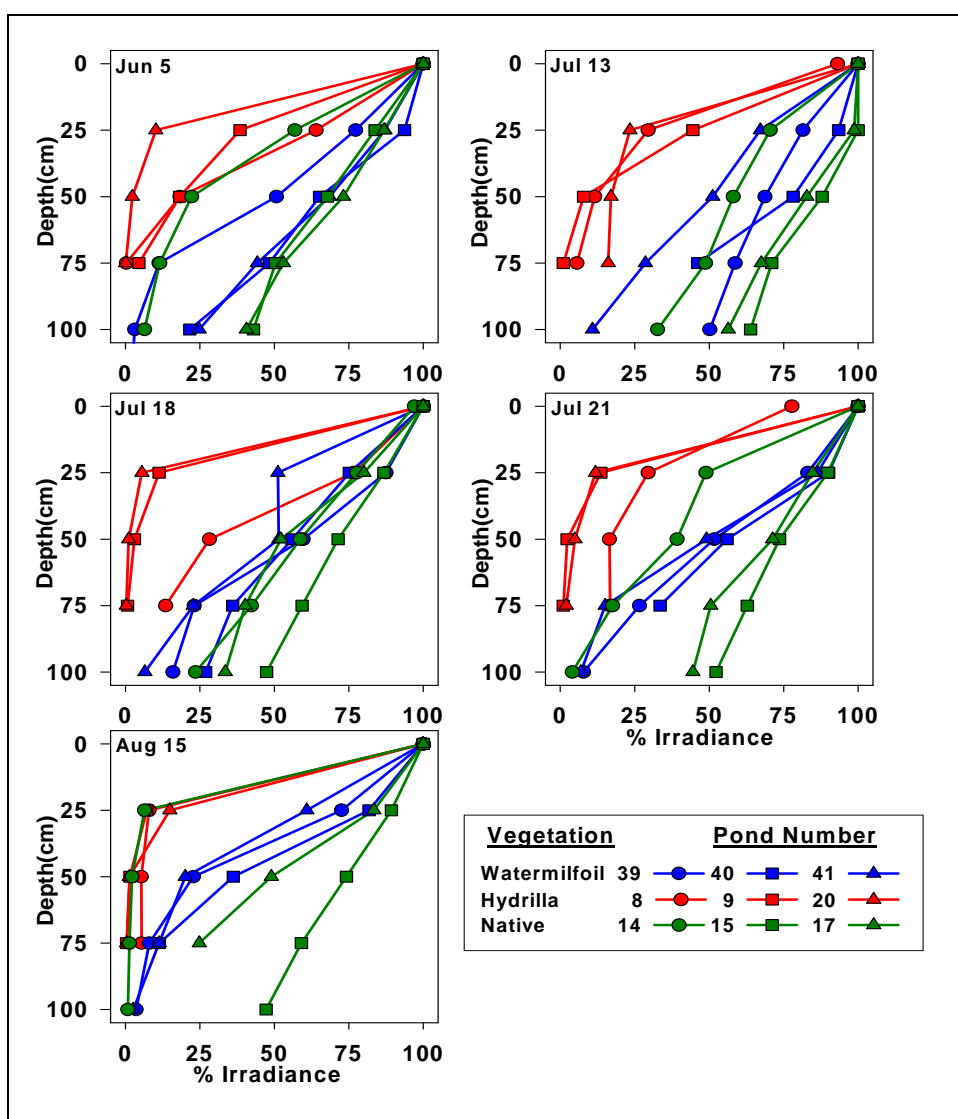


Figure 16. Canopy development of dominant species influenced percent irradiance in study ponds. In general, light penetration was greater in ponds dominated by native species. Light was not measured in Pond 28 (native).

Water quality

Beginning in June, differences in water quality were detected in ponds supporting different plant species. As the growing season progressed, some differences became more pronounced. For the most

part, differences were attributed to canopy structure of plants dominating each pond.

Water temperature

Water temperatures in experimental ponds were measured hourly at two depths (25 cm and 75 cm) from June through September. Watermilfoil ponds exhibited slightly higher average temperatures at both depths (Table 3). Water temperature averages at the 25 cm depth were similar for the hydrilla ponds, but were cooler in the hydrilla ponds at 75 cm. These differences were attributed to canopy development of each vegetation type. In watermilfoil ponds, the canopy remained at the surface throughout the sampling period, warming the 25 cm depths by absorbing solar irradiation. Although the highest temperatures at 25 cm occurred in hydrilla ponds, average temperatures at 25 cm were lower than watermilfoil because the hydrilla canopy did not reach the surface until mid-June, with more reflected solar radiation occurring during that time. The open structure of native canopies reduced solar absorption (and increased solar reflection by the water surface) and, therefore, warming during the entire study period. At the same time, light penetration below the watermilfoil canopy was moderate and contributed to warming at 75 cm. When combined with probable mixing of warmer surface water, overall average temperature in watermilfoil ponds was highest. Low average temperature at 75 cm in hydrilla ponds was due to reduced irradiation and mixing (both blocked by dense canopy). Moderate average temperature in native ponds was due primarily to light penetration and adequate mixing.

Table 3. Average hourly water temperatures measured at 25- and 75-cm depths in experimental ponds.

Depth (cm)	Watermilfoil (°C)	Hydrilla (°C)	Native (°C)
25	29.3	28.7	28.4
75	28.2	26.8	27.5

Evaluation of diel fluctuations of water temperatures at both depths supports conclusions drawn from average water temperatures. The following six graphs represent relationships between water temperature, depth, air temperature, and rainfall events that occurred in

watermilfoil, hydrilla, and native ponds. Periods observed were June 4 through June 15 and August 12 through August 24.

June water temperatures in watermilfoil ponds ranged from 24.3 to 30.2 °C at 25 cm and from 24.3 to 29.0 °C at 75 cm (Figure 17). Temperature differences between depths were moderate, but decreased on days with rainfall (or cloud cover) due to reduced solar irradiance. Diel fluctuations were higher at 25 cm, but occurred at both depths, regardless of the occurrence of rainfall (or cloud cover).

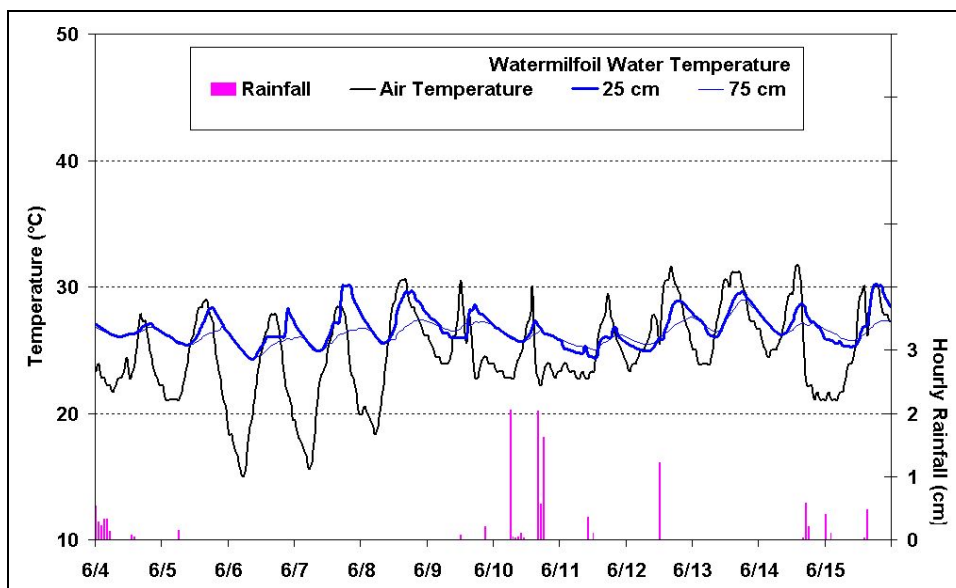


Figure 17. Hourly rainfall, air temperature, and water temperature compared at two depths in a watermilfoil pond (pond 39) during a two-week period in June 2000.

In August, water temperatures in watermilfoil ponds ranged from 29.1 to 34.9 °C at 25 cm and from 28.8 to 31.6 °C at 75 cm (Figure 18). Temperature differences between depths were moderate. Diel fluctuations were higher at 25 cm, but occurred at both depths. There were no rain events during this period.

In June, water temperatures in hydrilla ponds ranged from 23.7 to 31.4 °C at 25 cm and from 23.4 to 26.9 °C at 75 cm (Figure 19). Temperature differences between depths were moderate, but decreased on days with rainfall (or cloud cover) due to reduced solar irradiance. Diel fluctuations occurred at 25 cm, but were almost absent at 75 cm, regardless of the occurrence of rainfall (or cloud cover); this was likely due to low solar irradiance (and subsequent heating) and less mixing beneath the hydrilla canopy.

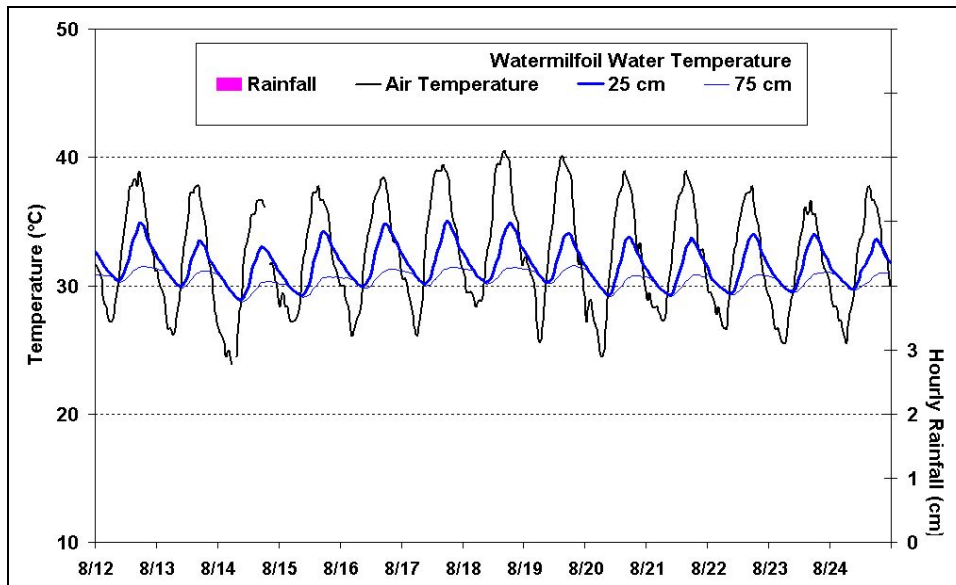


Figure 18. Hourly rainfall, air temperature, and water temperature compared at two depths in a watermilfoil pond (pond 41) during a two-week period in August 2000.

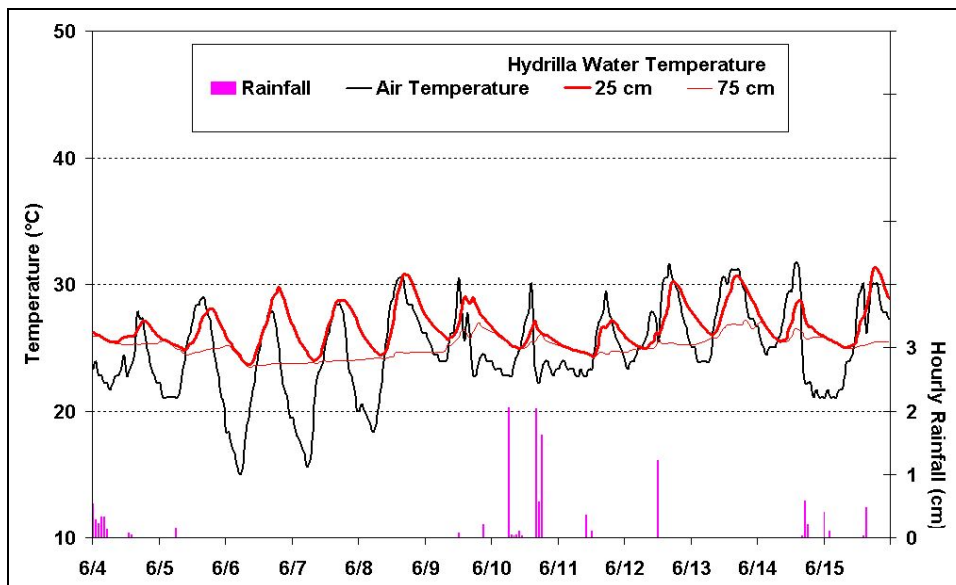


Figure 19. Hourly rainfall, air temperature, and water temperature compared at two depths in a hydrilla pond (pond 8) during a two-week period in June 2000.

In August, water temperatures in hydrilla ponds ranged from 27.8 to 33.9 °C at 25 cm and from 27.8 to 29.6 °C at 75 cm (Figure 20). Temperature differences between depths were moderate. Diel fluctuations occurred at 25 cm, but were almost absent at 75 cm, due to very low solar irradiance and less mixing beneath the hydrilla canopy. There were no rain events during this period.

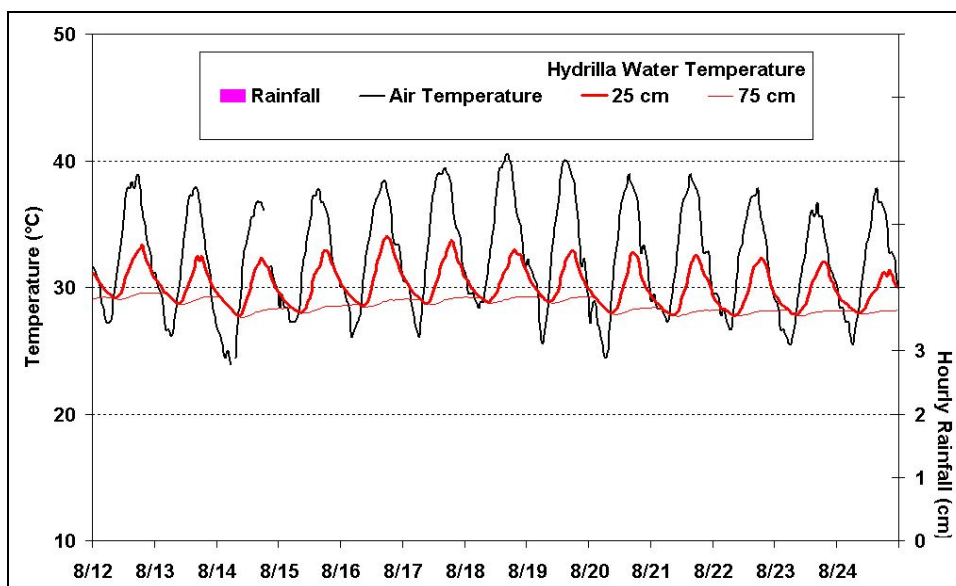


Figure 20. Hourly rainfall, air temperature, and water temperature compared at two depths in a hydrilla pond (pond 8) during a two-week period in August 2000.

June water temperatures in native ponds ranged from 24.3 to 29.6°C at 25 cm and from 24.2 to 27.3°C at 75 cm (Figure 21). Temperature differences between depths were moderate, but decreased on days with rainfall (or cloud cover) due to reduced solar irradiance. Diel fluctuations were highest at 25 cm, but occurred at both depths, regardless of the occurrence of rainfall (or cloud cover).

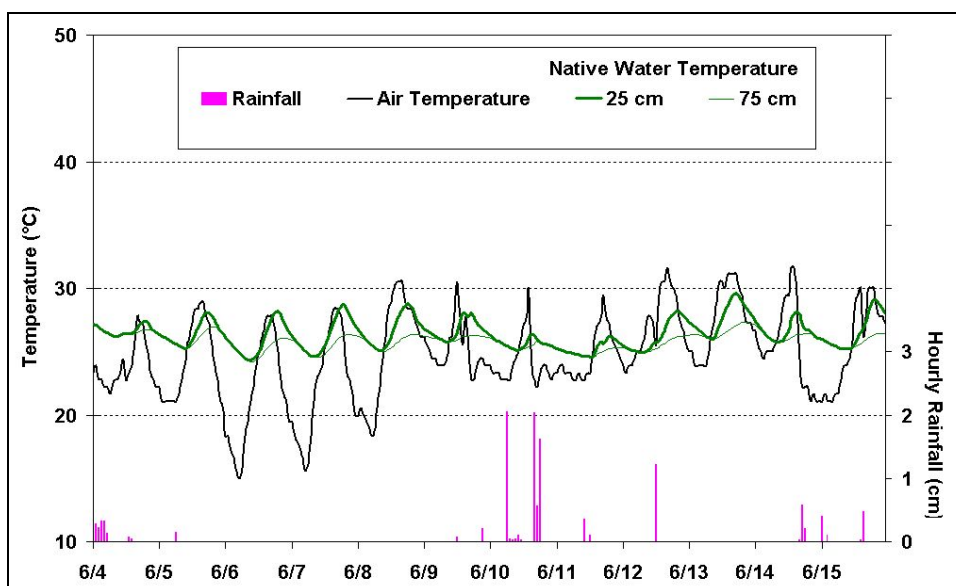


Figure 21. Hourly rainfall, air temperature, and water temperature compared at two depths in a native pond (pond 14) during a two-week period in June 2000.

In August, water temperatures in native ponds ranged from 28.5 to 33.9 °C at 25 cm and from 28.4 to 32.5 °C at 75 cm (Figure 22). Temperature differences between depths were low. Diel fluctuations occurred at both depths. There were no rain events during this period.

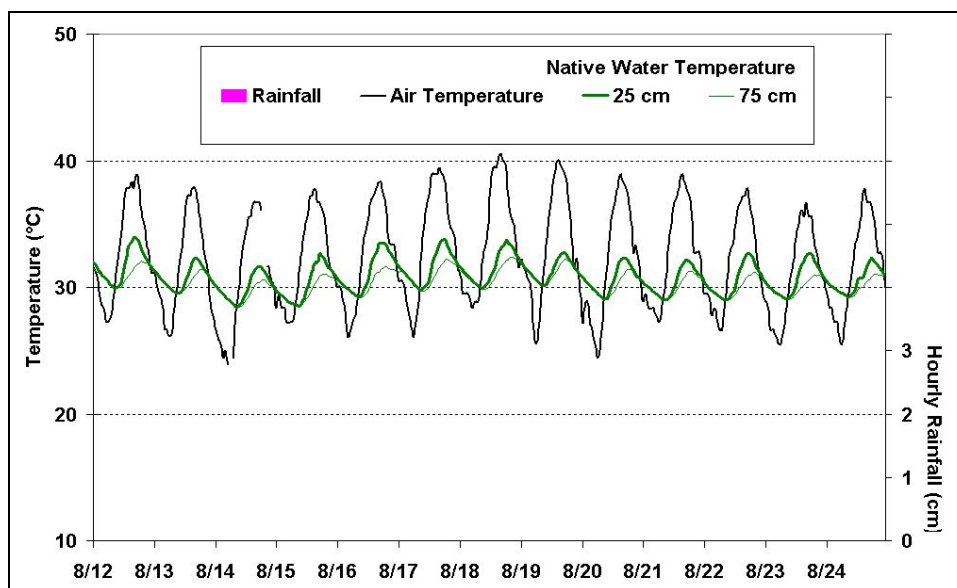


Figure 22. Hourly rainfall, air temperature, and water temperature compared at two depths in a native pond (pond 15) during a two-week period in August 2000.

The following graphs compare hourly water temperature variation between the 25- and 75-cm depths in watermilfoil, hydrilla, and native ponds. Hourly rainfall data plotted to indicate potential effects of rain events on water temperatures.

In June, water temperature differences between 25 and 75 cm were greatest in hydrilla ponds and lowest in native ponds, except on rainy days, when they were lowest in watermilfoil ponds (Figure 23). Although the hydrilla canopy was not yet at the surface, it evidently reduced mixing between depths, resulting in higher temperature differences. At the same time, the subsurface canopy prevented light penetration and warming in deeper water. Additionally, the canopy may have reduced mixing between depths. In watermilfoil ponds, the surface canopy contributed to warming at 25 cm, but light penetration and mixing beneath the canopy lessened temperature differences between depths. This effect was disrupted during rain events, when temperature differences were occasionally reversed (greater temperatures at 75 cm, due to cooling of surface waters by

rainfall or cloud cover, induced cooler air temperatures). Similar effects were seen in native ponds, although differences were generally lessened due to more open water areas.

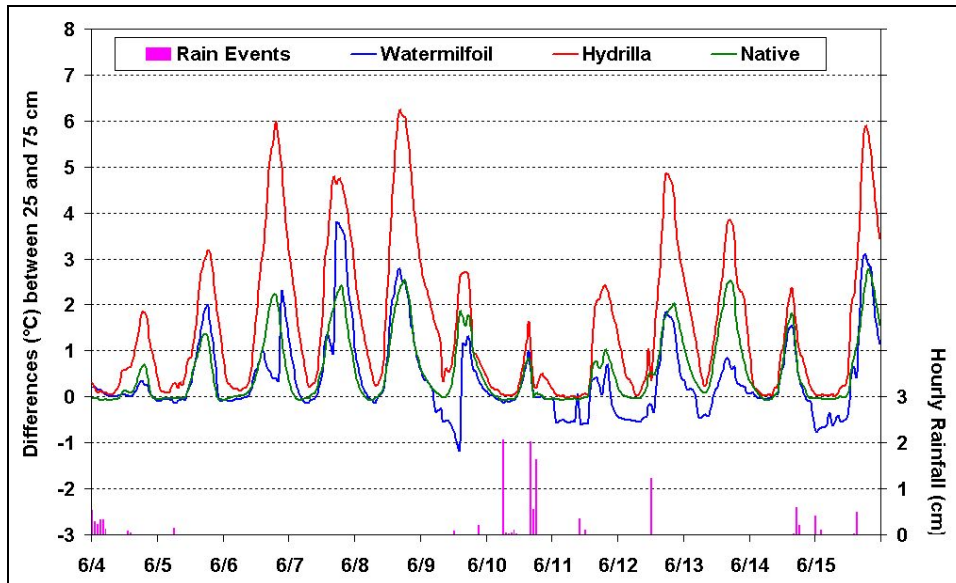


Figure 23. Hourly rainfall and average hourly temperature differences between 25- and 75-cm depths in watermilfoil (pond 39), hydrilla (pond 8), and native (pond 14) ponds during a two-week period in June 2000.

In August, water temperature differences between 25 and 75 cm were greatest in hydrilla and watermilfoil ponds and lowest in native ponds (Figure 24). The hydrilla canopy had reached the surface, absorbing solar radiation and heating surface water. At the same time, the surface canopy blocked light penetration (while continuing to reduce mixing), resulting in greater temperature differences between depths. In watermilfoil ponds, the surface canopy developed further, with increased warming at 25 cm, but reduced light penetration beneath the canopy, resulting in higher temperature differences between depths than occurred in June. In native ponds, differences in water temperatures between depths were similar to those seen in June: the surface canopy remained open, with light penetration and mixing resulting in relatively low temperature differences between depths.

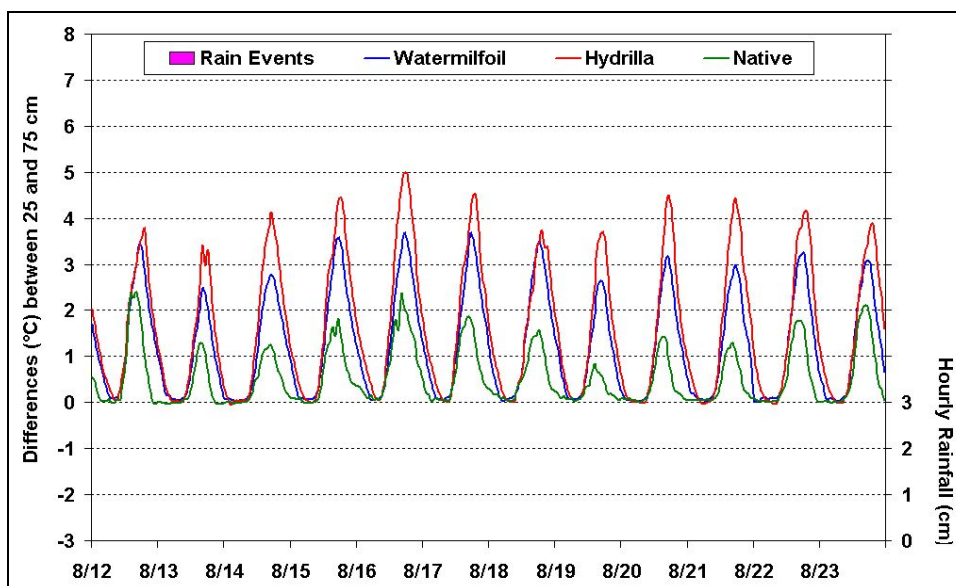


Figure 24. Hourly rainfall and average hourly temperature differences between 25- and 75-cm depths in watermilfoil (pond 41), hydrilla (pond 8), and native (pond 15) ponds during a two-week period in August 2000.

Water temperature differences attributable to diel fluctuations support conclusions regarding the influence of canopies (of each vegetation type) on water temperature differences between depths. Differences in hydrilla pond water temperatures were highest, followed by watermilfoil ponds, and then native ponds (Figure 25). Maximum daily temperature variance exceeded 8 °C on several occasions in hydrilla ponds, and frequently exceeded 6 °C. Daily water temperature variance in watermilfoil ponds exceeded 6 °C on several occasions, but was generally between 4 and 5 °C. In native ponds, daily temperature variance rarely exceeded 5 °C. This implied that the densest canopy (hydrilla) was absorbing solar radiation at the greatest rates, resulting in warmer surface waters. At the same time, shade provided by the dense hydrilla canopy reduced warming of deeper waters (by blocking light and reducing mixing), which remained cooler during the day than watermilfoil and native ponds.

High water temperatures can be detrimental to aquatic life. For instance, largemouth bass require temperatures under 30 °C for successful spawning, and cannot tolerate temperatures over 36 °C. After hatching, largemouth bass fry do not tolerate temperatures over 32 °C (Stuber et al. 1982). In early July, water temperatures at 25 cm exceeded 36 °C in a hydrilla pond on 4 days for up to 6 hours, making that portion of the water column lethal to bass. Deeper water (75 cm)

was cooler (29-30 °C) in that pond, providing refuge (although this refuge occurred where light penetration was poor, possibly interfering with foraging by sight predators such as bass). Water temperatures did not exceed 36 °C at any depth in either watermilfoil or native ponds.

Water temperature at 25 cm exceeded 32 °C in hydrilla, watermilfoil, and native ponds on numerous occasions during the study (Figure 25). It is interesting to note that in June, when bass fry are potentially present in LAERF ponds, lethal (25 cm depth) temperatures occurred in hydrilla and watermilfoil ponds, but not in native ponds. Water temperature at 75 cm did not exceed 30 °C in those ponds, providing potential temperature refuge for fry (albeit in heavily shaded water). Overall, maximum hourly water temperatures at 25 cm exceeded tolerance levels much more frequently and over greater lengths of time in watermilfoil and hydrilla ponds, implying potential negative ecological impacts in systems with plant canopies dominated by those species.

Dissolved oxygen

DO (mg/L) in experimental ponds was measured hourly at two depths (25 cm and 75 cm) from June through September. Watermilfoil ponds exhibited higher average DO at both depths (Table 4), attributed to the moderate surface canopy density: DO was generally produced at both depths in quantities greater than during the night. Although averaging less than watermilfoil ponds, daytime DO in hydrilla ponds (at 25 cm) was usually highest and nighttime DO was usually lowest, a result of the dense surface canopy: large quantities were produced during photosynthesis, but were frequently depleted during the night. Light penetration was essentially eliminated at 75 cm in hydrilla ponds, and DO was consistently lowest in those ponds. Average DO in native ponds was lowest at 25 cm, and was believed due to the species composition of the surface canopy: it consisted primarily of American pondweed, which produces floating leaves (and therefore contributed less to oxygen production than most other submersed species). At the same time, this species contributed less to oxygen demand and overall DO in native ponds was moderate.

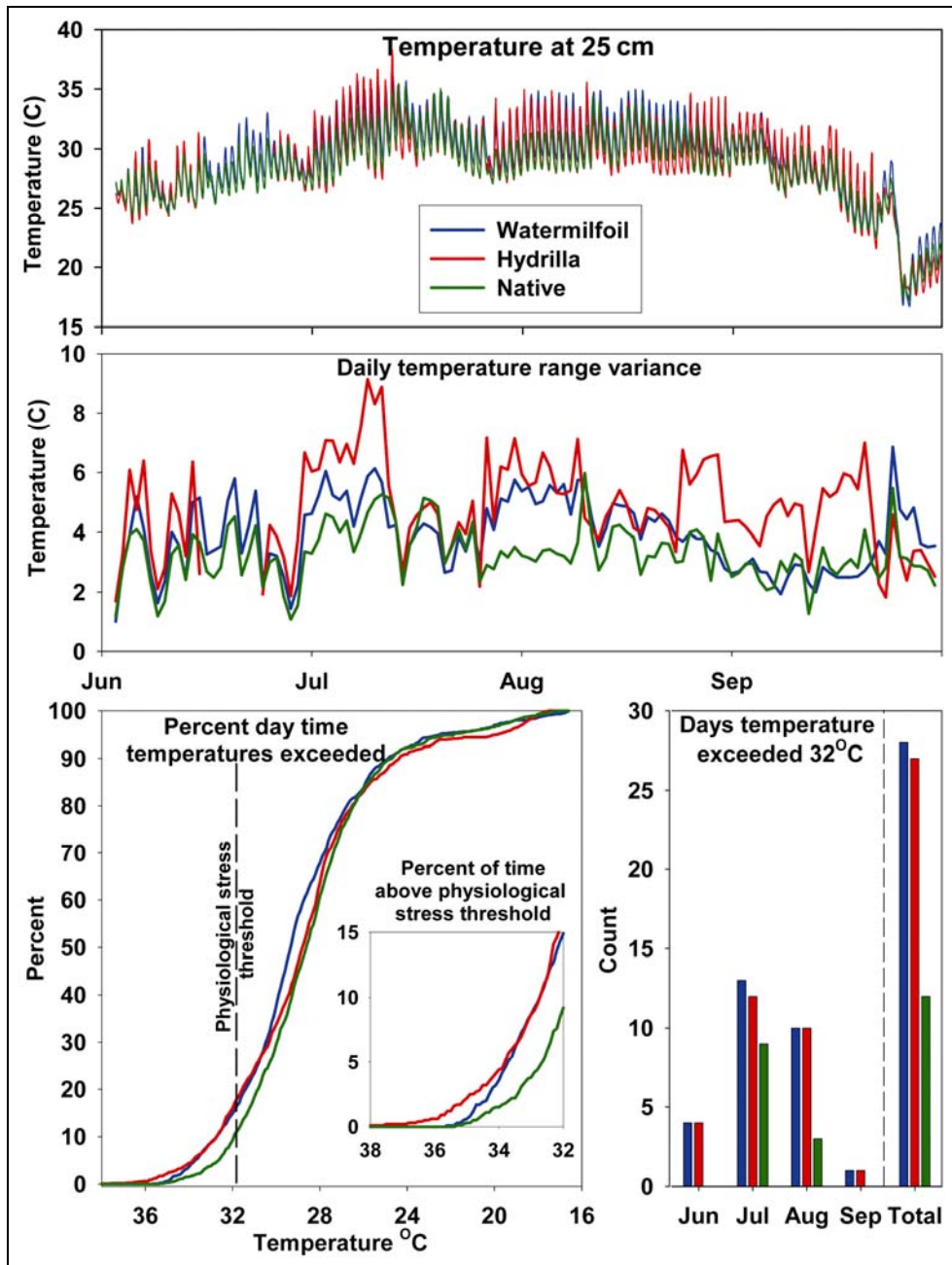


Figure 25. Water temperatures were highest in hydrilla ponds and lowest in native ponds at 25 cm. However, temperatures above physiological stress tolerance for fish were exceeded most often in watermilfoil ponds.

Table 4. Average hourly DO measured at 25- and 75-cm depths in experimental ponds.

Depth (cm)	Watermilfoil (mg/L)	Hydrilla (mg/L)	Native (mg/L)
25	9.3	7.8	6.8
75	6.6	3.6	5.2

In June, DO concentrations ranged from 2.5 to 11.5 mg/L at 25 cm and 2.0 to 11.5 mg/L at 75 cm in watermilfoil ponds (Figure 26). Mean differences in DO between depths were low (0.6 mg/L) and occurred on days without rainfall (or cloud cover). Light penetration was adequate for oxygen production (photosynthesis) at both depths, and mixing between depths may have contributed to similarities. Diel fluctuations occurred at both depths, but were greater at 25 cm on days without rainfall (or cloud cover). Periods of relatively low DO with little differences between depths occurred during rain events (or cloud cover).

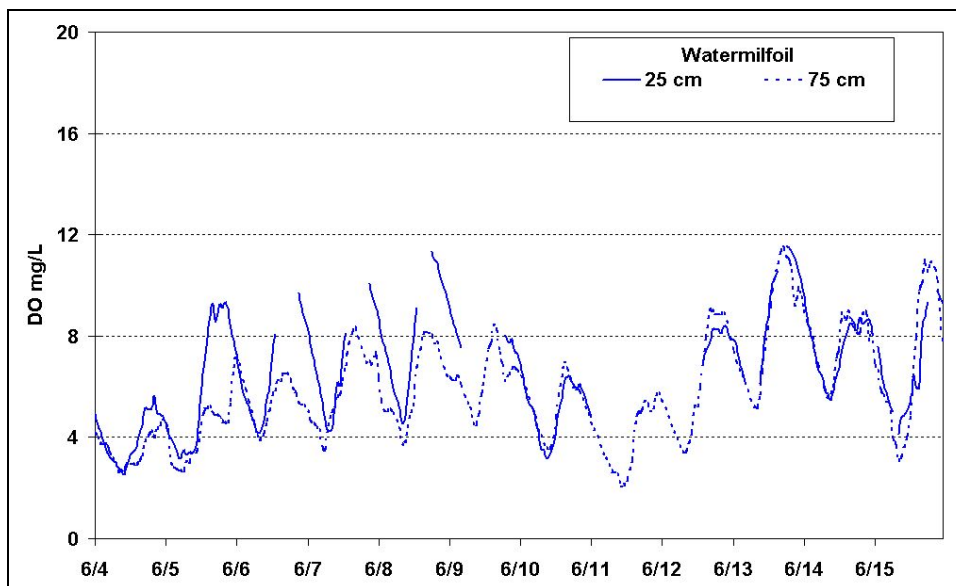


Figure 26. Dissolved oxygen was measured hourly at two depths in a watermilfoil pond (pond 39) during a two-week period in June 2000.

During August, DO in watermilfoil ponds was generally higher than in June, and ranged from 5.3 to 15.6 mg/L at 25 cm and 4.8 to 13.3 mg/L at 75 cm, despite higher water temperatures (Figure 27). Mean differences in DO between depths were moderate (2.7 mg/L) and were not disrupted by rainfall during this period. A greater difference between depths than in June reflects canopy development: less light penetration occurred in August, and mixing between depths may have been reduced. Diel fluctuations occurred at both depths, but were somewhat greater at 25 cm.

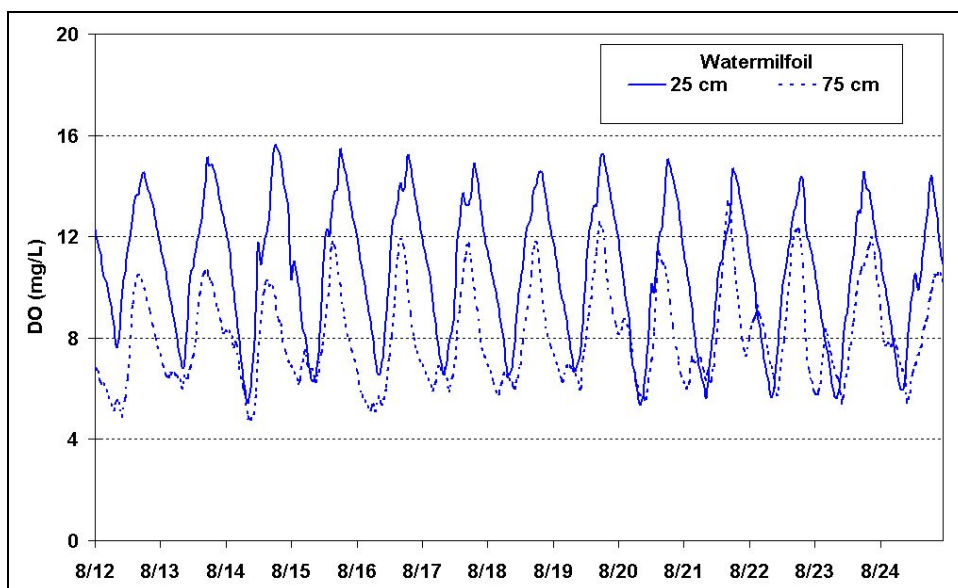


Figure 27. Dissolved oxygen was measured hourly at two depths in a watermilfoil pond (pond 41) during a two-week period in August 2000.

In June, DO concentrations ranged from 2.3 to 17.9 mg/L at 25 cm and 0.1 and 7.7 mg/L at 75 cm in hydrilla ponds (Figure 28). Mean differences in DO between depths were high (4.6 mg/L) and occurred on days with or without rainfall (or cloud cover), due to canopy-reduced light penetration and mixing at 75 cm. Diel fluctuations occurred at both depths, but were much greater at 25 cm.

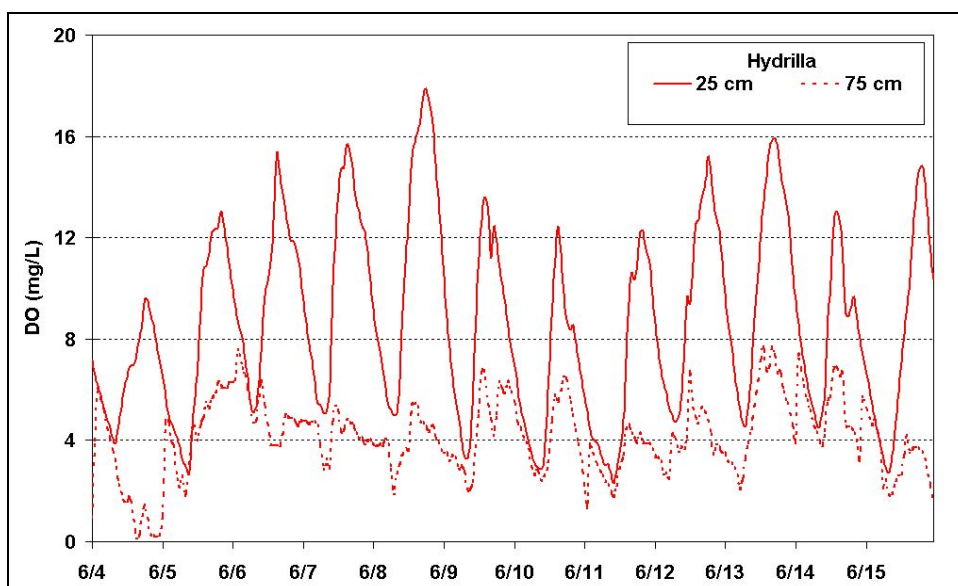


Figure 28. Dissolved oxygen was measured hourly at two depths in a hydrilla pond (pond 8) during a two-week period in June 2000.

During August, DO in hydrilla ponds was lower than in June, and ranged from 0.7 to 12.7 mg/L at 25 cm and less than 0.1- to 5.0 mg/L at 75 cm (Figure 29). Two factors may have contributed to this decline: 1) Temperatures (especially at 25 cm) were higher in August and reduced the water's capacity to carry dissolved oxygen, and 2) the canopy had topped out, with many stems and leaves forced above the water surface by the buoyancy of the surface mat; this may have blocked light from submersed portions, thereby reducing oxygen production in the water column. Because DO levels produced by the watermilfoil canopy at this same time (under slightly warmer conditions) were high, the latter likely played the most significant role. Mean differences in DO between depths were high (4.0 mg/L) due to canopy-reduced light penetration and mixing at 75 cm. Diel fluctuations occurred at both depths, but were much greater at 25 cm.

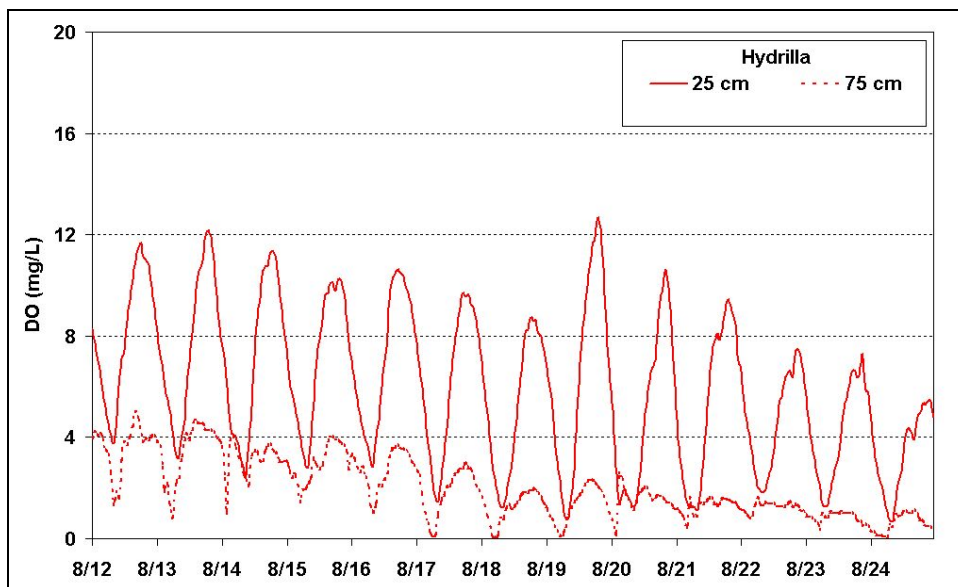


Figure 29. Dissolved oxygen was measured hourly at two depths in a hydrilla pond (pond 8) during a two-week period in August 2000.

In June, DO in native ponds ranged from 3.2 to 14.4 mg/L at 25 cm and 2.6 to 12.1 mg/L at 75 cm (Figure 30). Mean differences in DO between depths were moderate (1.1 mg/L) and occurred on days without rainfall (or cloud cover). Light penetration was adequate for oxygen production (photosynthesis) at both depths, and mixing may have occurred. Periods of relatively low DO with little or no differences between depths occurred during rain events (or cloud cover). Diel fluctuations occurred at both depths, regardless of the occurrence of rainfall.

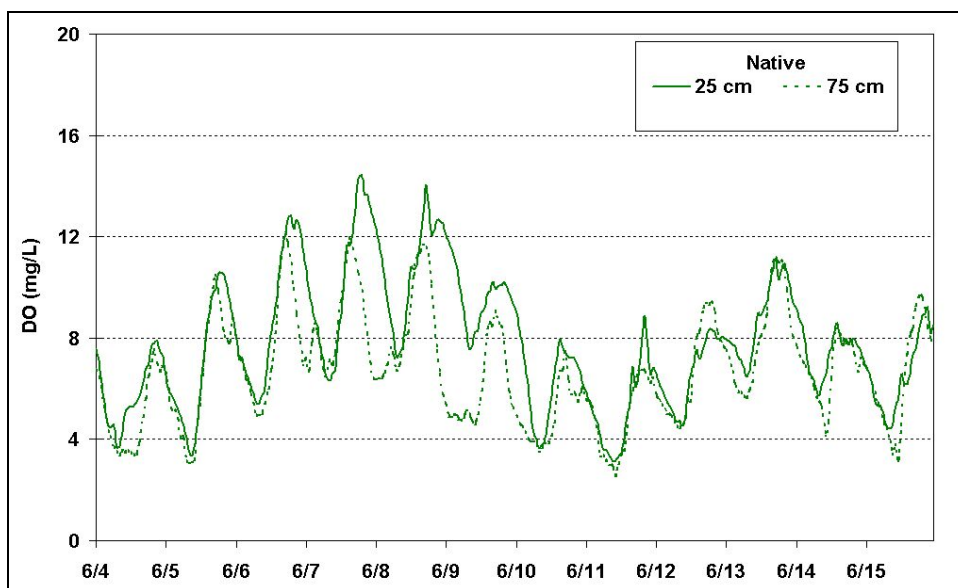


Figure 30. Dissolved oxygen was measured hourly at two depths in a native pond (pond 14) during a two-week period in June 2000.

In August, DO levels in native ponds were similar to those seen in June (except when disrupted by rainfall or cloud cover), and ranged from 3.0 to 13.1 at 25 cm and 2.4 to 13.5 at 75 cm (Figure 31). Mean differences in DO between depths were low (0.7 mg/L). Light penetration remained adequate for oxygen production at both depths, and mixing may have occurred. Occasional higher DO at 75 cm was due to greater subsurface photosynthetic activity, most likely by southern naiad and muskgrass. Diel fluctuations occurred at both depths.

In June, daytime DO at 25 cm was highest in hydrilla ponds and lowest in watermilfoil and native ponds (Figure 32). Higher biomass in the dense hydrilla subsurface canopy produced higher quantities of oxygen during photosynthesis, whereas lower biomass in the other canopies produced less. During the same period, nighttime DO was generally lowest in hydrilla ponds: this same high biomass increased oxygen demand during periods of no photosynthesis.

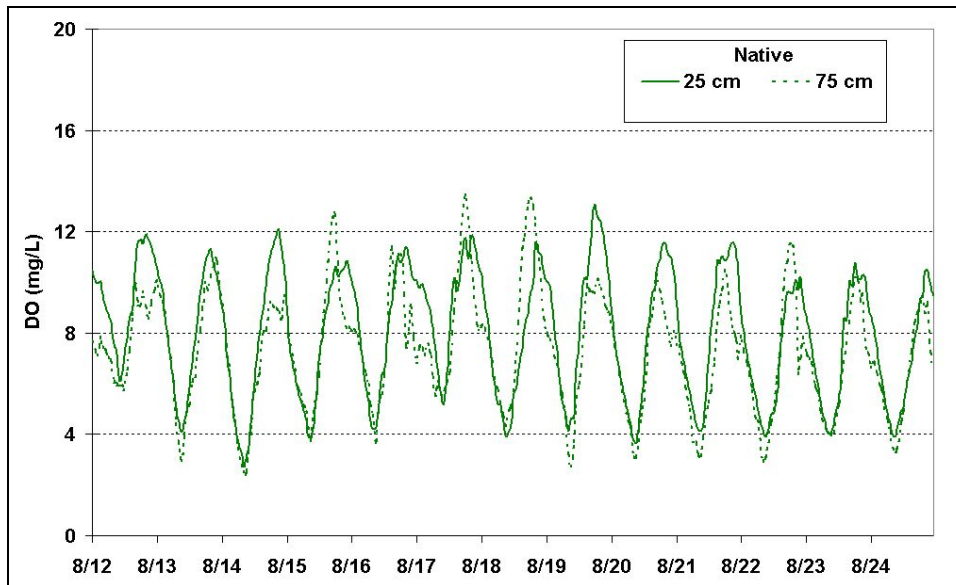


Figure 31. Dissolved oxygen was measured hourly at two depths in a native pond (pond 15) during a two-week period in August 2000.

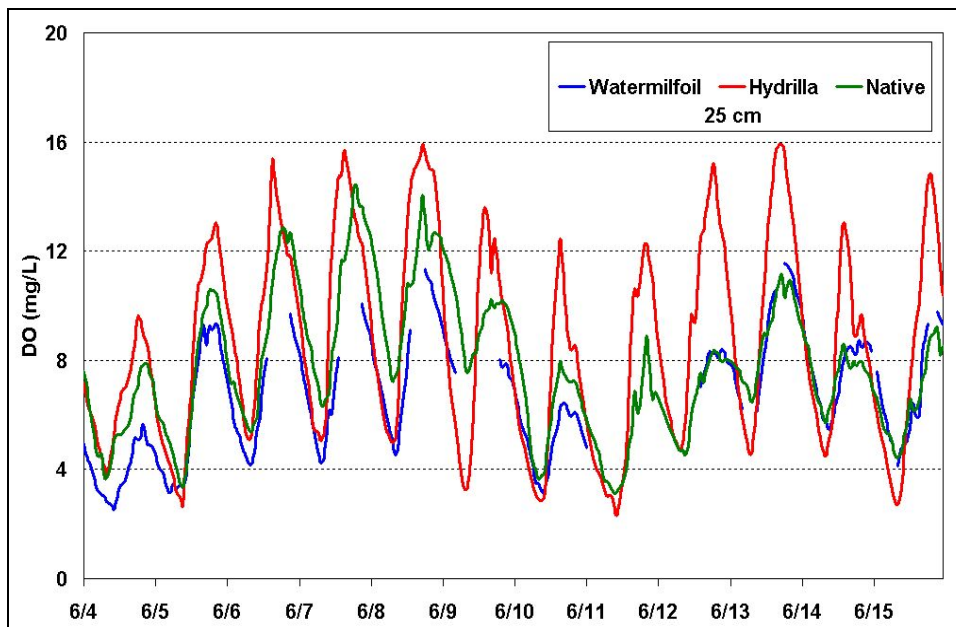


Figure 32. Dissolved oxygen was measured hourly in June at the 25-cm depth in ponds dominated by canopies of Eurasian watermilfoil (pond 39), hydrilla (pond 8), and native plants (pond 14).

In August, daytime DO at 25 cm was highest in watermilfoil ponds and lowest in hydrilla and native ponds (Figure 33). Increases in DO in watermilfoil ponds (over June) were due to increases in canopy biomass, which produced oxygen in quantities sufficient to remain elevated throughout the photoperiod. Lower oxygen in hydrilla ponds was due to leaves and stems extending above the water surface,

blocking light from submersed portions. During the same period, nighttime DO was generally lowest in hydrilla ponds due to higher oxygen demand and poor mixing with shallower water. Native pond DO was similar to that seen in June on days not disrupted by rainfall or cloud cover.

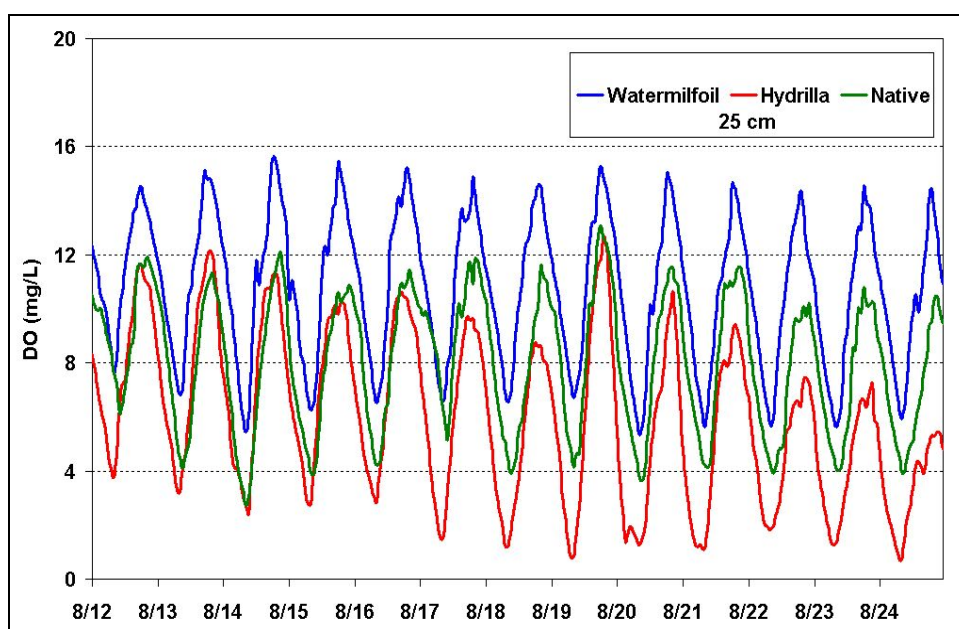


Figure 33. Dissolved oxygen was measured hourly in August at the 25-cm depth in ponds dominated by canopies of Eurasian watermilfoil (pond 41), hydrilla (pond 8), and native plants (pond 15).

In June, daytime and nighttime DO at 75 cm was highest in native ponds (and occasionally in watermilfoil ponds), due to light penetration beneath the canopy and mixing with well-oxygenated surface waters (Figure 34). During the same period, DO was generally lowest in hydrilla ponds during the full photoperiod, due to poor light penetration and mixing with surface waters.

In August, daytime DO at 75 cm was highest in watermilfoil and native ponds due to light penetration below the canopy and mixing with well-oxygenated surface waters (Figure 35). Daytime DO was lowest in hydrilla ponds because of poor light penetration and mixing; it rarely exceeded nighttime DO in other ponds. Nighttime DO was also lowest in hydrilla ponds.

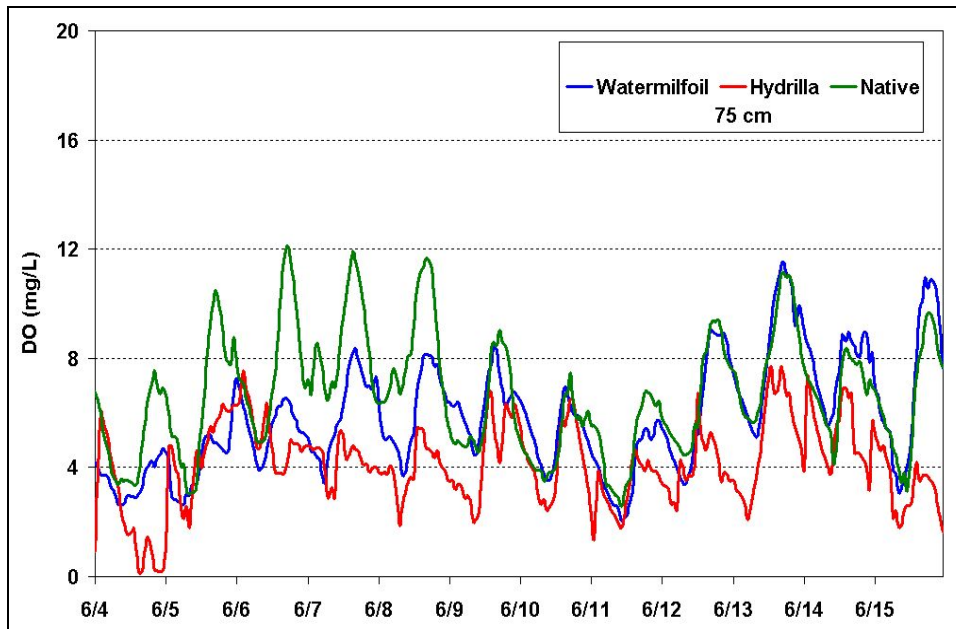


Figure 34. Dissolved oxygen was measured hourly in June at the 75-cm depth in ponds dominated by canopies of Eurasian watermilfoil (pond 39), hydrilla (pond 8), and native plants (pond 14).

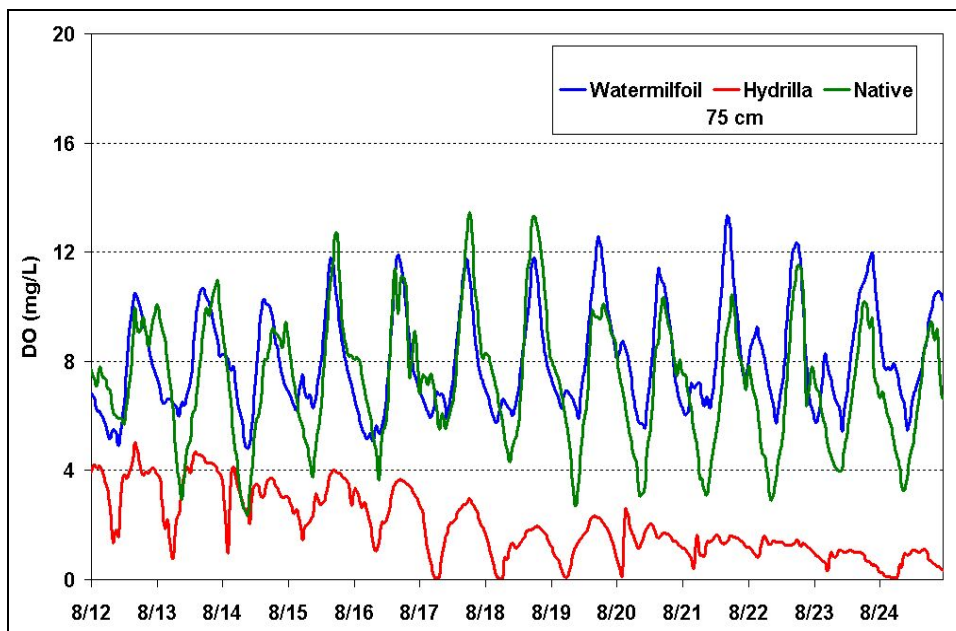


Figure 35. Dissolved oxygen was measured hourly in August at the 75-cm depth in ponds dominated by canopies of Eurasian watermilfoil (pond 41), hydrilla (pond 8), and native plants (pond 15).

DO concentrations below 5.0 mg/L are stressful to fish and other aquatic life; this and lower concentrations may be lethal when exposure is prolonged. Periods of low DO were recorded in all ponds during the study (Figures 36 and 37). At the 25-cm depth, low DO

was generally recorded during early morning and occurred in watermilfoil ponds 10 percent of the time and in hydrilla and native ponds about 30 percent of the time. At 75 cm, low DO occurred in watermilfoil ponds about 30 percent of the time (early morning), in hydrilla ponds about 80 percent of the time (all times except late afternoon), and in native ponds about 50 percent of the time (morning). Because many of the low DO events at both depths overlapped, fish in all ponds were exposed to stressful conditions from time to time. Fish in watermilfoil ponds were least likely to be stressed by low DO, whereas fish in hydrilla ponds were most likely to be stressed by low DO. During periods of low DO, fish often respond by gasping at the surface, where atmospheric exchange supplies oxygen in quantities sufficient to sustain survival. While moderately dense canopies of watermilfoil and open canopies of native plants permit this activity, the dense canopy of hydrilla does not, and may contribute to fish stress and even mortality.

Concentrations of DO suitable for fish (5-10 mg/L) occurred in watermilfoil and native ponds about half of the time. In hydrilla ponds, suitable concentrations of DO occurred only about a third of the time. Periods of low DO were attributed to respiration rates exceeding oxygen replenishment, and were most likely to occur in deeper water during low light periods (early morning). Periods of high DO were attributed to photosynthesis by plants.

When supersaturated (110 percent maximum dissolved concentrations), DO is stressful to fish and other aquatic life: at temperatures prevalent in experimental ponds, 10 mg/L DO was generally supersaturated (Boyd 1979). Periods of DO supersaturation occurred in all ponds, usually during mid- and late afternoon (Figures 36 and 37). At 25 cm, high DO was recorded in watermilfoil ponds about 45 percent of the time, in hydrilla ponds about 30 percent of the time, and in native ponds about 10 percent of the time. At 75 cm, high DO occurred in watermilfoil ponds 15 percent of the time, in hydrilla ponds less than 5 percent of the time, and in native ponds about 5 percent of the time.

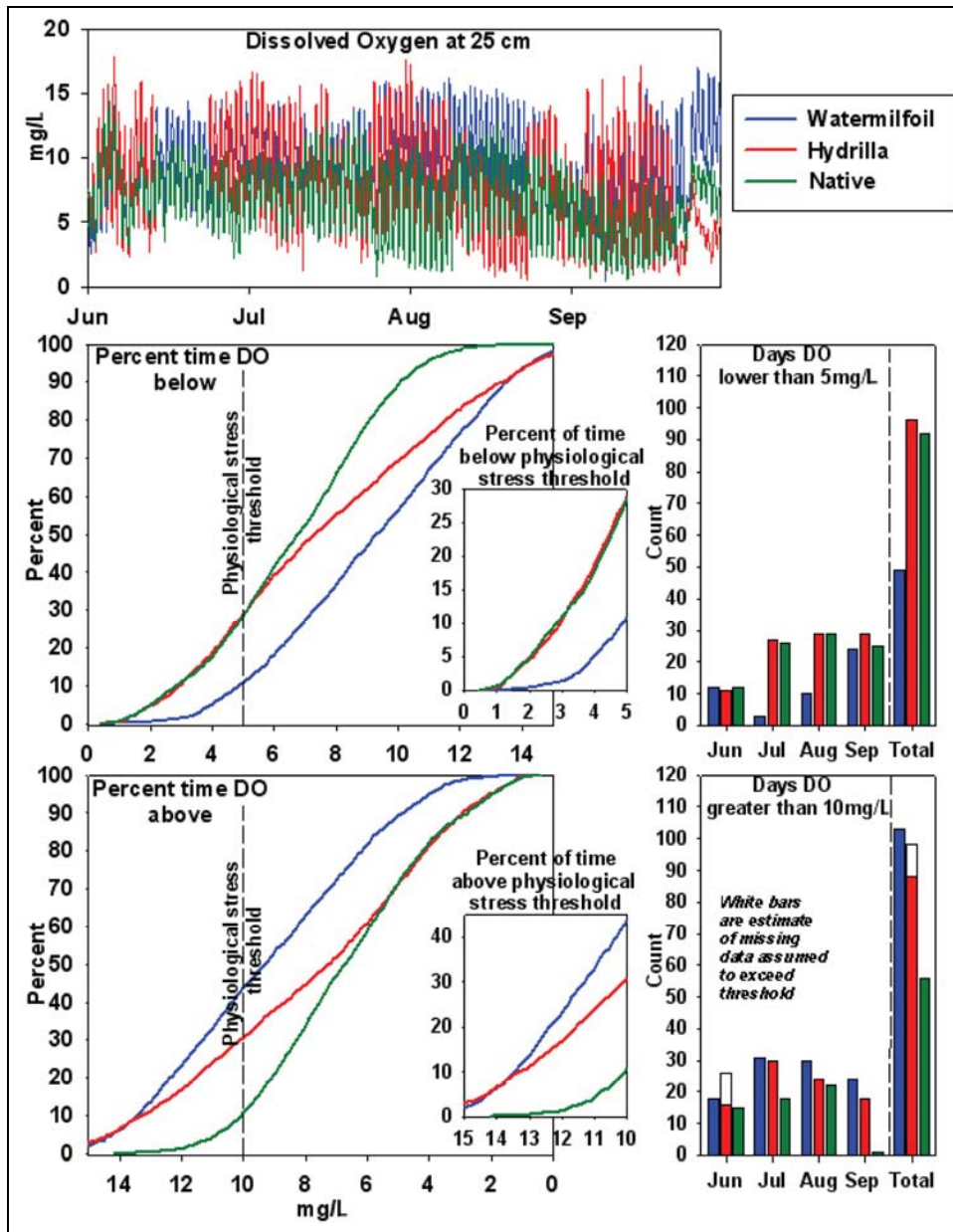


Figure 36. Concentrations of dissolved oxygen outside of the range suitable for fish (5-10 mg/L) occurred most frequently in hydrilla (below 5 mg/L) and watermilfoil (above 10 mg/L) ponds at the 25-cm depth.

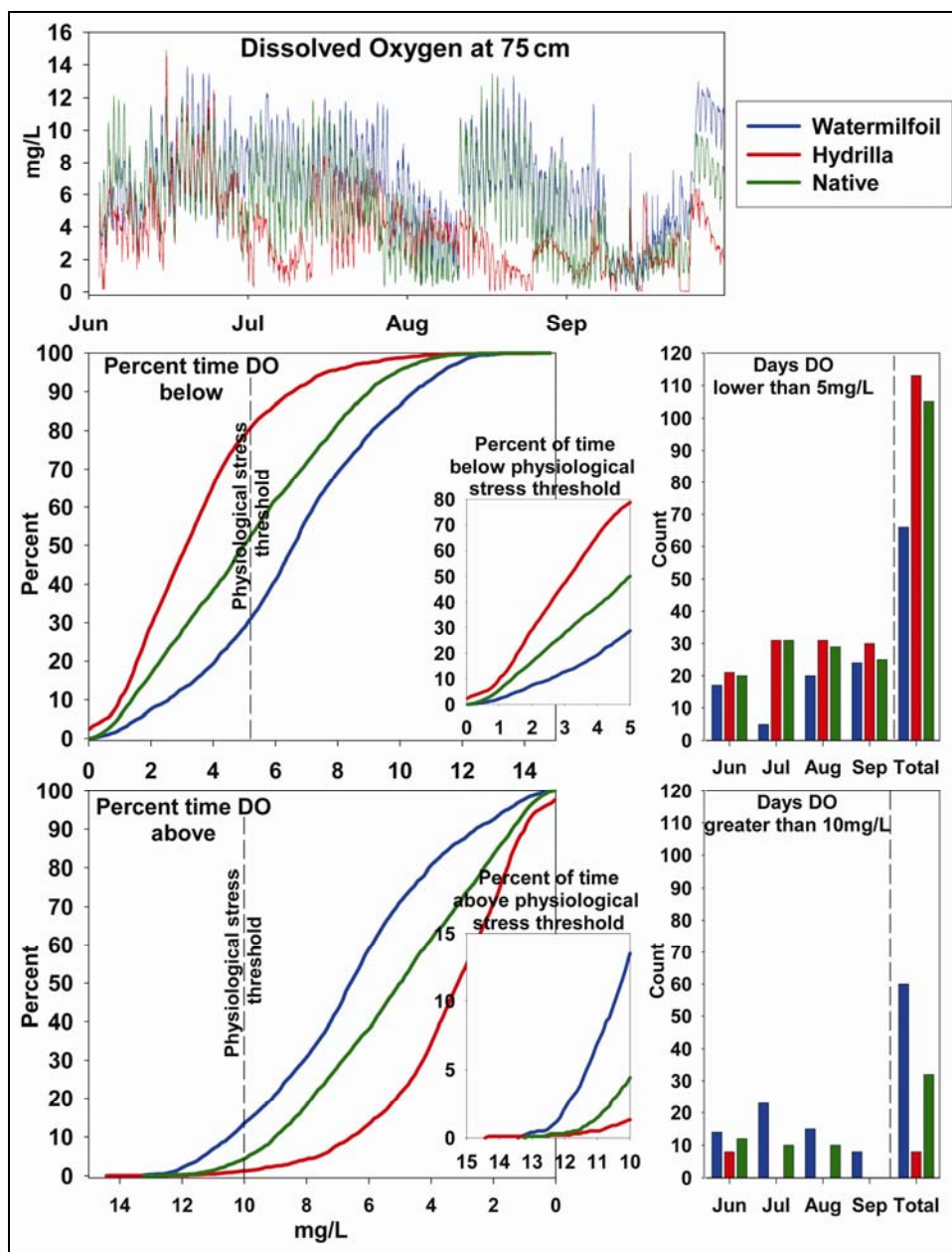


Figure 37. Concentrations of dissolved oxygen outside of the range suitable for fish (5-10 mg/L) occurred most frequently in hydrilla (below 5 mg/L) and watermilfoil (above 10 mg/L) ponds at the 75-cm depth.

pH:

pH in experimental ponds was measured hourly at two depths (25 cm and 75 cm) from June through September. Differences were attributed primarily to two canopy characteristics, both of which affected photosynthetic rates: 1) biomass, and 2) shading of deeper water. Degrees of mixing between depths may have also contributed to pH differences. Watermilfoil ponds exhibited highest median pH

at both depths (Table 5) due to a relatively high biomass combined with a moderate oxygen demand. Although daytime pH in hydrilla ponds was generally higher than in watermilfoil ponds (due to greater biomass and photosynthetic rates), nighttime pH was lower (due to higher respiration rates), resulting in a lower median pH. Native pond median pH was lowest overall, reflecting moderate biomass and oxygen demand.

Table 5. Median hourly pH measured at the 25- and 75-cm depths in experimental ponds.

Depth (cm)	Watermilfoil pH units	Hydrilla pH units	Native pH units
25	9.2	8.9	8.4
75	8.6	7.9	7.9

In June, pH in watermilfoil ponds ranged from 8.5 to 10.0 at 25 cm and 7.7 to 9.5 at 75 cm (Figure 38). Mean differences in pH between depths were moderate (0.5) and occurred on days with and without rainfall (or cloud cover), indicating some light penetration and mixing. Diel fluctuations occurred at both depths, regardless of the occurrence of rainfall.

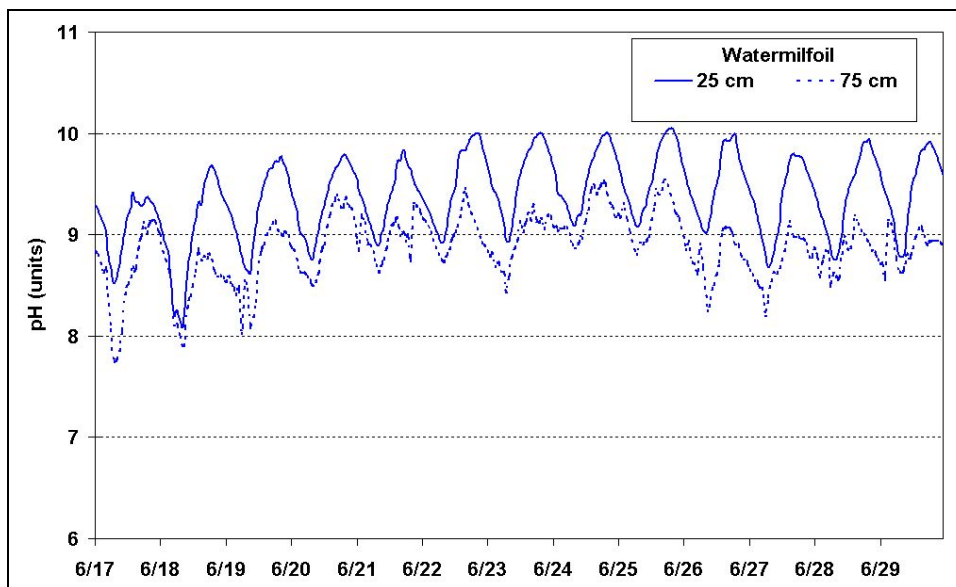


Figure 38. Hourly pH recorded at two depths in a watermilfoil pond (pond 40) during a two-week period in June 2000. Data for the period June 4-June 15 were not available.

During August, pH in watermilfoil ponds ranged from 8.2 to 10.0 at 25 cm and 7.9 to 9.3 at 75 cm, similar to pH in June (Figure 39). Mean differences in pH between depths were moderate (0.6). Diel fluctuations were greatest at 25 cm, but occurred at both depths.

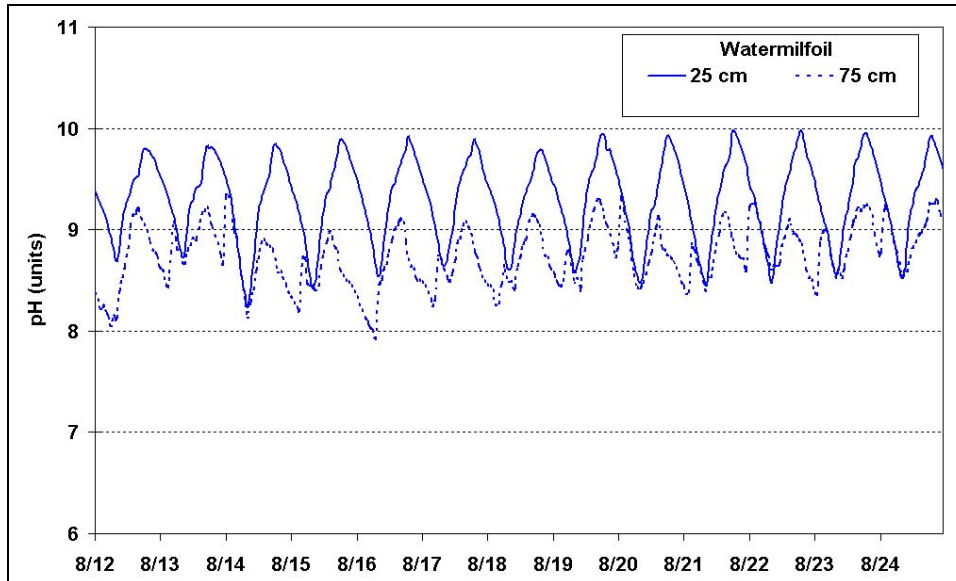


Figure 39. Hourly pH recorded at two depths in a watermilfoil pond (pond 41) during a two-week period in August 2000.

In June, pH in hydrilla ponds ranged from 7.1 to 10.4 at 25 cm and 7.3 to 9.2 at 75 cm (Figure 40). Mean differences in pH between depths were moderate (0.6), although they were reduced on days with rainfall (or cloud cover). Differences were likely due to high photosynthetic rates at 25 cm and reduced photosynthetic rates at 75 cm (no light penetration), as well as poor mixing between depths. Diel fluctuations were greatest at 25 cm, but occurred at both depths regardless of the incidence of rainfall.

In August, pH in hydrilla ponds ranged from 7.2 to 10.2 at 25 cm and 7.4 to 8.4 at 75 cm, similar to levels seen in June, except on days with rainfall or cloud cover (Figure 41). Mean differences in pH between depths were high (0.9), indicating higher photosynthesis rates at 25 cm and poor mixing. Diel fluctuations were greatest at 25 cm, but occurred at both depths.

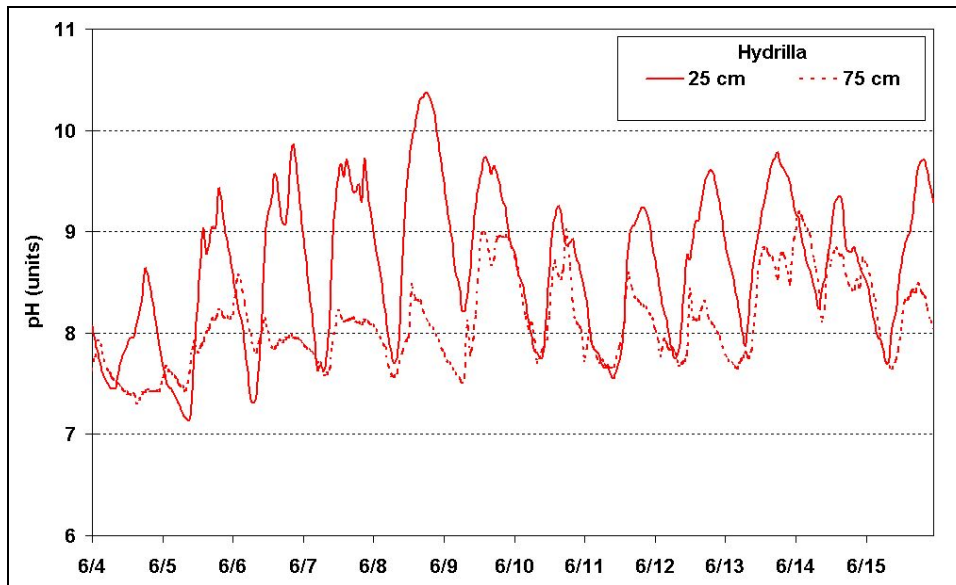


Figure 40. Hourly pH recorded at two depths in a hydrilla pond (pond 8) during a two-week period in June 2000.

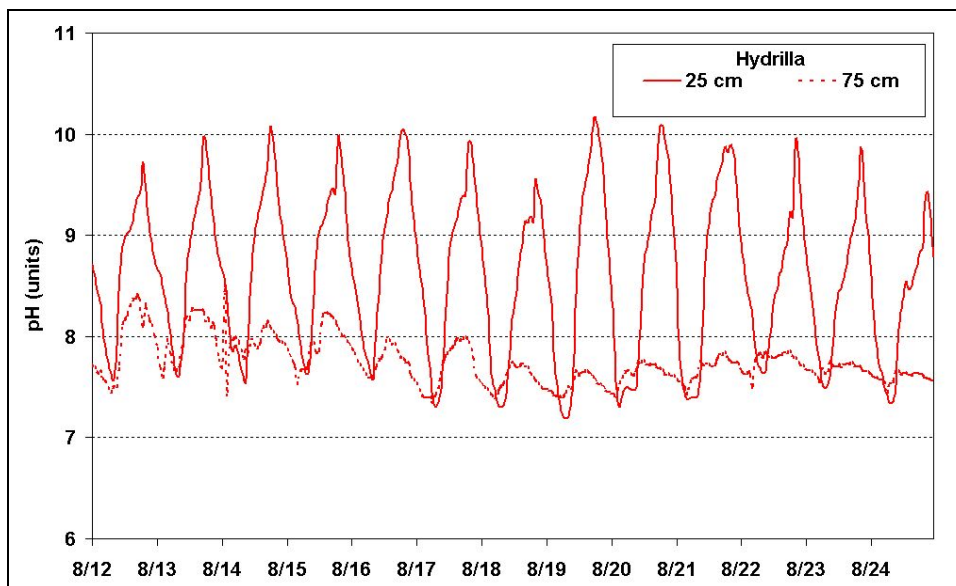


Figure 41. Hourly pH recorded at two depths in a hydrilla pond (pond 8) during a two-week period in August 2000.

In June, pH in native ponds ranged from 7.4 to 9.2 at 25 cm and 7.5 to 8.9 at 75 cm (Figure 42). Mean differences in pH between depths were low (0.1), and likely due to light penetration beneath the canopy and mixing between depths. Differences were reduced on days with rainfall (or cloud cover). Diel fluctuations occurred at both depths regardless of the incidence of rainfall.

In August, pH in native ponds ranged from 7.9 to 9.7 at 25 cm and 7.7 to 9.3 at 75 cm, similar to pH in June, except on days with rainfall or cloud cover (Figure 43). Mean differences in pH between depths were low (0.3). Diel fluctuations occurred at both depths.

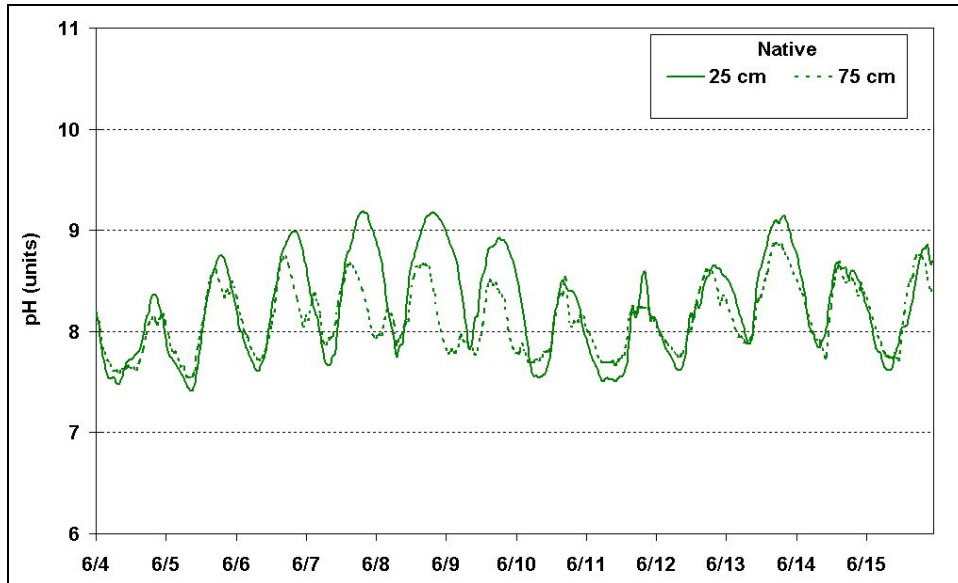


Figure 42. Hourly pH recorded at two depths in a native pond (pond 14) during a two-week period in June 2000.

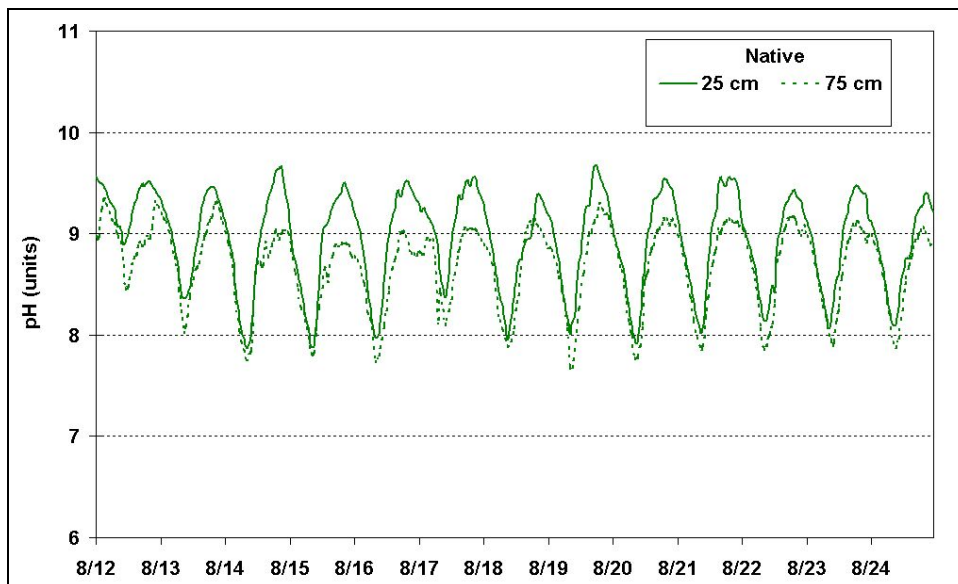


Figure 43. Hourly pH recorded at two depths in a native pond (pond 15) during a two-week period in August 2000.

In June, daytime pH was highest in hydrilla ponds and lowest in native ponds at 25 cm, due to higher canopy biomass in hydrilla ponds (Figure 44). On days with rainfall or cloud cover, pH in both was reduced. Nighttime pH was similar in both ponds; the greater drop in pH in hydrilla ponds was indicative of higher respiration rates of the canopy biomass. Watermilfoil pH data were not collected from 25 cm during this period due to equipment malfunction.

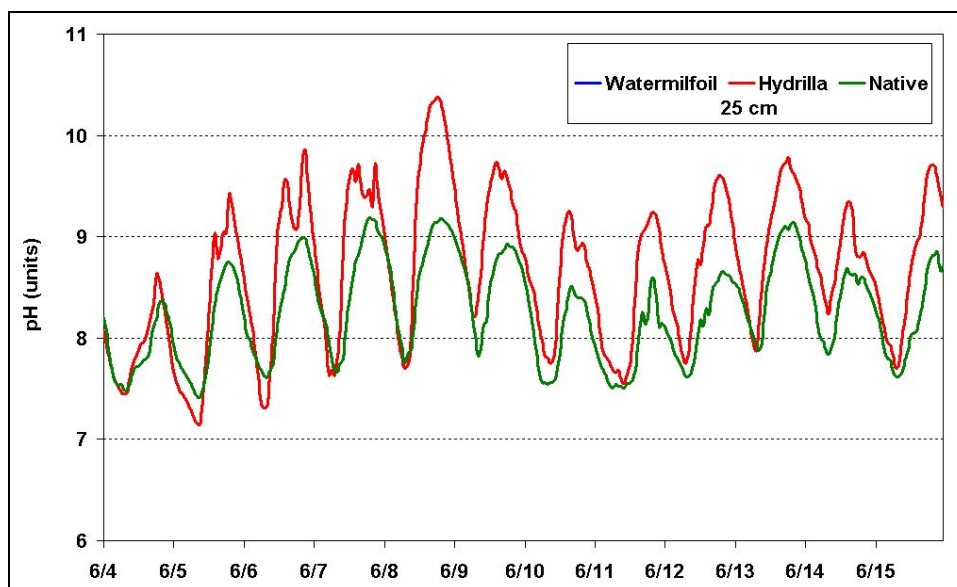


Figure 44. June 2000 hourly pH recorded at 25 cm in ponds dominated by canopies of hydrilla (pond 8) and native plants (pond 14). Data from watermilfoil ponds were not available during this period.

In August, daytime pH was highest in hydrilla and watermilfoil ponds at 25 cm, reflecting high biomass of those canopies (Figure 45). Lower biomass in native canopies resulted in lower daytime pH. Nighttime pH was highest in watermilfoil ponds, indicating relatively low respiration rates. Diel fluctuations in native pH were the slightest, due to lower canopy biomass (photosynthetic and respiration rates).

In June, daytime and nighttime pH measurements were similar in all ponds at 75 cm (Figure 46), although for different reasons. Daytime rises in hydrilla pH at 75 cm were most likely a result of mixing with high pH water at 25 cm that was able to occur before development of dense surface canopies. Native pH at 75 cm was more likely influenced by photosynthesis occurring at that depth. Although 25-cm pH was not recorded in watermilfoil ponds at that time, later in

June (17-29) differences were recorded, likely caused by both factors: high 25-cm pH (mixing) and photosynthesis at 75 cm.

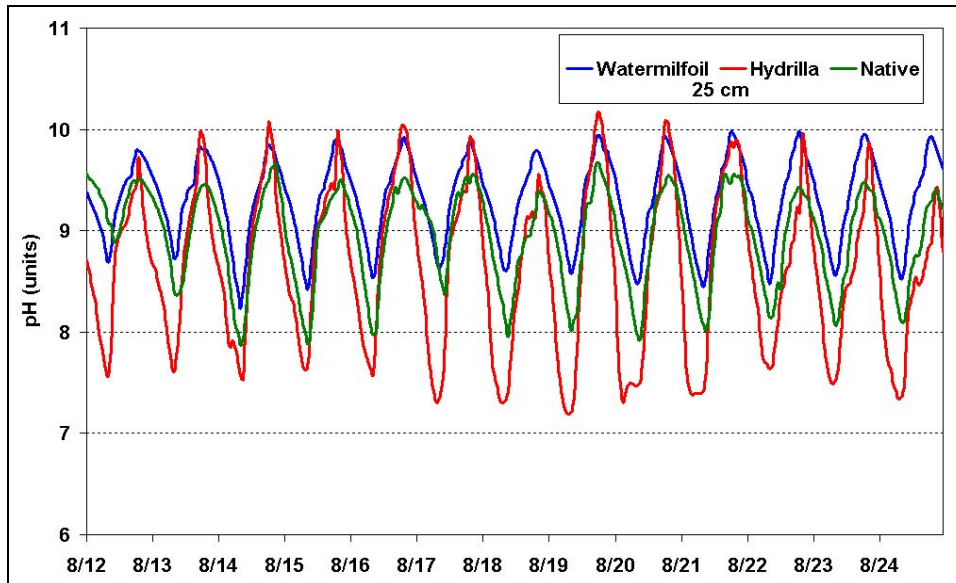


Figure 45. August 2000 hourly pH recorded at 25 cm in ponds dominated by canopies of Eurasian watermilfoil (pond 41), hydrilla (pond 8), and native plants (pond 15).

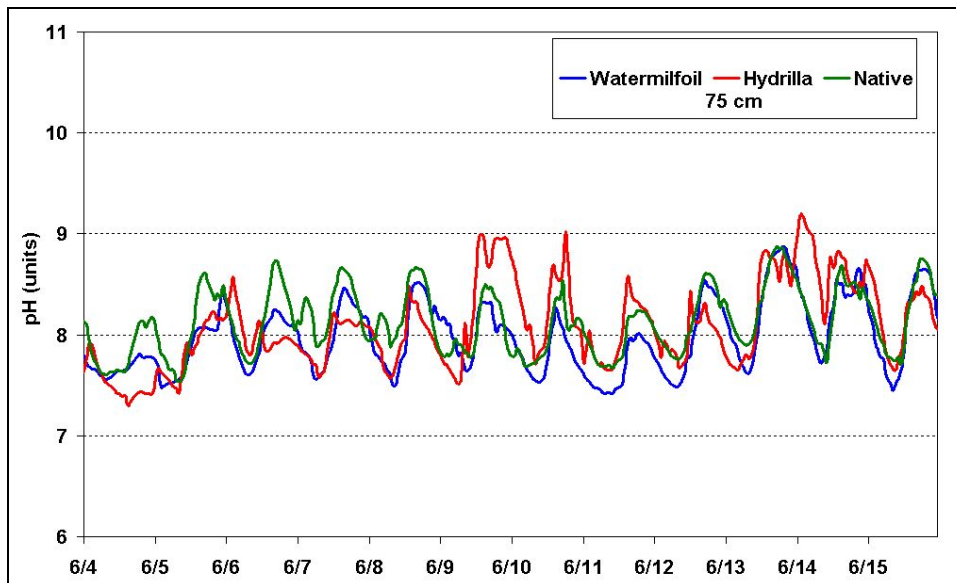


Figure 46. June 2000 hourly pH recorded at 75 cm in ponds dominated by canopies of Eurasian watermilfoil (pond 39), hydrilla (pond 8), and native plants (pond 14).

By August, daytime pH had increased in watermilfoil and native ponds at 75 cm, reflecting increased photosynthetic activity at that depth as well as mixing with high pH water at 25 cm (Figure 47). Daytime pH had decreased in hydrilla ponds, indicating continued absence of photosynthesis and less mixing with high pH water at

25 cm. Nighttime pH was highest in watermilfoil ponds, indicating lower respiration rates than in native ponds. Nighttime pH in hydrilla ponds remained low.

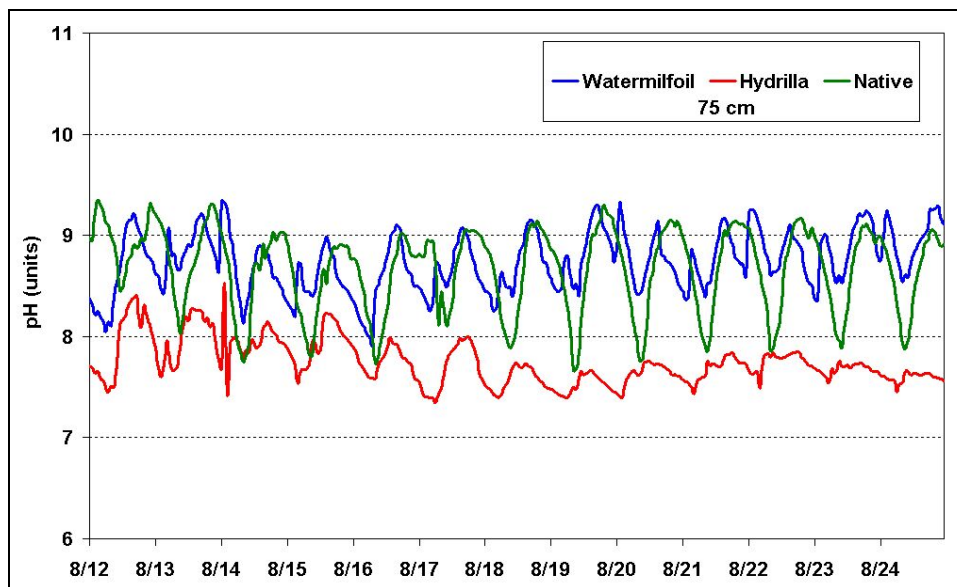


Figure 47. August 2000 hourly pH recorded at 75 cm in ponds dominated by canopies of Eurasian watermilfoil (pond 41), hydrilla (pond 8), and native plants (pond 15).

Daily pH range variance was moderate in watermilfoil and native ponds, but high in hydrilla ponds at the 25-cm depth (Figure 48). High pH (9.5 or above) occurred on most days in watermilfoil and hydrilla ponds, and infrequently in native ponds. Generally, pH at 75 cm was below 9.0, except in watermilfoil ponds, which occasionally exceeded 9.5. High pH typically occurred during mid- to late afternoon, coinciding with peak photosynthetic activity.

High pH (9.5 or above) is stressful to fish and other aquatic life. At 25 cm, high pH occurred in watermilfoil and hydrilla ponds about 20 percent of the time, and in native ponds less than 5 percent of the time. Because deeper water usually exhibited lower pH, fish and other mobile aquatic organisms could generally avoid high pH by moving deeper. However, on some occasions, pH was high throughout the water column in hydrilla (10 days) and watermilfoil (5 days), and fish were likely stressed. Fish were less likely to be stressed by high pH in native ponds, where no readings over 9.5 were recorded in deeper water. The alkaline deathpoint for freshwater fish (11.0) was not recorded in any pond during the study.

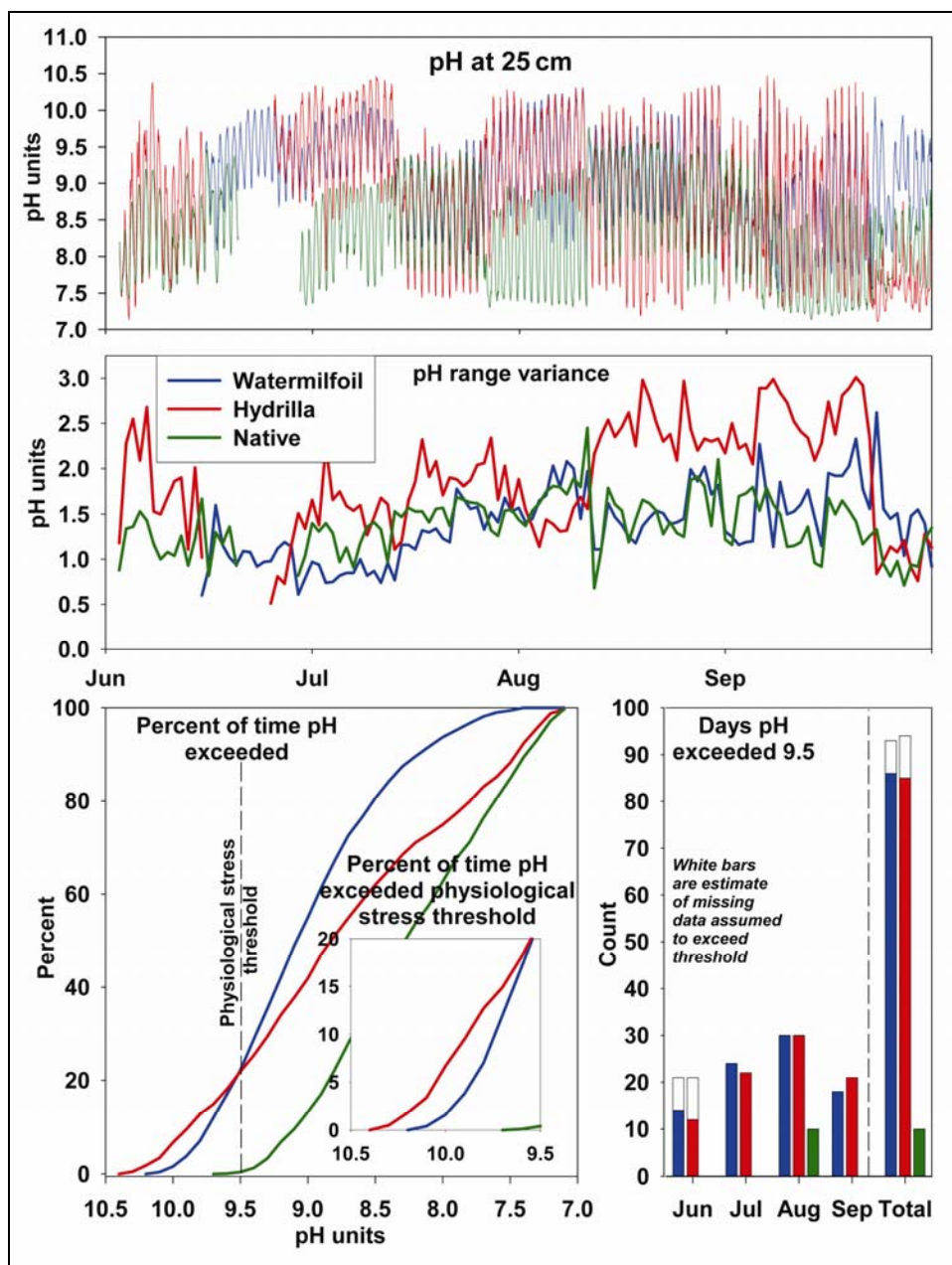


Figure 48. pH exceeded levels stressful to fish most frequently in watermilfoil and hydrilla ponds at the 25-cm depth.

Other water chemistry

Water chemistry was similar in all ponds, regardless of canopy dominance by any one species, with some exceptions (Table 6). Alkalinity was similar in all ponds; reduction in alkalinity relative to source water was due to carbon uptake by plants during photosynthesis. Higher turbidity and total suspended solids in hydrilla and watermilfoil ponds (relative to native ponds) were attributed to

particulate matter being knocked from leaves and stems during sampling, and were not characteristic of the water quality in those ponds. Turbidity was otherwise lower in study ponds when compared with source water. Phosphorus (total and soluble reactive) concentrations were generally lower in study ponds than in source water, indicating use by plants, except in hydrilla ponds: elevated phosphorus was attributed to release from sediments during periods of low dissolved oxygen concentrations. Nitrogen (nitrate and ammonia) concentrations were similar in all ponds, but lower than source water, indicating use by plants. Chlorophyll *a* concentrations were highest in hydrilla and watermilfoil ponds, reflecting organic debris knocked free from leaves and stems during sampling. All ponds exhibited higher chlorophyll *a* concentrations than source water. Sodium concentrations were similar in study ponds, about twice that of source water. Calcium concentrations were similar in all ponds but about half that of source water, indicating use by plants. Potassium and magnesium concentrations were similar in all ponds and source water. Water quality measurements are graphed in Appendix B.

Table 6. Average water quality measurements made in study ponds. Pond 39 was dominated by native species and pond 17 was dominated by hydrilla by the end of the study. Source water (LL) is from Lake Lewisville in Denton County, Texas.

Parameter	LL	Dominant Species									
		Watermilfoil			Hydrilla			Native			
Pond number	LL	39	40	41	8	9	20	14	15	17	28
Alkalinity (mg/L as CaCO ₃)	101	68	63	59	74	60	63	84	67	76	78
Turbidity (NTU)	7.3	6.6	5.7	5.1	6.2	8.6	12.9	3.2	2.7	2.8	4.1
Total suspended solids (mg/L)	5	16	7	11	11	17	23	5	3	5	5
Total phosphorus (mg/L)	0.05	0.06	0.04	0.04	0.07	0.08	0.07	0.04	0.04	0.04	0.04
Soluble reactive phosphorus (mg/L)	0.007	0.002	0.001	0.001	0.002	0.004	0.007	0.000	0.001	0.002	0.001
Nitrate-nitrogen (mg/L)	0.16	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.03
Ammonia nitrogen (mg/L)	0.07	0.02	0.02	0.03	0.05	0.02	0.03	0.03	0.03	0.02	0.02
Chlorophyll <i>a</i> (mg/L)	5.4	20.3	10.0	11.6	22.0	14.2	22.9	8.9	6.7	9.4	6.8
Sodium (mg/L)	18.3	36.4	35.9	37.1	37.6	36.3	36.4	35.6	36.2	36.9	37.4
Potassium (mg/L)	4.9	4.9	5.2	5.2	5.5	4.6	5.3	5.5	5.3	5.1	5.4
Calcium (mg/L)	41.0	17.4	16.6	15.2	19.0	16.1	16.6	21.8	17.4	19.1	19.4
Magnesium (mg/L)	3.8	3.5	3.7	3.6	3.7	3.8	3.9	3.9	3.8	3.9	3.8

Plankton

Densities (counts per liter) of plankton in the developing plant communities were very low, similar to those reported from unfertilized earthen ponds (Boyd 1979). Despite the addition of nitrogen to sediments during pond preparation, limited resources (nutrients and light) resulting from the presence of macrophytes and epiphytic organisms evidently suppressed plankton communities.

Densities were variable between ponds, although some similarities occurred in ponds dominated by like vegetation (Figure 49). In general, counts in watermilfoil ponds were most variable, with highest numbers occurring in June and November and lowest numbers occurring in August and September. Hydrilla plankton counts were lowest in June, highest in August, and moderate in September and November. Counts in native ponds were similar at all sample periods.

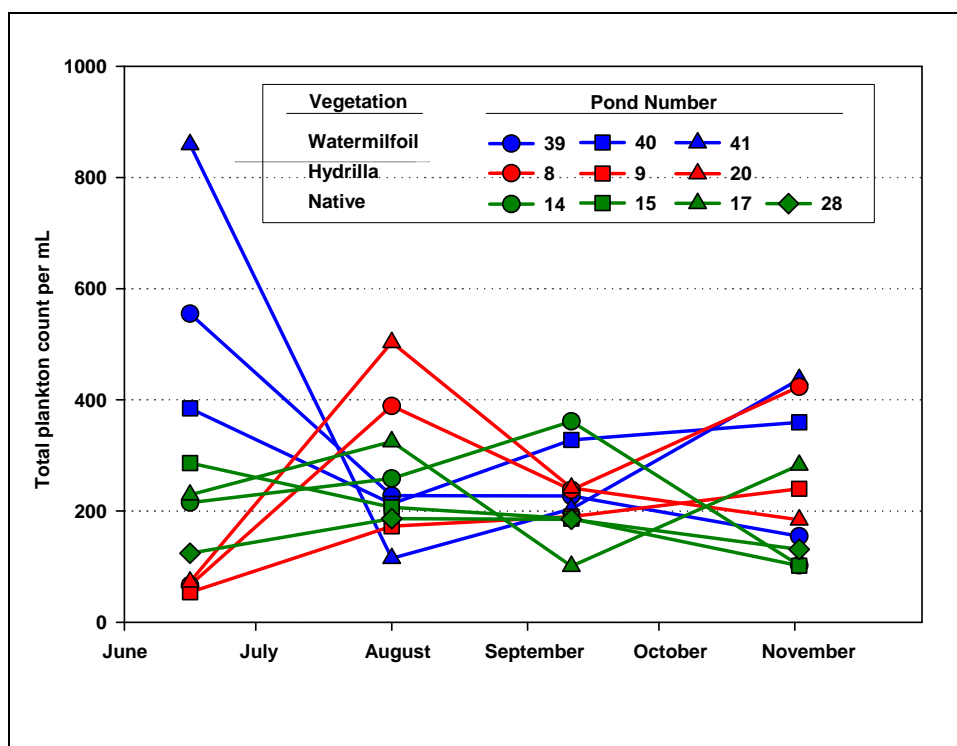


Figure 49. Plankton densities were low due to the presence of macrophytes, but were least variable among ponds dominated by native vegetation.

Phytoplankton were more abundant than zooplankton and generally represented 80-95 percent (by count) of the community. Phytoplankton were dominated by green algae (Chlorophycophyta) in all ponds on all sample dates (88.1 percent), but also included

blue-green algae (Cyanochloronta (9.4 percent) and diatoms (Chrysophycophyta, 2.5 percent). The most abundant phytoplankton in all ponds were multi-flagellated reproductive spores (zoospores of filamentous species), which represented over 60 percent of the green algae present and over 50 percent of all phytoplankton. Zooplankton generally accounted for less than 15 percent of the plankton community and were represented primarily by rotifers (44 percent), microcrustaceans such as *Daphnia* and *Cyclops* (37 percent), and ciliates (16 percent).

In June, total plankton counts were highest in watermilfoil ponds and lowest in hydrilla ponds (Figure 50). Higher counts in watermilfoil ponds were a result of elevated numbers of zoospores in those ponds: higher water temperatures (by about 2 °C) in watermilfoil ponds evidently stimulated reproduction by the algae. Low plankton counts in hydrilla ponds may have been due to low concentrations of nitrogen at that time. Zooplankton numbers were relatively low compared to phytoplankton in all ponds, representing less than 5 percent total counts. New growth of macrophytes may not yet have supported epiphytic (algal) growth necessary to support higher numbers of grazing zooplankton species.

By August, total plankton counts were highest in hydrilla ponds, a result of zoospore production possibly stimulated by elevated phosphorus concentrations occurring in those ponds (Figure 51). Zoospore counts had declined in watermilfoil ponds since June, resulting in lower overall counts. Plankton counts remained stable between June and August in native ponds. Zooplankton abundance was higher in most ponds in August, averaging about 11 percent of the total plankton count, possibly a result of epiphyte (food) establishment on maturing macrophyte communities.

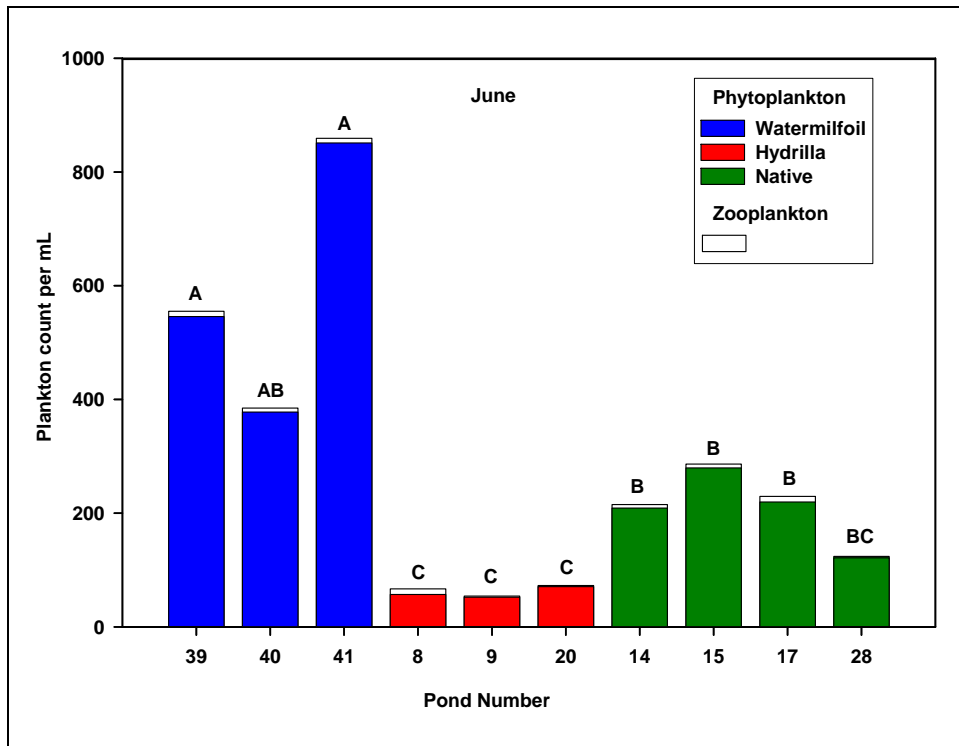


Figure 50. Plankton densities measured in watermilfoil, hydrilla, and native ponds in June 2000. Letters above bars represent significant differences ($p > 0.05$).

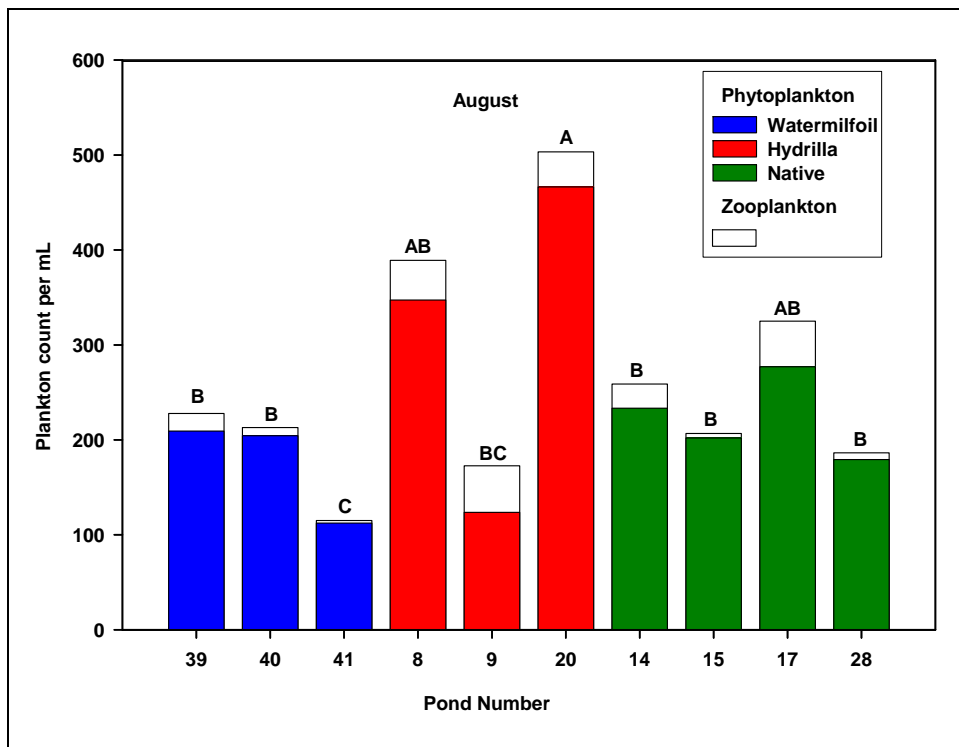


Figure 51. Plankton densities measured in watermilfoil, hydrilla, and native ponds in August 2000. Letters above bars represent significant differences ($p > 0.05$).

By September, total plankton counts were variable in most ponds (Figure 52). Zoospore production had declined in hydrilla ponds; although phosphorus concentrations remained high, the canopy had further developed and light penetration into the water column was reduced, probably limiting phytoplankton growth. Higher counts in one watermilfoil pond (40) and one native pond (14) were due to higher numbers of zoospores, while higher numbers in one hydrilla pond (8) was due to increases in zooplankton. Zooplankton abundance was similar in most ponds, averaging about 9 percent, but was high in two hydrilla ponds (8 and 9) due to increased numbers of rotifers. Rotifer numbers may have increased in response to high numbers of zoospores that occurred earlier (August), but had not yet declined following zoospore declines.

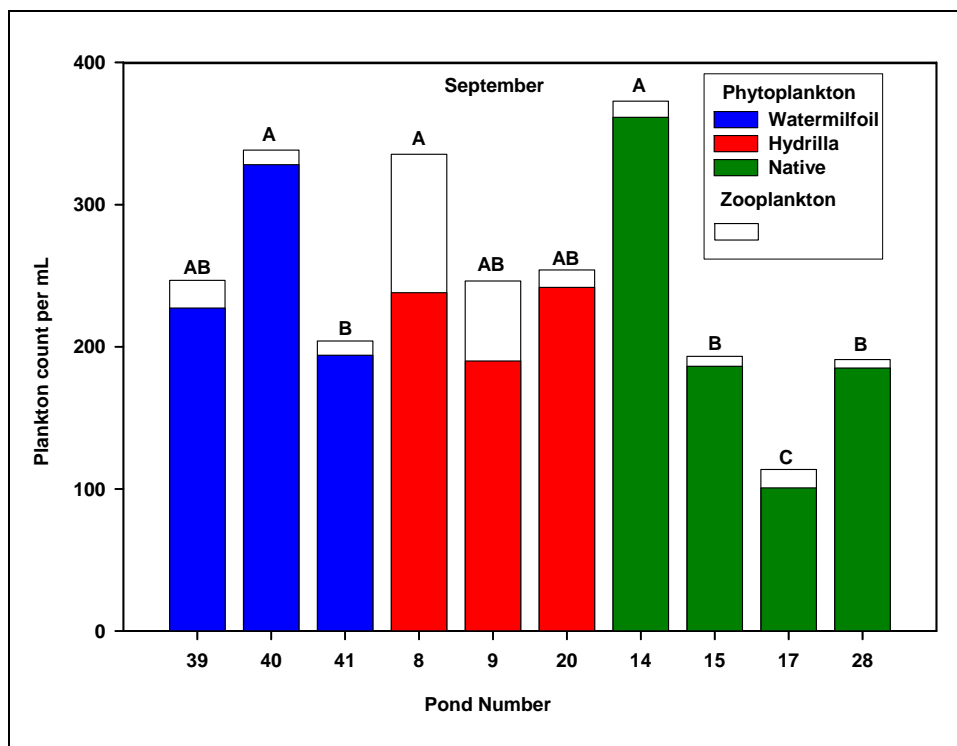


Figure 52. Plankton densities measured in watermilfoil, hydrilla, and native ponds in September 2000. Letters above bars represent significant differences ($p > 0.05$).

By November, zoospore production resulted in higher total plankton counts in two watermilfoil ponds (40 and 41). Counts were low in the third watermilfoil pond (39), which was no longer dominated by watermilfoil (Figure 53). Counts were higher in one hydrilla pond (8) due to greater numbers of zoospores and rotifers. Counts in other hydrilla ponds were similar those observed in September. Counts

were higher in one native pond (17, dominated by hydrilla at that time) due to zoospore production. Other native pond counts were similar to those seen in September.

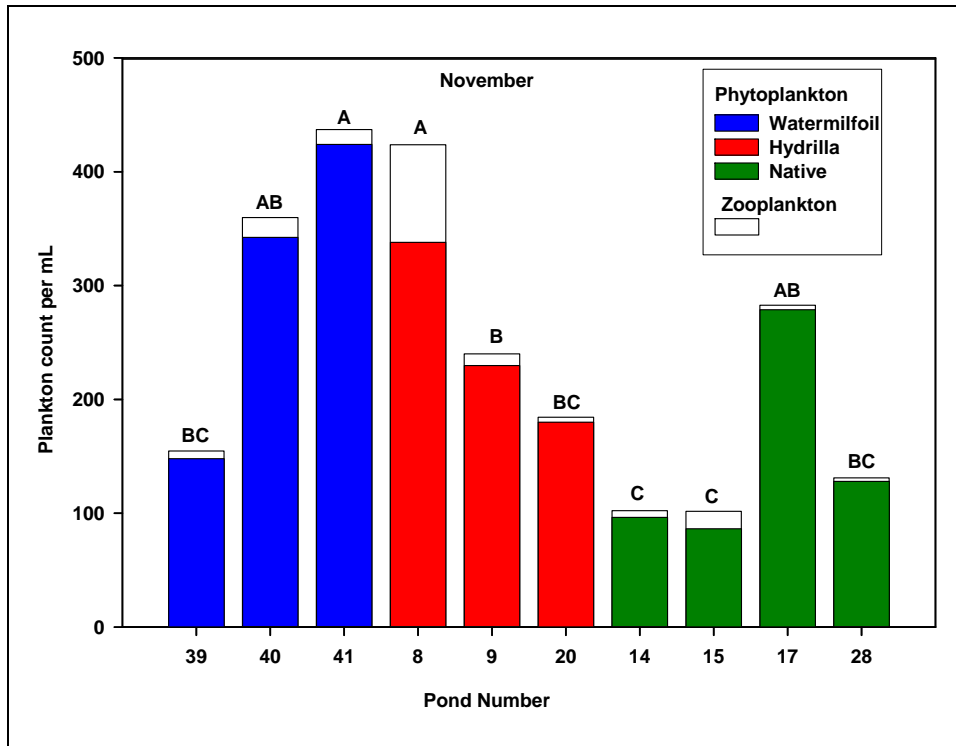


Figure 53. Plankton densities measured in watermilfoil, hydrilla, and native ponds in November 2000. Letters above bars represent significant differences ($p > 0.05$).

Macroinvertebrates

Macroinvertebrates were collected in early June, late July, and early November at four stations within each pond, identified to a reasonable taxon, and counted (Table 7). Most groups collected occurred in all ponds on all sample dates, and were comprised of aquatic insects (predominantly chironomids and/or odonates), snails, and segmented worms.

Table 7. Macroinvertebrate taxa collected from study ponds.

Phylum	Class	STET	Common Order name	Family	Genus		
Arthropoda	Insecta	Odonata	Dragonflies & damselflies	Coenaagrionidae	<i>Enallagma</i>		
				Lestidae	<i>Lestes</i>		
				Libellulidae	<i>Libellula</i>		
				Aeshnidae	<i>Anax</i>		
				Baetidae	<i>Callibaetis</i>		
		Ephemeroptera	Mayflies	Caenidae	<i>Caenis</i>		
		Hemiptera	True bugs	Notonectidae	<i>Buenoa</i>		
				Belastomatidae	<i>Belastomatidae</i>		
				Corixidae	<i>Neocorixa</i>		
				Mesoveliidae	<i>Mesovelia</i>		
				Nepiidae			
		Coleoptera	Beetles	Hydrophilidae	<i>Berosus</i> <i>Tropisternus</i>		
				Haliplidae	<i>Peltodytes</i> <i>Haliplus</i>		
		Diptera	Flies	Chironomidae	<i>Chironominae</i> <i>Tanypodinae</i> <i>Orthoclaadiinae</i> Pupae		
					Chaoboridae	Pupae	
					Ceratopogonidae		
					Stratiomyidae		
				Culicidae			
				Trichoptera	Stoneflies	Hydroptilidae	
<i>Mollusca</i>	Gastropoda				Snails	Physidae	<i>Physa</i>
						Planorbidae	
Annelida	Oligochaeta		Segmented worms				

Total macroinvertebrate counts were variable, with significant differences detected only in hydrilla ponds over time ($\alpha=0.05$). Counts averaged 1,227 in June, 1,535 in July, and 1,717 in November (Figure 54). Higher averages in July and November were due primarily to increases in chironomids in two ponds (8 and 39). Otherwise, macroinvertebrate counts increased slightly in watermilfoil ponds, increased significantly in hydrilla ponds (between June and July), and decreased slightly in native ponds. These differences may have been due to season cycles and/or fish predation.

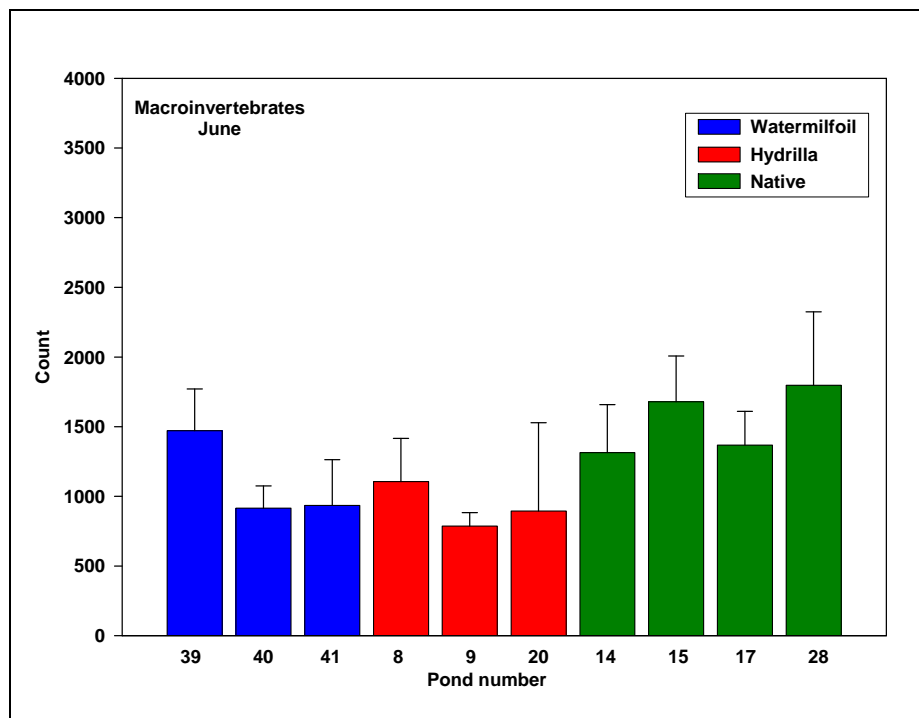


Figure 54. Macroinvertebrate counts increased over time in most ponds.

In June, macroinvertebrate counts averaged 1,107 in watermilfoil ponds (925 excluding pond 39), 930 in hydrilla ponds, and 1,539 in native ponds (1,597 excluding pond 17). Higher counts from pond 39 may have been related to the presence of significant stands of native vegetation in that pond. Although counts in native ponds were higher, no significant differences were detected (Figure 55). Odonates, chironomids, snails, and segmented worms were the most common macroinvertebrates collected from all ponds.

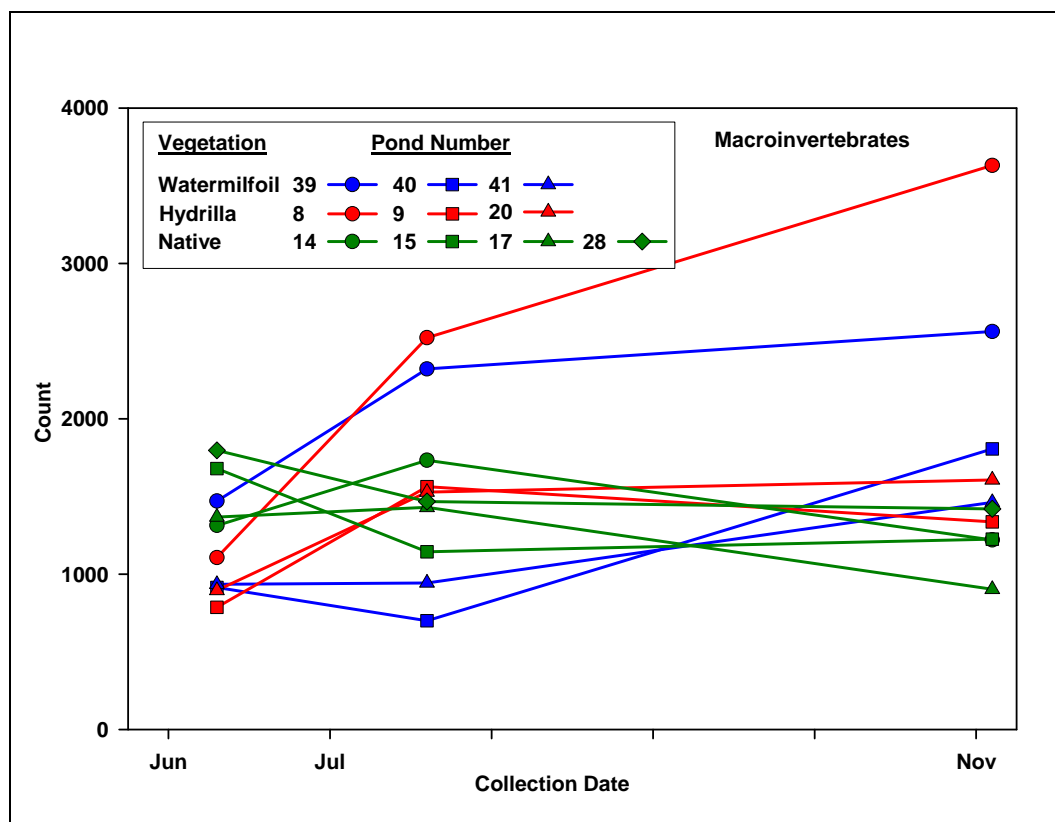


Figure 55. Numbers of macroinvertebrates collected from experimental ponds in June 2000 were not significantly different ($\alpha=0.05$).

In July, macroinvertebrate counts averaged 1,322 in watermilfoil ponds (822 excluding pond 39), 1,871 in hydrilla ponds, and 1,444 in native ponds (1,449 excluding pond 17); no significant differences were detected among ponds (Figure 56). Although average counts in watermilfoil ponds increased over those seen in June, this was due to increases in one pond (39), which was not clearly dominated by watermilfoil at that time. Counts in hydrilla ponds increased over those seen in June by nearly twofold. Counts in native ponds were slightly lower than those seen in June. Chironomids comprised the majority of counts in all ponds, followed by odonates, snails, and segmented worms.

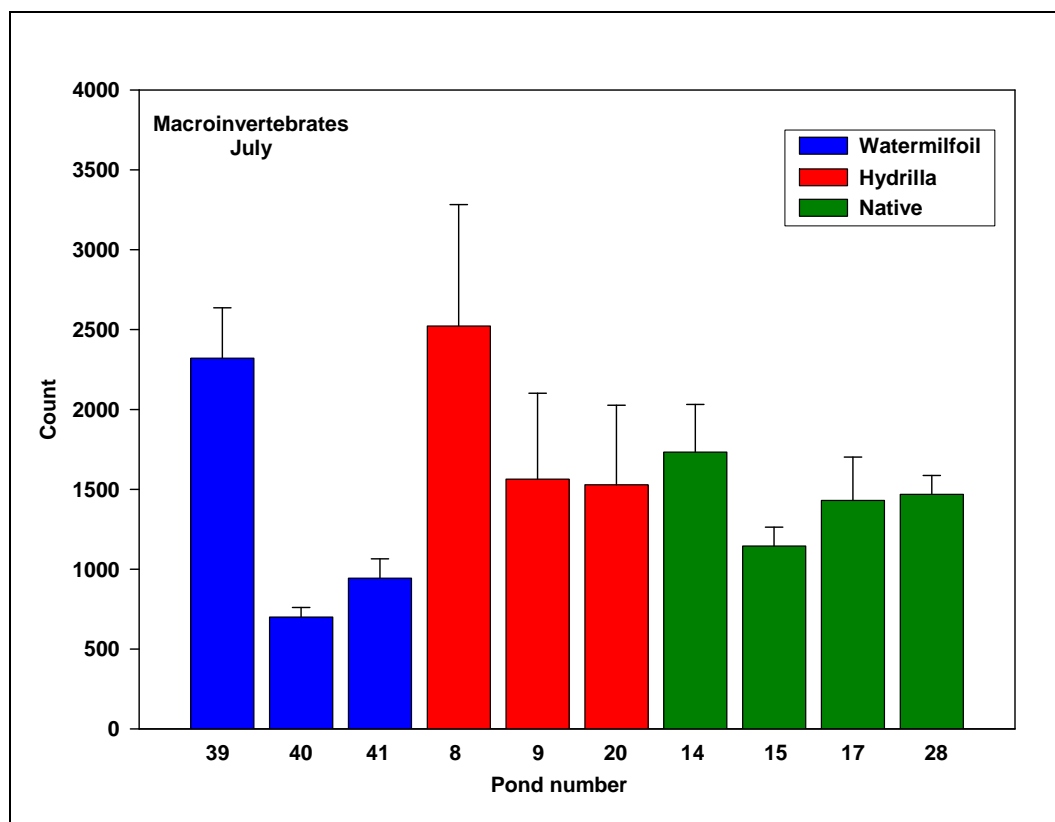


Figure 56. Numbers of macroinvertebrates collected from experimental ponds in June 2000 were not significantly different ($\alpha=0.05$).

In November, macroinvertebrate counts averaged 1,943 in watermilfoil ponds (1,634 excluding pond 39), 2,191 in hydrilla ponds, and 1,192 in native ponds (1,249 excluding pond 17); significantly higher numbers occurred in one hydrilla pond (8) and two watermilfoil ponds (39 and 40) (Figure 57). Counts in watermilfoil ponds increased over those seen in July, due primarily to higher counts of snails and segmented worms. Counts in hydrilla ponds increased over those seen in July, due mostly to increases in snails and segmented worms, particularly in one pond (8). Counts in native ponds were slightly lower than those seen in July. Chironomids comprised the majority of counts in all ponds, followed by snails and segmented worms (and odonates in hydrilla ponds).

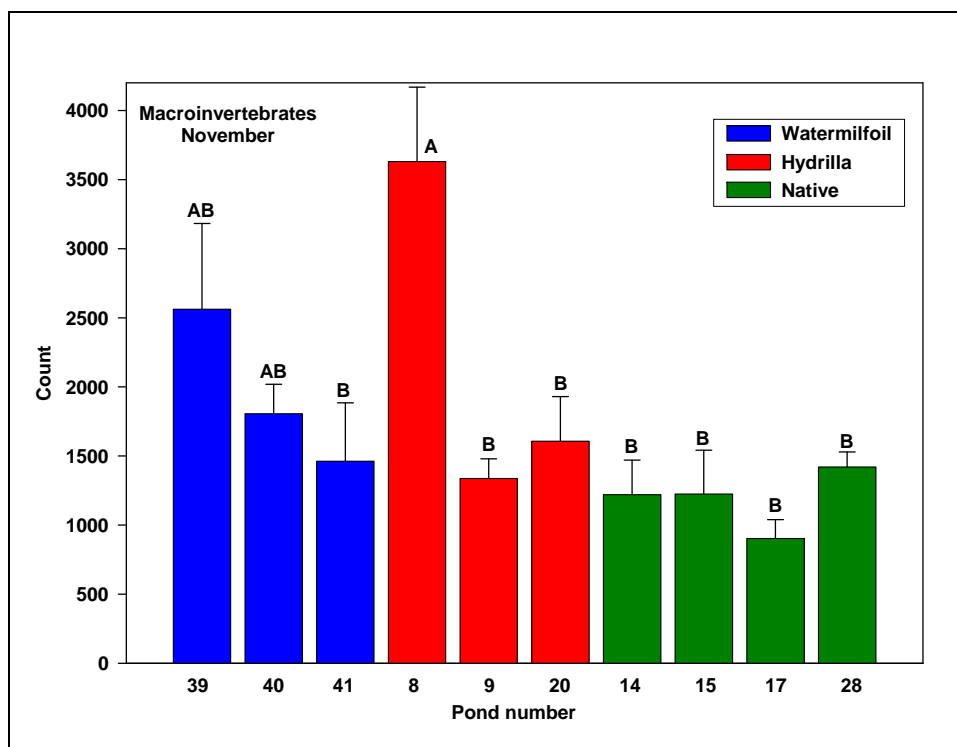


Figure 57. Numbers of macroinvertebrates collected from experimental ponds in November 2000 were significantly higher in several ponds ($\alpha=0.05$).

Aquatic plant species dominance (or canopy development) did not appear to be a factor in macroinvertebrate diversity. Species composition was similar among all ponds at all collection dates, although it generally shifted over time, most likely due to season cycles of aquatic insects (Table 8). In June, Shannon-Weaver diversity indices were highest, averaging 1.31 in watermilfoil ponds, 1.33 in hydrilla ponds, and 1.41 in native ponds. By July, indices had declined in all vegetation types, averaging 0.85 in watermilfoil ponds, 0.98 in hydrilla ponds, and 1.03 in native ponds. By November, indices increased in watermilfoil and hydrilla ponds, averaging 1.06 and 1.13, respectively, but declined slightly in native ponds, averaging 0.98.

Table 8. Shannon-Weaver diversity indices calculated for macroinvertebrate communities in experimental ponds.

Pond #	Treatment	June	July	November
39	Watermilfoil	1.34	0.86	1.15
40	Watermilfoil	1.27	0.83	0.95
41	Watermilfoil	1.32	0.87	1.09
8	Hydrilla	1.49	0.79	1.07
9	Hydrilla	1.54	1.00	1.14
20	Hydrilla	0.95	1.14	1.18
14	Native	1.52	1.04	0.88
15	Native	1.34	0.96	0.96
17	Native	1.50	1.06	1.02
28	Native	1.29	1.05	1.06

When individual macroinvertebrate groups (such as insect orders) were analyzed separately, additional statistical differences were detected, most notably in greater numbers of odonate larvae occurring in hydrilla-dominated ponds (Figure 58). High stem density typically associated with hydrilla may have served as cover to reduce predation on odonates, which have been reported as the primary food for small bass and adult bluegills in LAERF ponds (Morrow et al. 1990).

Fish

Juvenile largemouth bass and adult bluegills were stocked in fall 1999, following planting of aquatic vegetation. After one year (fall 2000), ponds were drained for a short period and stocked fish were collected and measured for length and weight. Young-of-the-year bass and bluegills were counted, and sub-samples taken for measurements. In general, greatest bass survival occurred in native ponds, greatest size was attained in native and hydrilla ponds, and greatest condition (relative weights, W_r) occurred in native ponds. Bass recruitment had occurred in one watermilfoil pond and two native ponds. Bass standing crop was highest in native ponds and lowest in hydrilla ponds. Bluegill recruitment had occurred in all ponds: bluegills were most numerous in native and watermilfoil ponds, but significantly smaller and in poorer condition in the latter. Numbers of

bluegills were low in hydrilla ponds.

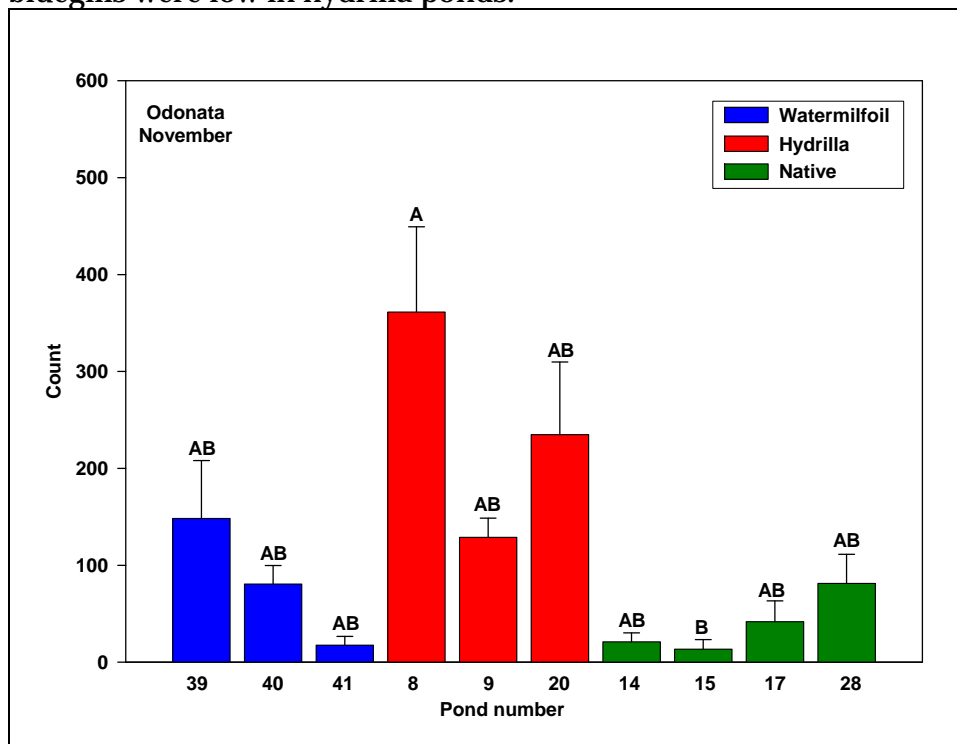


Figure 58. Odonata (dragonflies and damselflies) counts were highest in hydrilla ponds in November. The watermilfoil pond in which higher counts occurred (39) was not dominated by watermilfoil at that time. Lower counts in native and watermilfoil ponds may have reflected predation by bass and bluegill on odonate populations. Letters above bars indicate significant differences ($p > 0.05$).

Adult largemouth bass were recovered from all study ponds, and were presumed to represent surviving bass stocked the previous year (inlets were screened to prevent introduction of wild fish). Bass from some ponds (watermilfoil and native) were known to be lost to predation by great blue herons, and this likely occurred in others. Survival averaged 32 percent in watermilfoil ponds, 16 percent in hydrilla ponds, and 36 percent in native ponds (Figure 59). Survival was somewhat low (21 percent) in the native pond (17) that was dominated by hydrilla during part of the study, and when excluded from other native ponds, average survival in native ponds was 41 percent, slightly lower than survival in unvegetated Texas ponds reported elsewhere (Brown 1952). Macrophytes in all ponds supported predators (such as diving beetles and dragonfly larvae) capable of utilizing small bass as prey, possibly contributing to lower survival than unvegetated ponds. Lower survival in watermilfoil ponds may have resulted from early morning predation by wading birds on fish swimming near the surface in search of oxygen:

although wading birds were periodically observed congregating in watermilfoil and native ponds, higher numbers invariably occurred in watermilfoil ponds. Much lower survival in hydrilla ponds was most likely a result of poor water quality, and especially extended periods of DO depletion: although not observed during the study, fish kills due to low DO have been documented in LAERF ponds supporting hydrilla on several occasions.

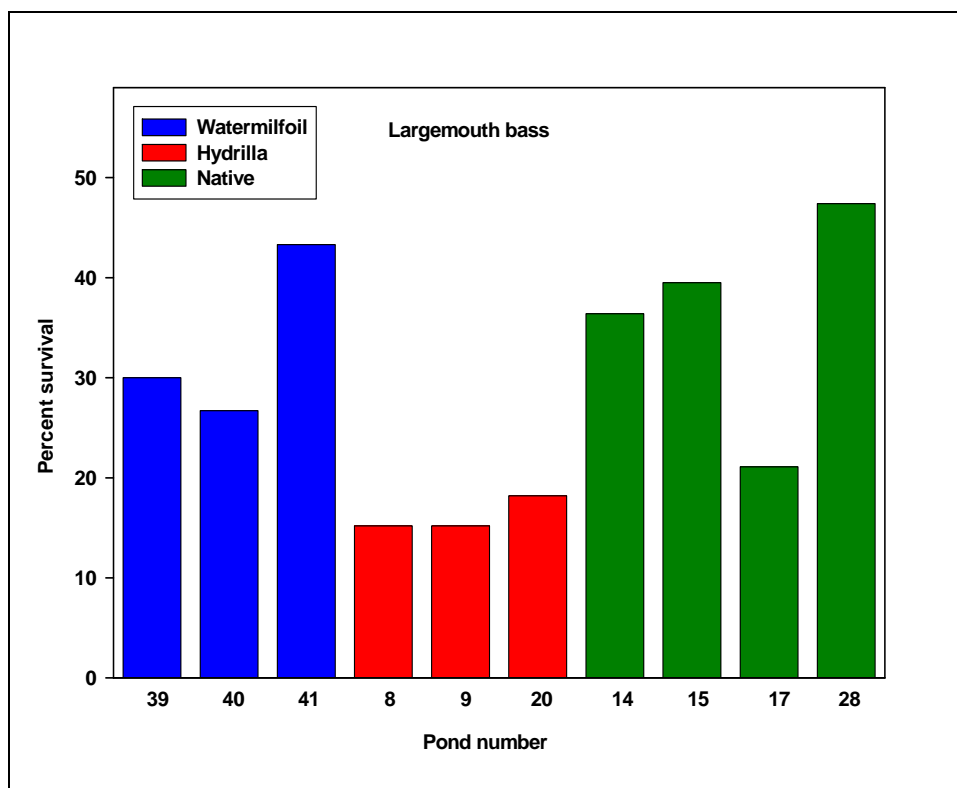


Figure 59. Percent survival of largemouth bass was measured in ponds dominated by different vegetation types one year after stocking. One watermilfoil pond (39) supported significant stands of hydrilla and native plants; one native pond (17) was dominated by hydrilla by the end of the study.

Largemouth bass standard lengths (SL) were greatest in native and hydrilla ponds and lowest in watermilfoil ponds (Figure 60). Bass SL in all ponds was within ranges for same-aged fish reported from Texas ponds (Carlander 1977). Differences in fish size between vegetation types may have been due in part to bass density: moderately high survival in watermilfoil ponds may have led to more intense competition for available food, limiting bass growth. However, greater lengths were attained in native ponds, where even higher densities occurred. It is more likely that prey availability contributed to poor growth in watermilfoil ponds.

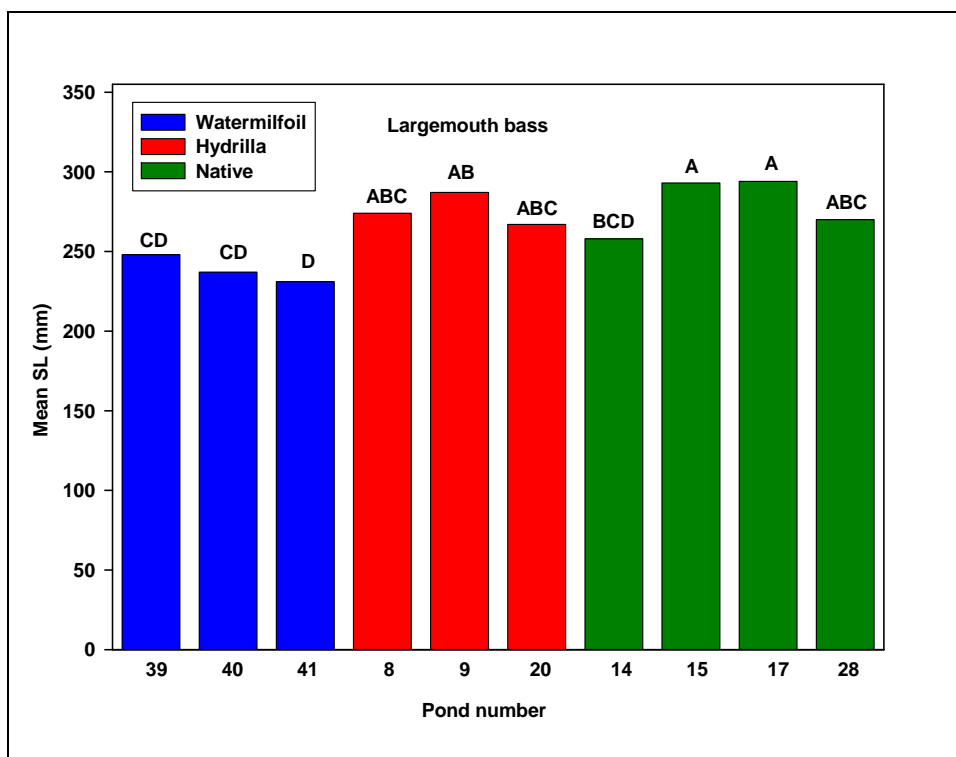


Figure 60. Mean standard lengths (SL) of largemouth bass in ponds dominated by different vegetation types after one year. One watermilfoil pond (39) supported significant stands of hydrilla and native plants; one native pond (17) was dominated by hydrilla by the end of the study. Letters above bars indicate significant differences ($p > 0.05$).

Largemouth bass weights were highest in native and hydrilla ponds and lowest in watermilfoil ponds (Figure 61). Greater weights in native and hydrilla ponds coincided with greater SL attained in those ponds. However, relative weights (W_r) of adult largemouth bass were highest in native ponds and lowest in hydrilla and watermilfoil ponds, indicating fish in native ponds were in better condition (Figure 62). Interestingly, bass in the watermilfoil pond (39) that supported significant native vegetation (over 30 percent) were in slightly better condition than in other watermilfoil ponds. Additionally, bass in the native pond that had become dominated by hydrilla (17) were in slightly poorer condition than in other native ponds, implying that even partial dominance by those plant species may impact bass growth and size.

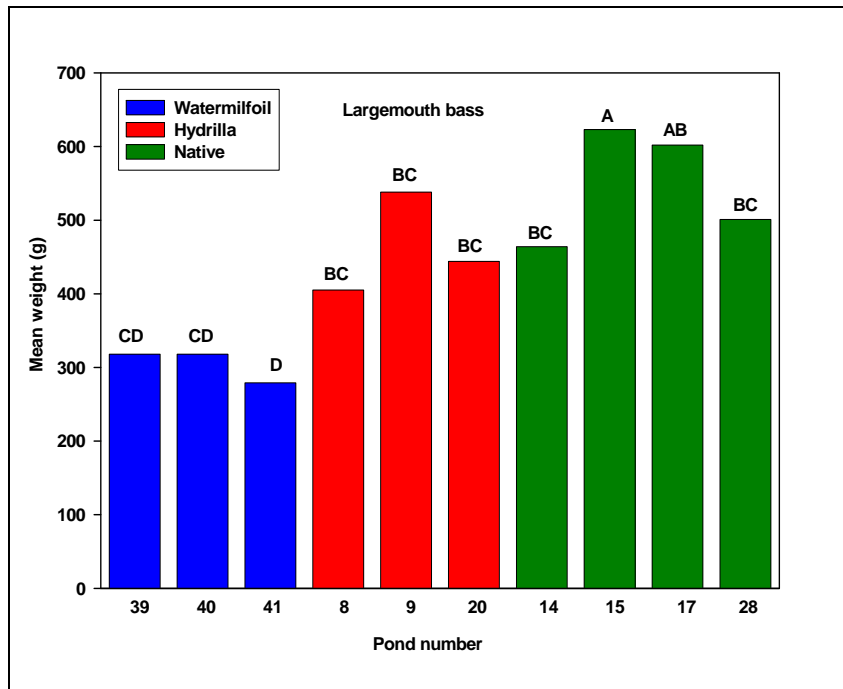


Figure 61. Mean weights of largemouth bass in ponds dominated by different vegetation types after one year. One watermilfoil pond (39) supported significant stands of hydrilla and native plants; one native pond (17) was dominated by hydrilla by the end of the study. Letters above bars indicate significant differences ($p > 0.05$).

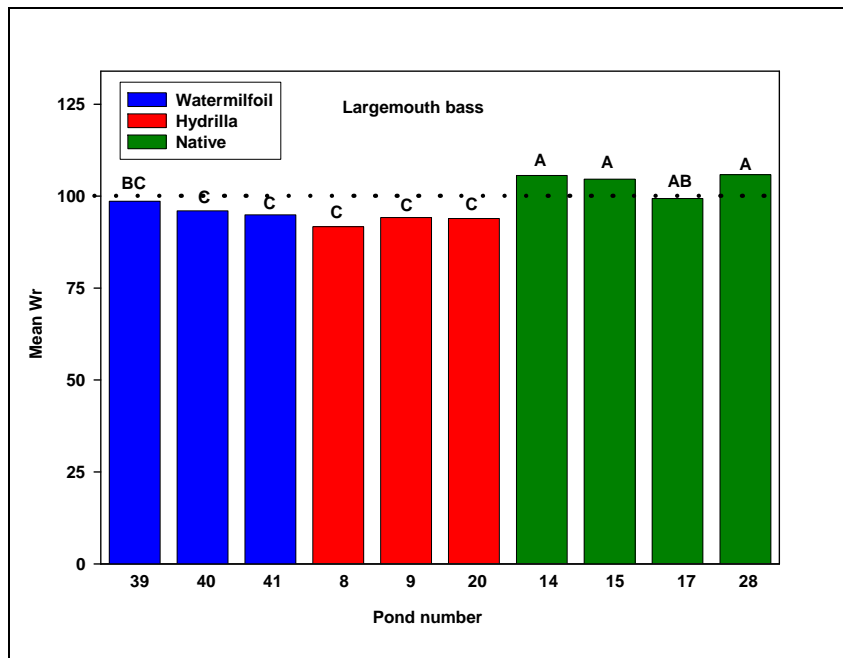


Figure 62. Mean relative weights (W_r) of largemouth bass in ponds dominated by different vegetation types after one year. One watermilfoil pond (39) supported significant stands of hydrilla and native plants; one native pond (17) was dominated by hydrilla by the end of the study. Letters above bars indicate significant differences ($p > 0.05$).

Bass production was low to moderate compared with other small ponds reported in the literature (Carlander 1977). Low production was in part due to the short period in which the study was conducted and absence of recruitment in most ponds: the ponds did not have time to achieve balance.¹ Differences between vegetation types did occur, however, indicating effects on overall bass production (Figure 63). Watermilfoil and hydrilla ponds exhibited similar standing crops, averaging 4.2 kg/ha and 3.9 kg/ha, respectively. Although production was similar, it was for different reasons: watermilfoil bass were moderately numerous but small and skinny, whereas bass in hydrilla ponds were less numerous but large and skinny. Native pond bass averaged nearly four times the standing crop at 16.2 kg/ha, due in part to recruitment in two ponds (15 and 28). However, even with young-of-the-year excluded, bass production averaged 14.6 kg/ha, more than three times greater than watermilfoil or hydrilla ponds. When pond 17 (dominated by hydrilla) is excluded, standing crop including young-of-the-year averaged 18.6 kg/ha.

Adult bluegills (those stocked) were recovered from all study ponds. Survival was highest in watermilfoil ponds, and was lowest in one hydrilla and one native pond (Table 9).

Bluegills (those originally stocked) had increased in SL from an average of 105 mm to over 170 mm by the end of the study (Figure 64). SL was similar in most ponds, although fish attained slightly greater size in one native pond (14) and were smaller in one watermilfoil pond (40) and one hydrilla pond (9). Weights were also similar between ponds with the same exceptions as SL (Figure 65). Standing crops of adult bluegills averaged 1.8 kg/ha in watermilfoil ponds, 1.8 kg/ha in hydrilla ponds, and 2.9 kg/ha in native ponds (Figure 66). Excluding pond 17, standing crop averaged 3.3 kg/ha in native ponds.

¹ Personal Communication. 2004. Richard M. Ott, District Biologist, Texas Parks and Wildlife Inland Fisheries, Tyler, Texas.

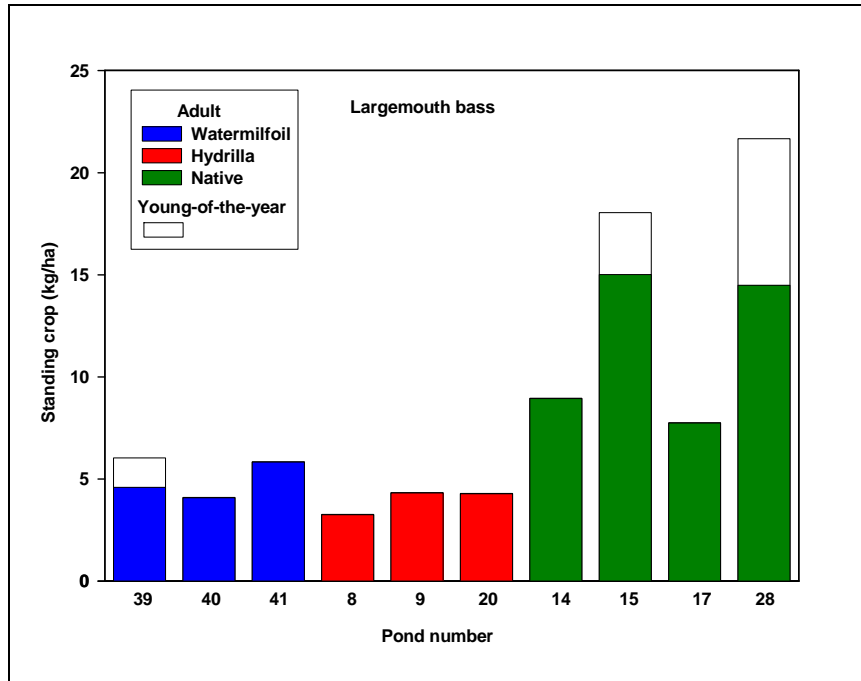


Figure 63. Standing crops of largemouth bass were calculated for ponds dominated by different vegetation types after one year. One watermilfoil pond (39) supported significant stands of hydrilla and native plants; one native pond (17) was dominated by hydrilla by the end of the study.

Table 9. Adult bluegills were harvested from 10 ponds managed for dominance by watermilfoil, hydrilla, or native vegetation. Pond 17 was invaded by hydrilla during the study period; Eurasian watermilfoil did not achieve dominance in pond 39.

Pond #	Treatment	N stocked	N harvested	Percent survival
39	Watermilfoil	10	5	50.0
40	Watermilfoil	10	5	50.0
41	Watermilfoil	10	7	70.0
8	Hydrilla	14	5	35.7
9	Hydrilla	14	8	57.1
20	Hydrilla	14	7	50.0
14	Native	14	4	28.6
15	Native	16	9	56.3
17	Native	16	5	31.3
28	Native	16	10	62.5

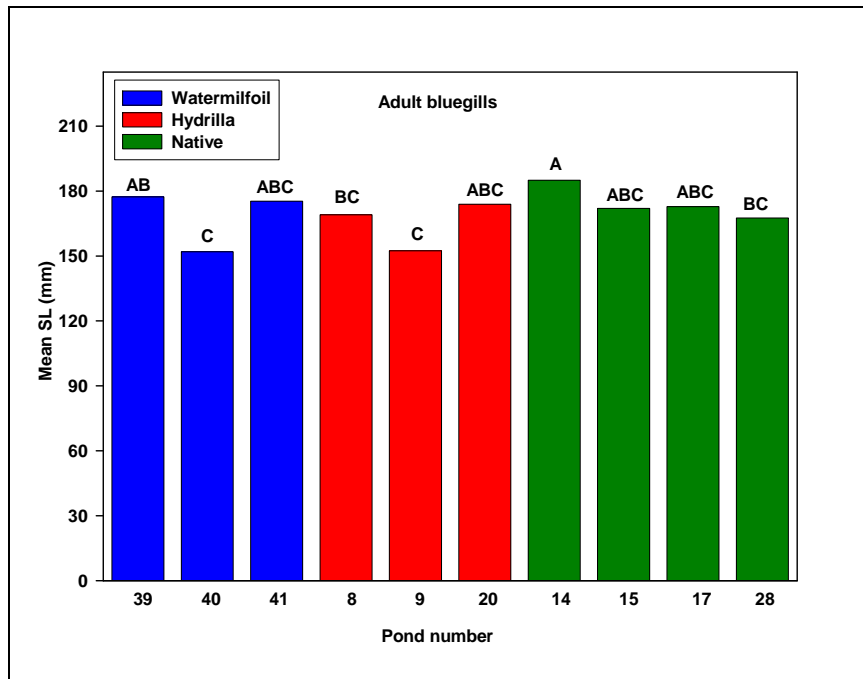


Figure 64. Mean standard lengths (SL) of adult bluegills in ponds dominated by various vegetation types after one year. One watermilfoil pond (39) supported significant stands of hydrilla and native plants; one native pond (17) was dominated by hydrilla by the end of the study. Letters above bars indicate significant differences ($p > 0.05$).

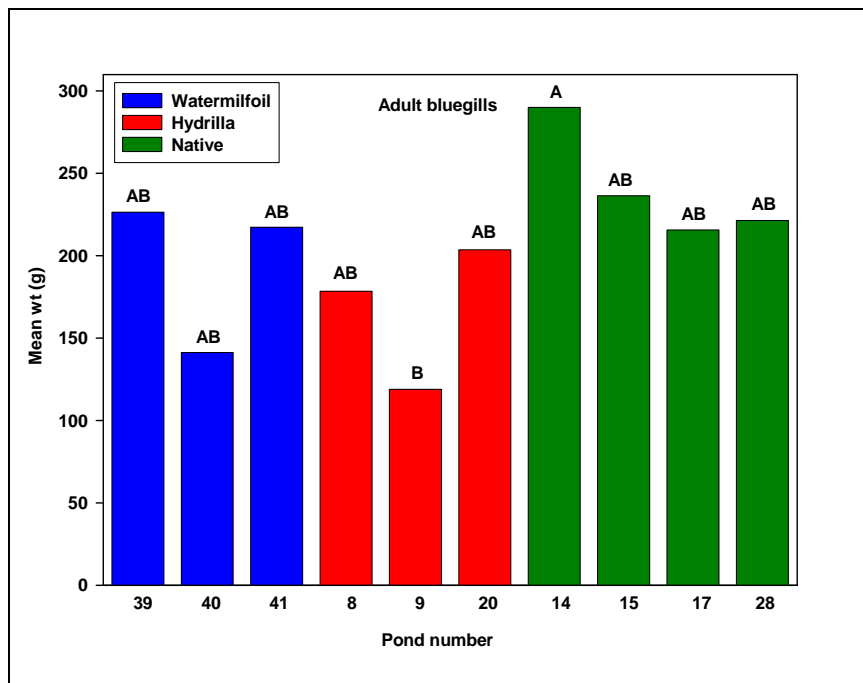


Figure 65. Mean weights (g) of adult bluegills in ponds dominated by different vegetation types after one year. One watermilfoil pond (39) supported significant stands of hydrilla and native plants; one native pond (17) was dominated by hydrilla by the end of the study. Letters above bars indicate significant differences ($p > 0.05$).

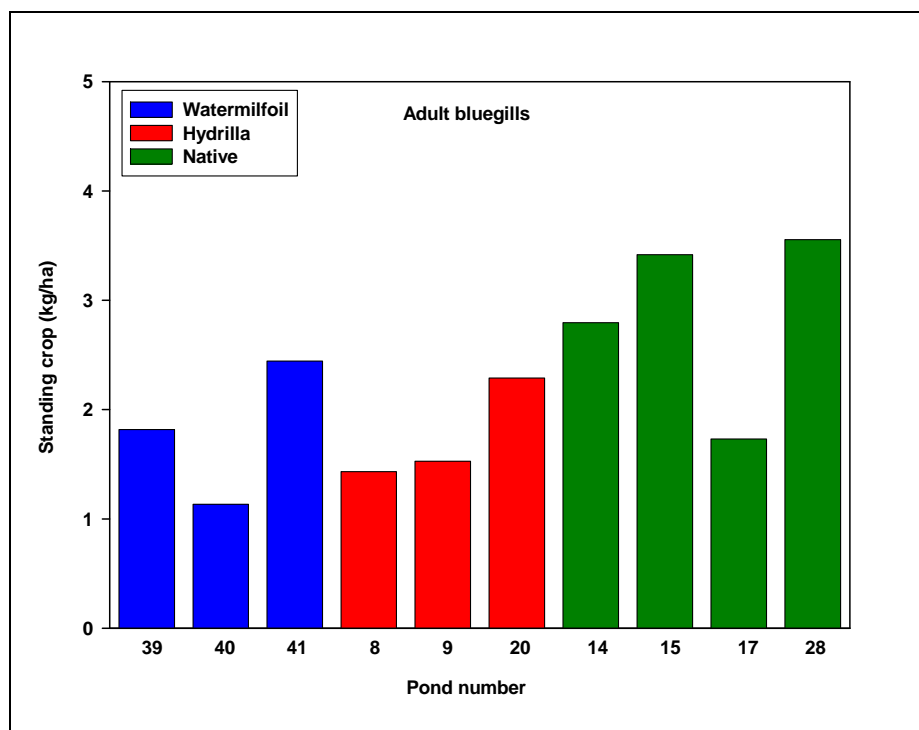


Figure 66. Standing crops of adult bluegills in ponds dominated by different vegetation types after one year. One watermilfoil pond (39) supported significant stands of hydrilla and native plants; one native pond (17) was dominated by hydrilla by the end of the study.

Young-of-the-year bluegills were collected from all study ponds. An average of 1,979 were collected from watermilfoil ponds, 2,995 from native ponds (3,262 when excluding pond 17) and 310 from hydrilla ponds (Figure 67). Predation by wading birds may have contributed to less recruitment in watermilfoil ponds than in native ponds. Low recruitment in hydrilla ponds was likely due to poor water quality, which may have inhibited reproductive success and increased mortality of young-of-the-year fish.

Sizes of young-of-the-year bluegills were variable between ponds, but were generally greatest in hydrilla ponds (Figure 68). Larger fish were apparently able to survive hostile conditions in those ponds. Bluegills in watermilfoil and native ponds were similar in size.

Standing crops of young-of-the-year bluegills averaged 20.2 kg/ha in watermilfoil ponds, 6.9 kg/ha in hydrilla ponds, and 34.1 kg/ha in native ponds (39.7 kg/ha excluding pond 17) (Figure 69).

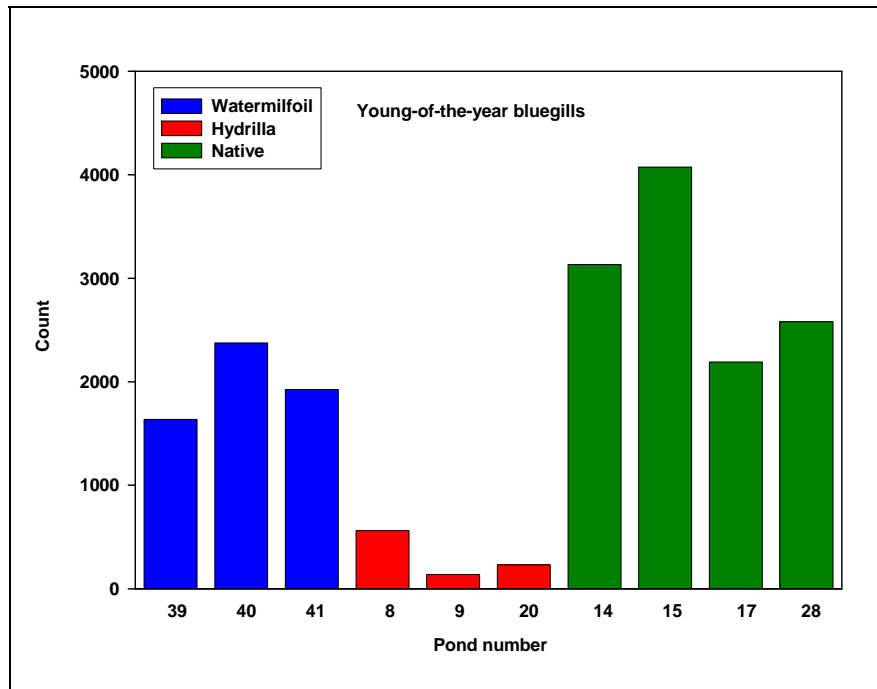


Figure 67. Young-of-the-year bluegills were counted in ponds dominated by different vegetation types after one year. One watermilfoil pond (39) supported significant stands of hydrilla and native plants; one native pond (17) was dominated by hydrilla by the end of the study.

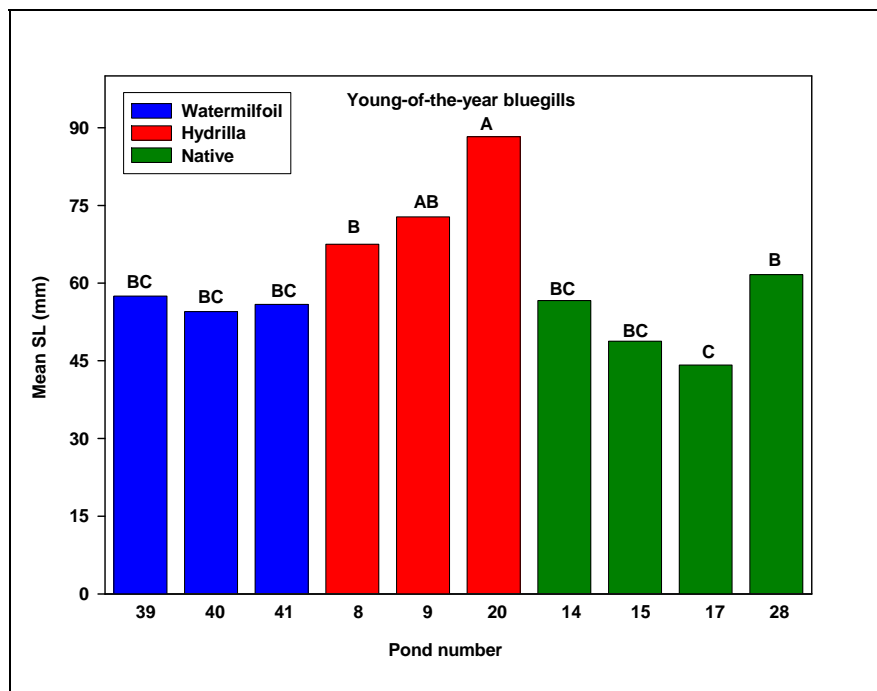


Figure 68. Mean SL of young-of-the-year bluegills in ponds dominated by different vegetation types after one year. One watermilfoil pond (39) supported significant stands of hydrilla and native plants; one native pond (17) was dominated by hydrilla by the end of the study. Letters above bars indicate significant differences ($p > 0.05$).

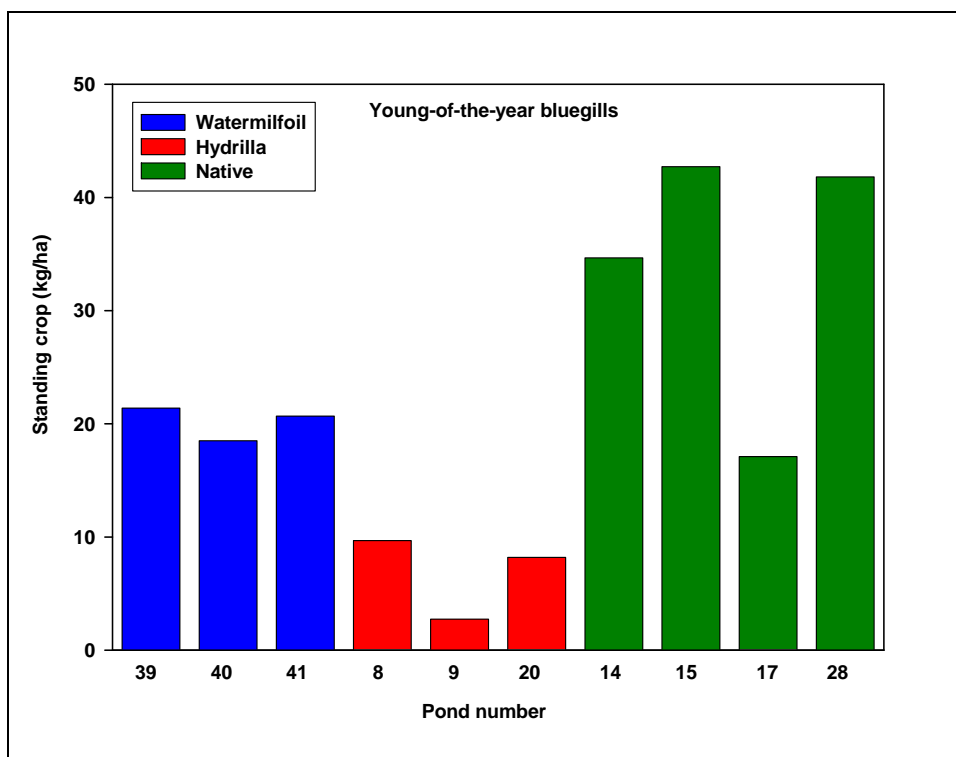


Figure 69. Standing crops of young-of-the-year bluegills in ponds dominated by different vegetation types after one year. One watermilfoil pond (39) supported significant stands of hydrilla and native plants; one native pond (17) was dominated by hydrilla by the end of the study.

Standing crops of bass and bluegills averaged 28 kg/ha in watermilfoil ponds (26 kg/ha excluding pond 39), 13 kg/ha in hydrilla ponds, and 51 kg/ha in native ponds (59 kg/ha excluding pond 17) (Figure 70). Watermilfoil ponds were poorly productive from a fishery perspective: although sufficient numbers of bluegills were present to support the bass fishery, these were apparently too large for bass to eat, or had too much cover provided by watermilfoil stems and leaves for bass to effectively forage. This resulted in poor utilization of forage by the bass, which failed to grow at rates seen in other ponds. Overall, populations consisted of small, skinny bass. In hydrilla ponds, mortality due to poor water quality apparently resulted in low productivity. Bluegills were as large as or larger than watermilfoil and native pond fish, but their condition was poor and numbers were low, resulting in very low standing crops. Standing crops in native ponds were much higher, and bass were in better condition.

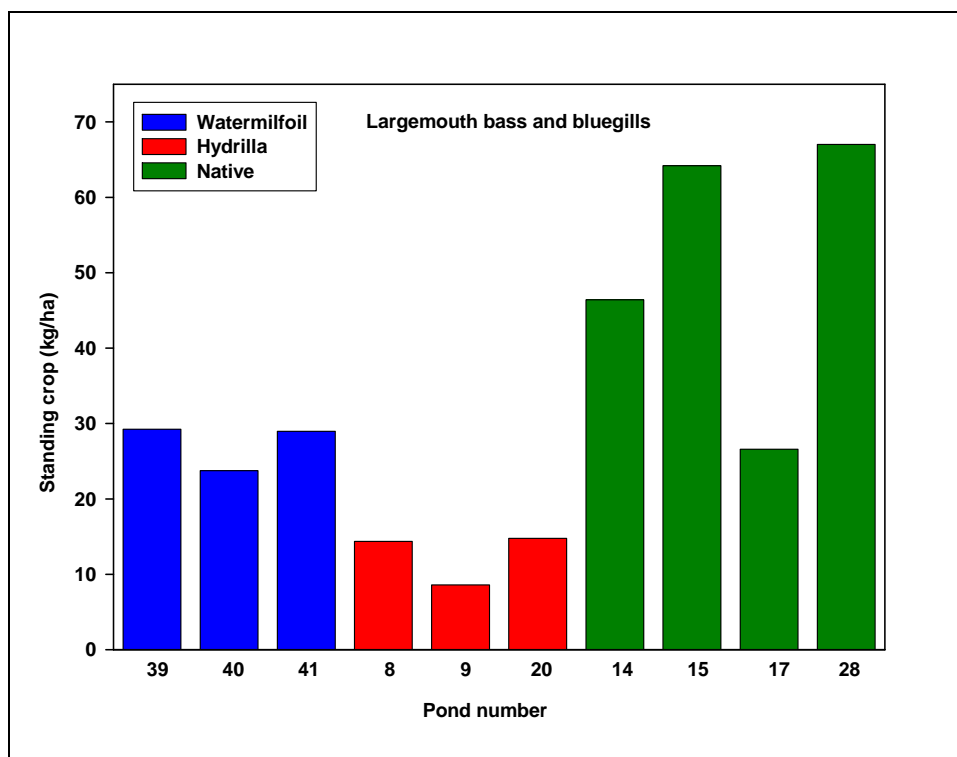


Figure 70. Standing crops of largemouth bass and bluegills in ponds dominated by different vegetation types after one year. One watermilfoil pond (39) supported significant stands of hydrilla and native plants; one native pond (17) was dominated by hydrilla by the end of the study.

Other Vertebrates

Vertebrates associated with the study ponds were surveyed periodically. Total counts appeared to reflect habitat values of different plant communities for a particular species. Several frog species were recorded during these surveys, with American bullfrogs (*Rana catesbiana*) the most frequently observed. Red-eared sliders (*Trachemys scripta elegans*) were the only reptile species observed in the ponds. Several species of wading birds and waterbirds were also recorded in the ponds. No statistical differences ($\alpha=0.05$) were detected among frequency of occurrence in association with vegetation types, primarily due to low numbers of observations of all vertebrate species.

Amphibians

Although not statistically significant, higher numbers of bullfrogs occurred in watermilfoil ponds (Figures 71 and 72). Moderately dense stems may have provided cover from predators for bullfrogs and their

tadpoles (natives may have provided less cover). Additionally, major predators (largemouth bass) were small in watermilfoil ponds and may not have been able to exploit larger tadpoles as forage. In hydrilla ponds, the dense canopy may have prevented surface breathing by tadpoles. Other frog species observed included small numbers of green treefrogs (*Hyla cinerea*) and Blanchard's cricket frogs (*Acris crepitans*).



Figure 71. American bullfrogs (*Rana catesbeiana*) were frequently observed in hydrilla (and Eurasian watermilfoil) ponds.

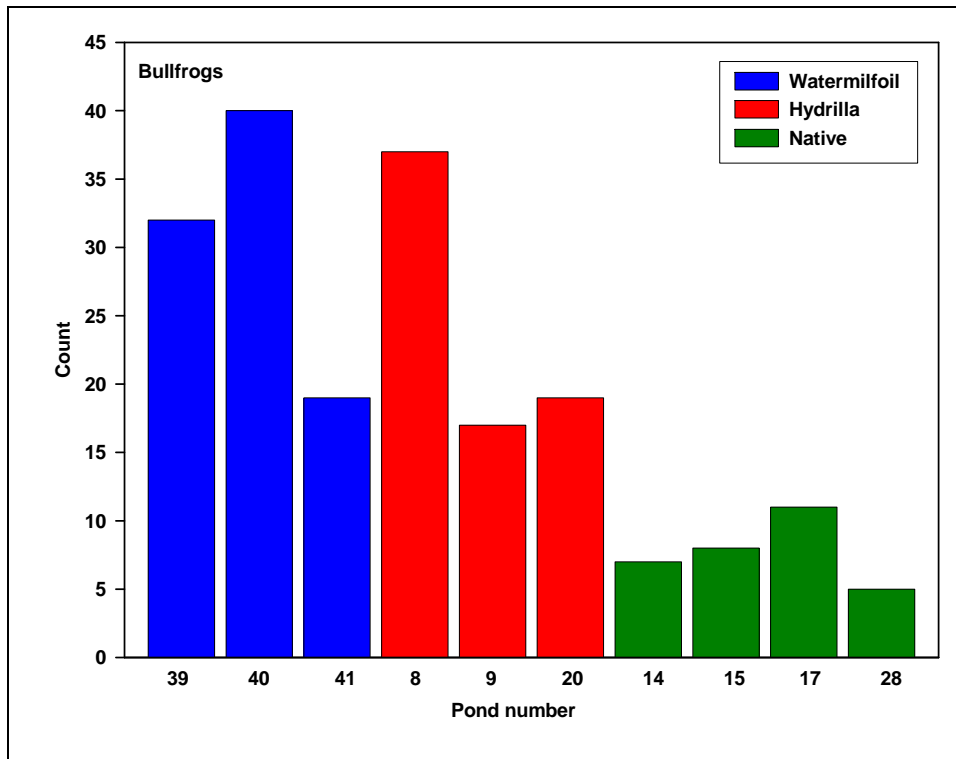


Figure 72. Bullfrogs were most commonly seen in watermilfoil and hydrilla ponds.

Reptiles

Although not statistically significant, higher numbers of red-eared sliders were observed in hydrilla ponds (Figure 73). Red-eared sliders show a preference for hydrilla as food over watermilfoil and many native plants, including American pondweed, southern naiad, and muskgrass (Dick et al. 1995), which may have contributed to distribution of turtles among the ponds. Additionally, the dense surface canopy of hydrilla served as a basking site, which was not readily available in watermilfoil or native ponds. However, Mauermann et al. (1994) did not detect spatial distribution of the LAERF red-eared slider population dependent upon plant community dominance.

Herons and egrets

Five species of herons and egrets were observed in association with the study ponds, including great blue herons (*Ardea herodias*), little blue herons (*Florida caerulea*), common egrets (*Casmerodius albus*), snowy egrets (*Leucophoyx thula*), and yellow-crowned night herons (*Nyctanassa violacea*). Although not statistically significant, total

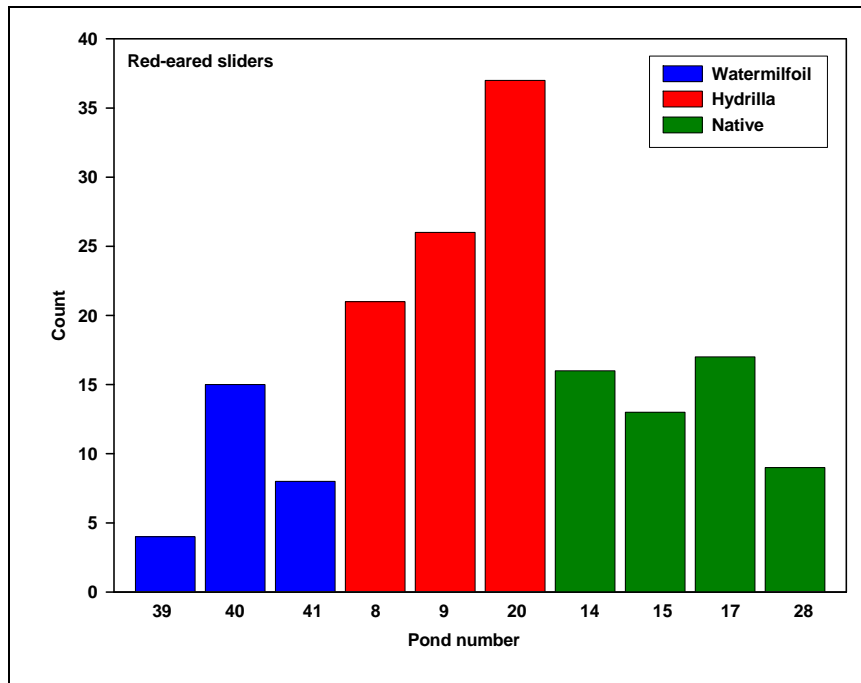


Figure 73. Red-eared sliders were most commonly seen in hydrilla ponds.

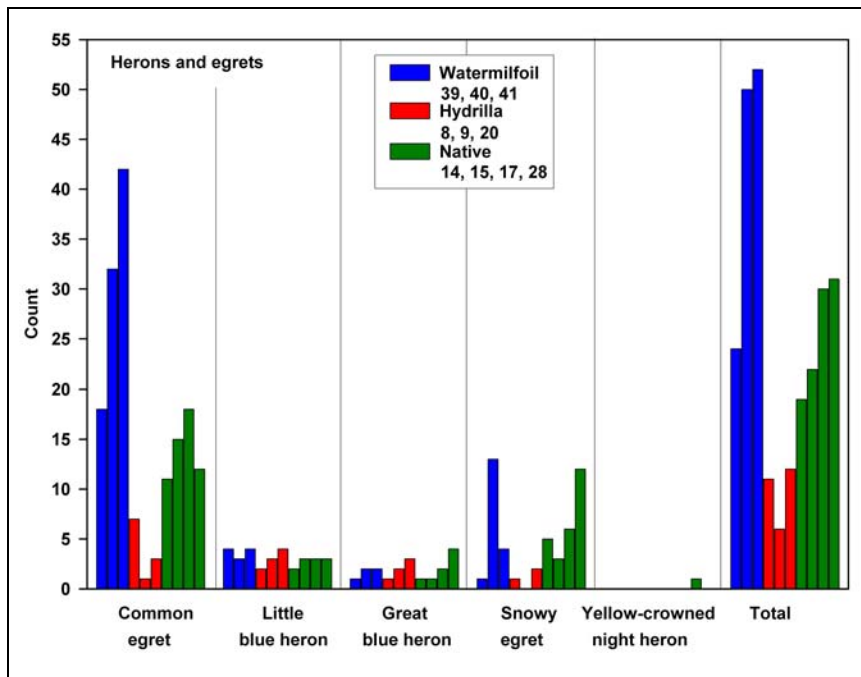


Figure 74. Several species of wading birds were observed in all ponds during the study.

numbers of observations were highest from watermilfoil ponds (Figure 74).

Greater use of watermilfoil ponds by herons and egrets was believed to be due to periodic availability of easy-to-catch food (small bluegill). Large numbers (50+) of common and snowy egrets were observed (falling outside the survey periods) feeding on fish gasping at the water surface during early morning in ponds 40 and 41 in late August and early September, when DO concentrations were lowest in those ponds (Figure 75). Smaller numbers (<10) of egrets and herons were observed hunting in similar fashion in native ponds 14, 15, and 17 during the same periods.



Figure 75. Egrets and herons flocked to feed on fish gasping at the surface for oxygen in ponds dominated by Eurasian watermilfoil during late August.

This phenomenon was not observed in hydrilla ponds. Surface canopies in hydrilla ponds may have interfered with hunting strategies of herons and egrets, which visually stalk or ambush prey in shallow waters. Additionally, low numbers of fish in hydrilla ponds may have limited utilization by piscivorous birds.

Depredation by birds accounted for some mortality of stocked largemouth bass during the study. Great blue herons were observed taking largemouth bass on four occasions: twice from pond 28 (native pond) and once each from pond 14 (native pond) and pond 41 (watermilfoil).

4 Conclusions

Aquatic vegetation had significant impacts on pond ecosystem dynamics in this study, especially regarding canopy development and diel fluctuations in water quality. Greater canopy development such as that seen in hydrilla and watermilfoil resulted in higher temperatures, DO, and pH in shallow waters, while at the same time reduced light penetration and mixing with deeper water, resulting in lower temperatures, DO, and pH at greater depths. Water quality extremes and differences between depths were lower and occurred less frequently in native aquatic plants, where canopy development was not as extensive. These differences, most likely in combination with morphology (leaf and stem densities) of dominant plant species, resulted in dissimilarity among populations of other aquatic organisms in the ponds.

The presence of aquatic macrophytes resulted in plankton counts being very low in all ponds, regardless of the dominant plant species: reduction in nutrients and light penetration by plants was sufficient to repress phytoplankton growth. Although plankton numbers were not greatly impacted by dominant vegetation, higher numbers did occur earlier in watermilfoil ponds, due to reproductive spikes triggered by warmer surface temperatures occurring in those ponds earlier in the year.

Macroinvertebrate counts were highest in hydrilla and watermilfoil ponds, with greater proportions (and numbers) of poor water quality indicators (e.g. snails) probably reflecting water quality degradation over the course of the study. Lower macroinvertebrate counts in native ponds were possibly a result of better utilization as forage by fish as well as greater rates of predation by higher densities of fish predators.

The largemouth bass/bluegill fishery was most productive in native ponds, with high survival and growth of originally stocked fish together with recruitment by both species resulting in standing crops nearly double that of watermilfoil ponds and nearly quadruple that of hydrilla ponds. Additionally, fish in native ponds were in better

condition (length-weight relationship), indicating that food availability was sufficient to sustain healthy fisheries in native ponds. Stressful or lethal water quality conditions, increased predation due to behavioral avoidance of stressful conditions, and excessive cover (and thus limited food availability) in watermilfoil and hydrilla ponds resulted in much poorer quality fisheries in those ponds.

Other vertebrates also appeared to be affected by dominant vegetation. Higher American bullfrog counts in hydrilla and watermilfoil ponds were apparently due to cover provided by dense canopies, which limited predation by fish. Frogs were able to take refuge in surface canopies and were not available as prey to adult bass in those ponds. Red-eared sliders were most common in hydrilla ponds, most likely due to inclusion of hydrilla in their diet and preference for hydrilla over other watermilfoil, American pondweed, southern naiad, and muskgrass. Interestingly, both of these species (bullfrogs and red-eared sliders) are problematic in parts of the United States, and may benefit from invasive spread of hydrilla and watermilfoil. Greater numbers of herons and egrets observed in association with ponds dominated by watermilfoil were attributed to opportunistic predation on fish stressed during low DO events. Although greater availability of food is immediately good for the birds, such events may result in elimination of forage populations, thereby limiting food resources in the longer term.

Extrapolation of these results to aquatic plants occurring in large reservoirs is difficult, particularly because coverage in reservoirs is generally limited to shallow waters (ponds exhibited near 100-percent coverage). In large water bodies, unvegetated deeper waters buffer shifts in water quality resultant from plant metabolism and presence, and provide refuge for aquatic organisms away from poor water quality areas associated with plants. However, within stands of vegetation supporting dense surface canopies, such as hydrilla and watermilfoil, it may be that conditions are less than ideal for many aquatic organisms, with suitable habitat limited to the “edge” between plants and open water. At the same time, less dense canopy species, such as native species, provide refuge and habitat within the plant stand itself, and result in maximum resource productivity.

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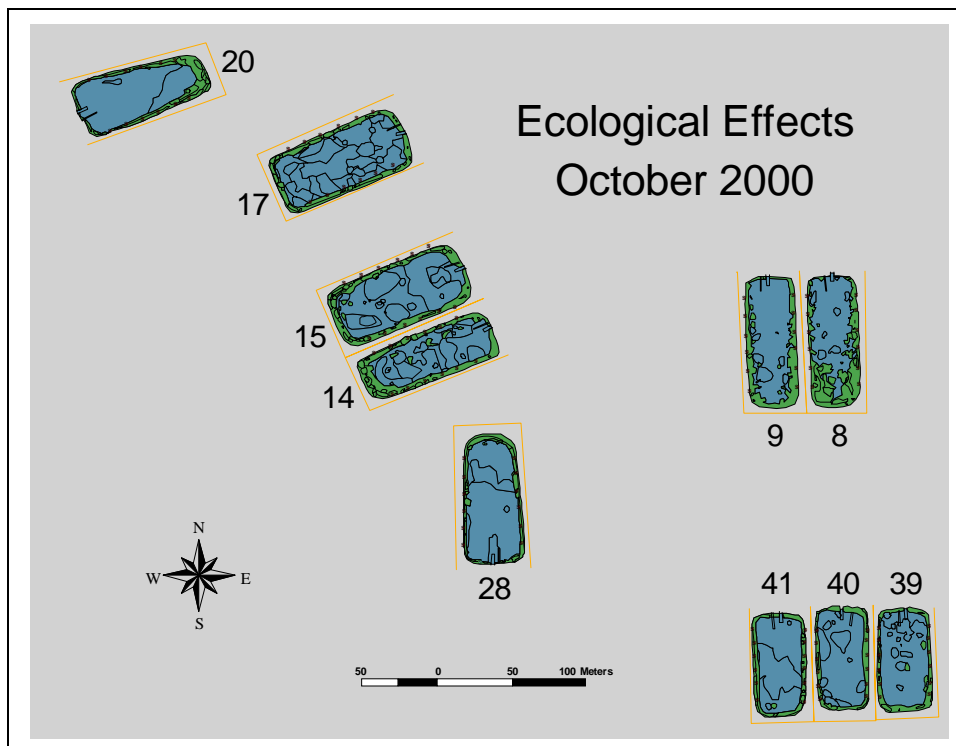
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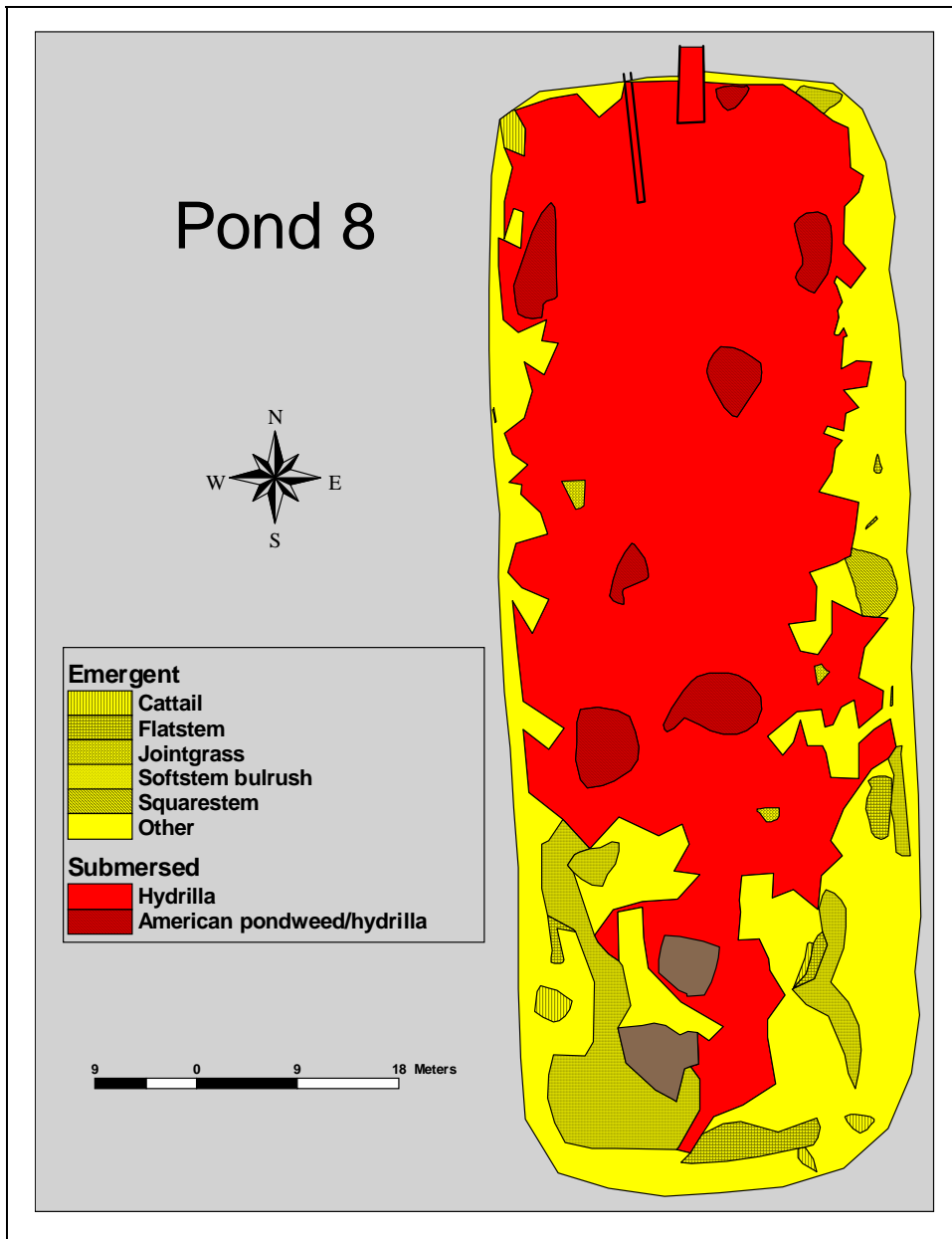
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Appendix A: GIS Mapping of Study Ponds

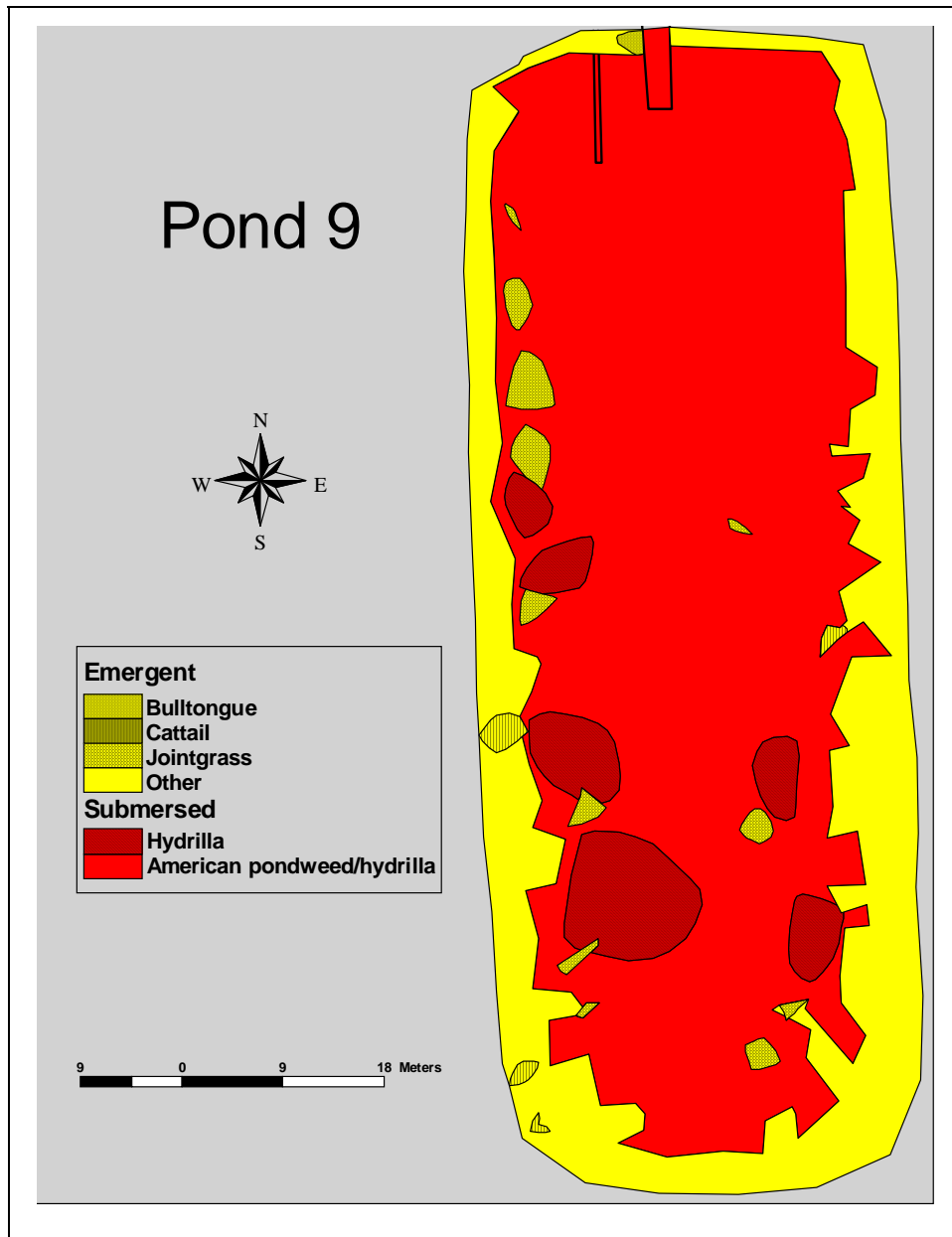
Following drawdown, ponds were mapped using GPS. Perimeters of colonies within each pond were recorded. Colonies were distinguished by species or species assemblages (e.g., monotypic stands of hydrilla; mixed stands of American pondweed, southern naiad, and muskgrass).



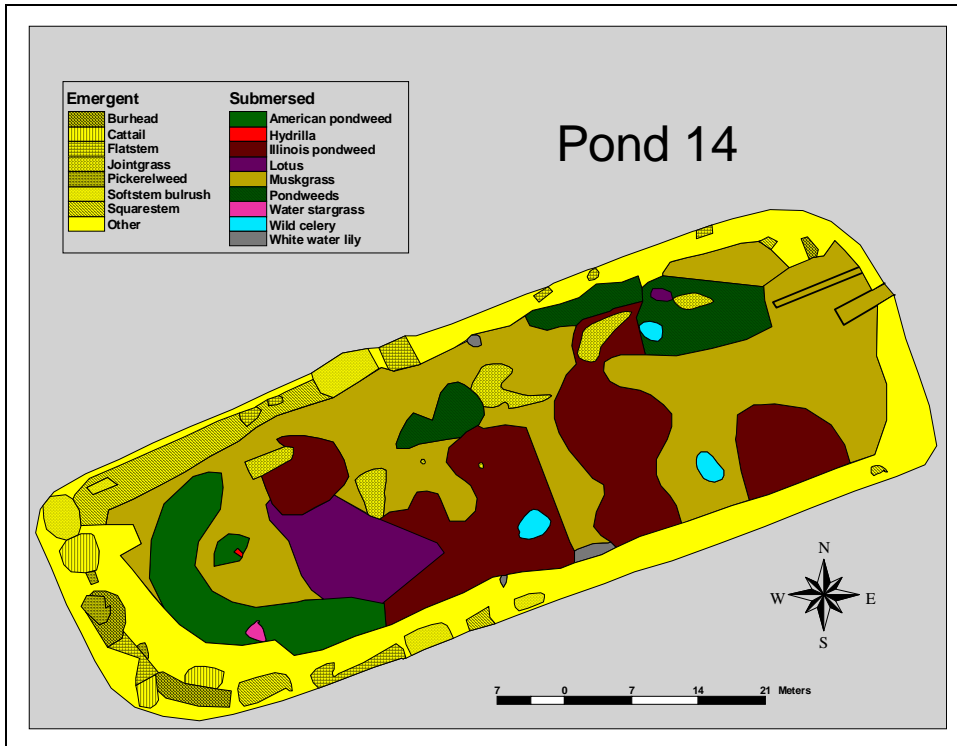
Ten ponds at the Lewisville Aquatic Ecosystem Research Facility were manipulated (beginning June 1999) to support plant communities dominated by hydrilla, Eurasian watermilfoil, or an assemblage of native aquatic species. Ponds were drained and vegetation mapped using GPS in early November 2000.



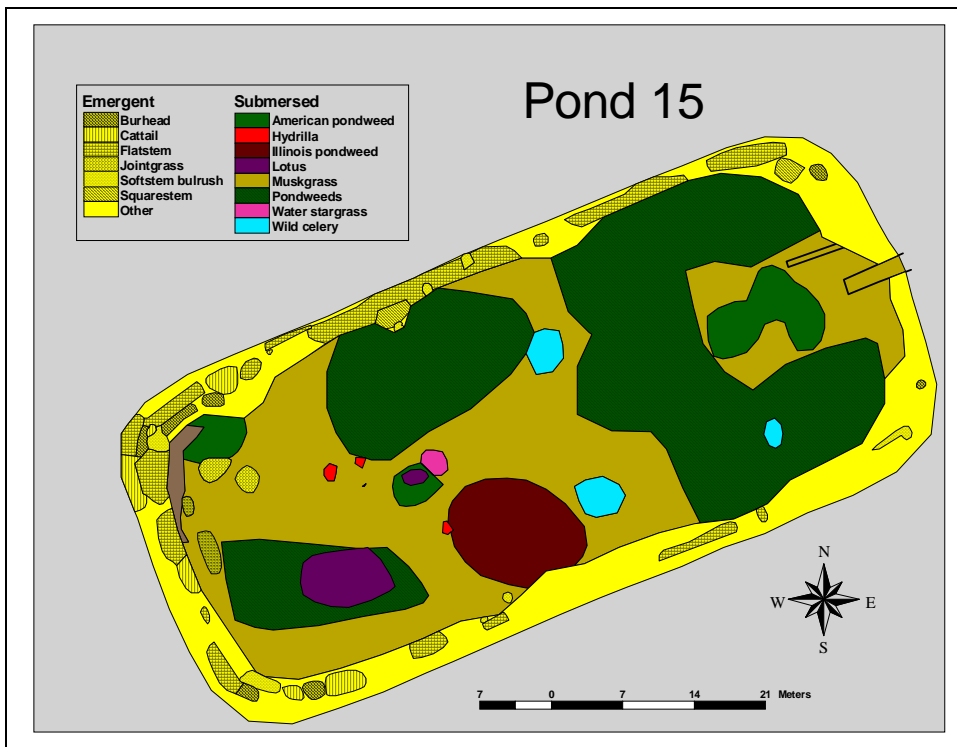
Pond 8 was managed to support an aquatic plant community dominated by hydrilla (*Hydrilla verticillata*). This objective was achieved during the study period.



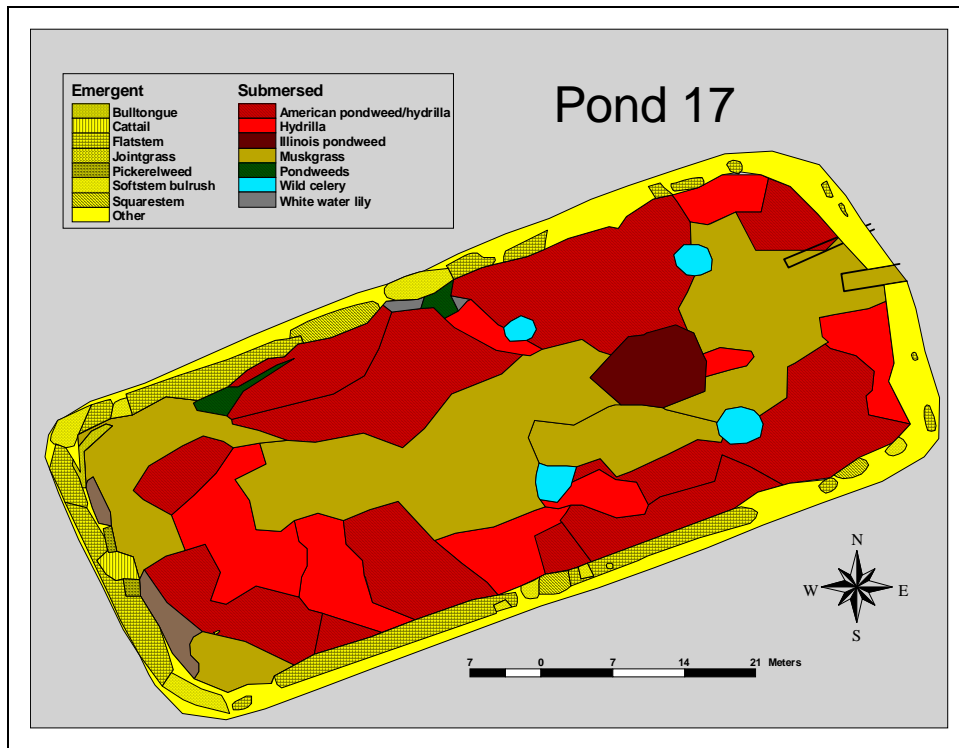
Pond 9 was managed to support an aquatic plant community dominated by hydrilla (*Hydrilla verticillata*). This objective was achieved during the study period.



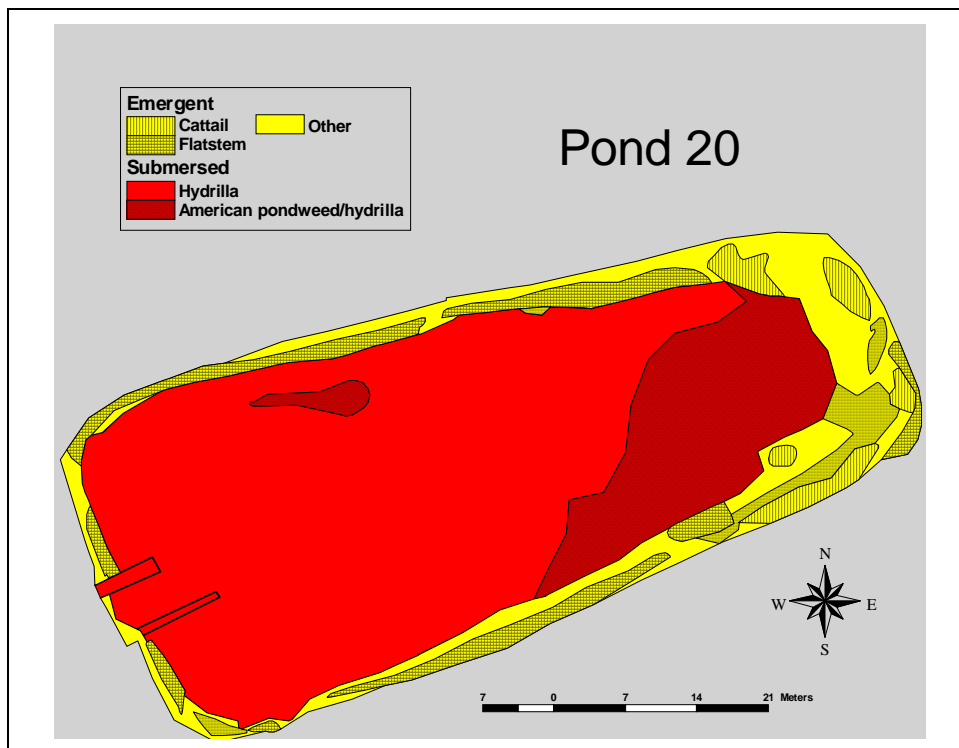
Pond 14 was managed to support an aquatic plant community dominated by native species. This objective was achieved during the study.



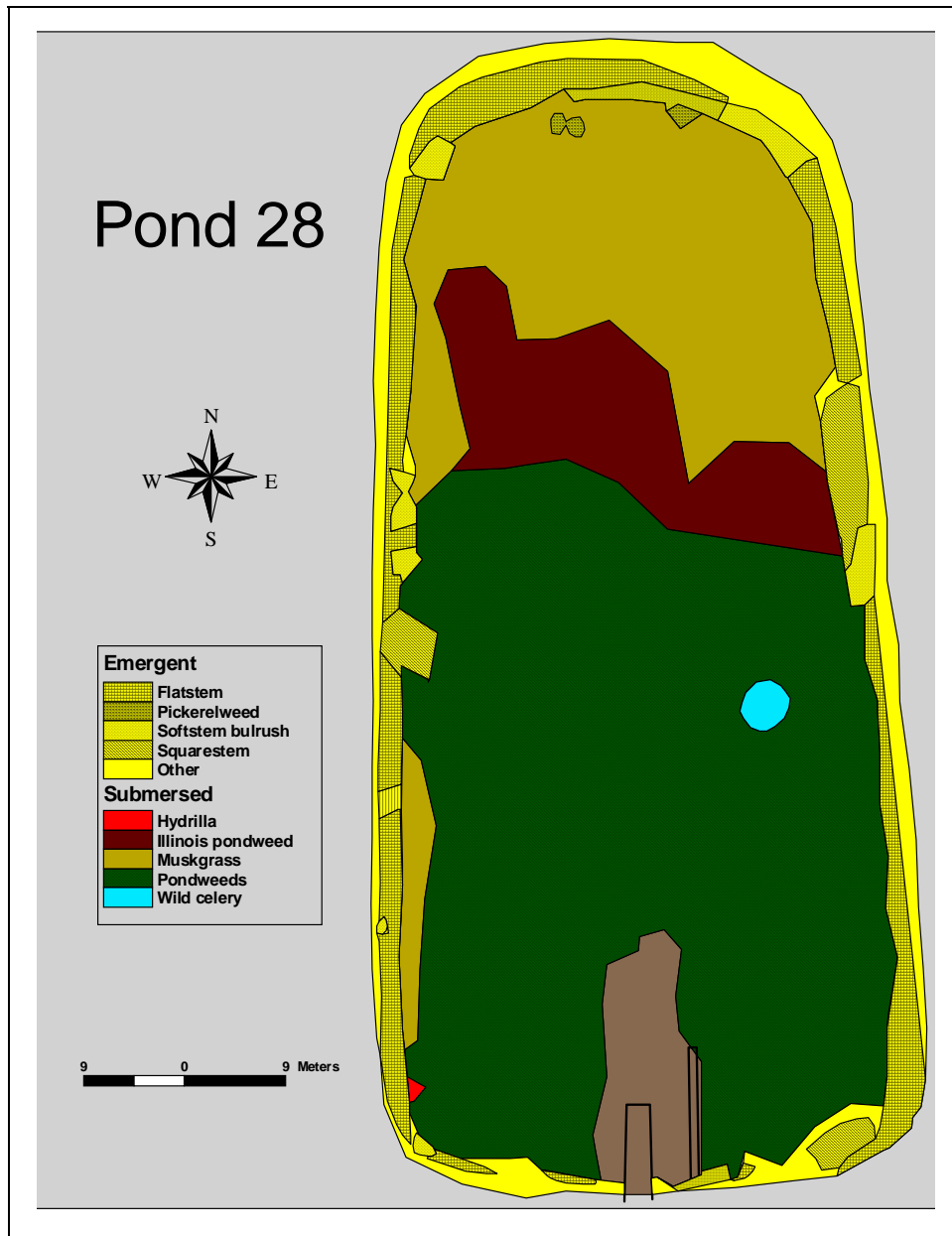
Pond 15 was managed to support an aquatic plant community dominated by native species. This objective was achieved during the study.



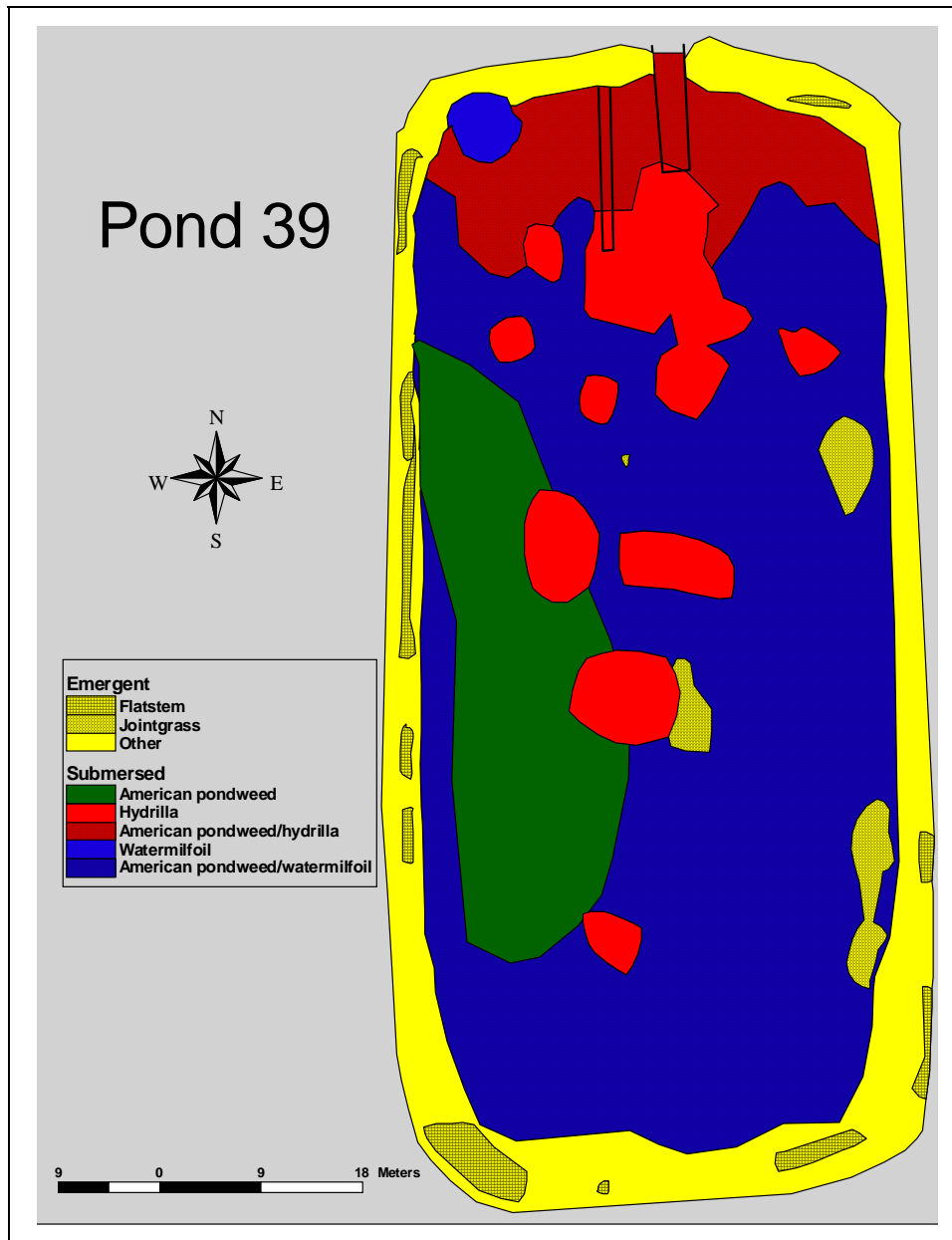
Pond 17 was managed to support an aquatic plant community dominated by native species. This objective was not achieved: early infestation by hydrilla (*Hydrilla verticillata*) resulted in its dominance in the pond by the end of the study.



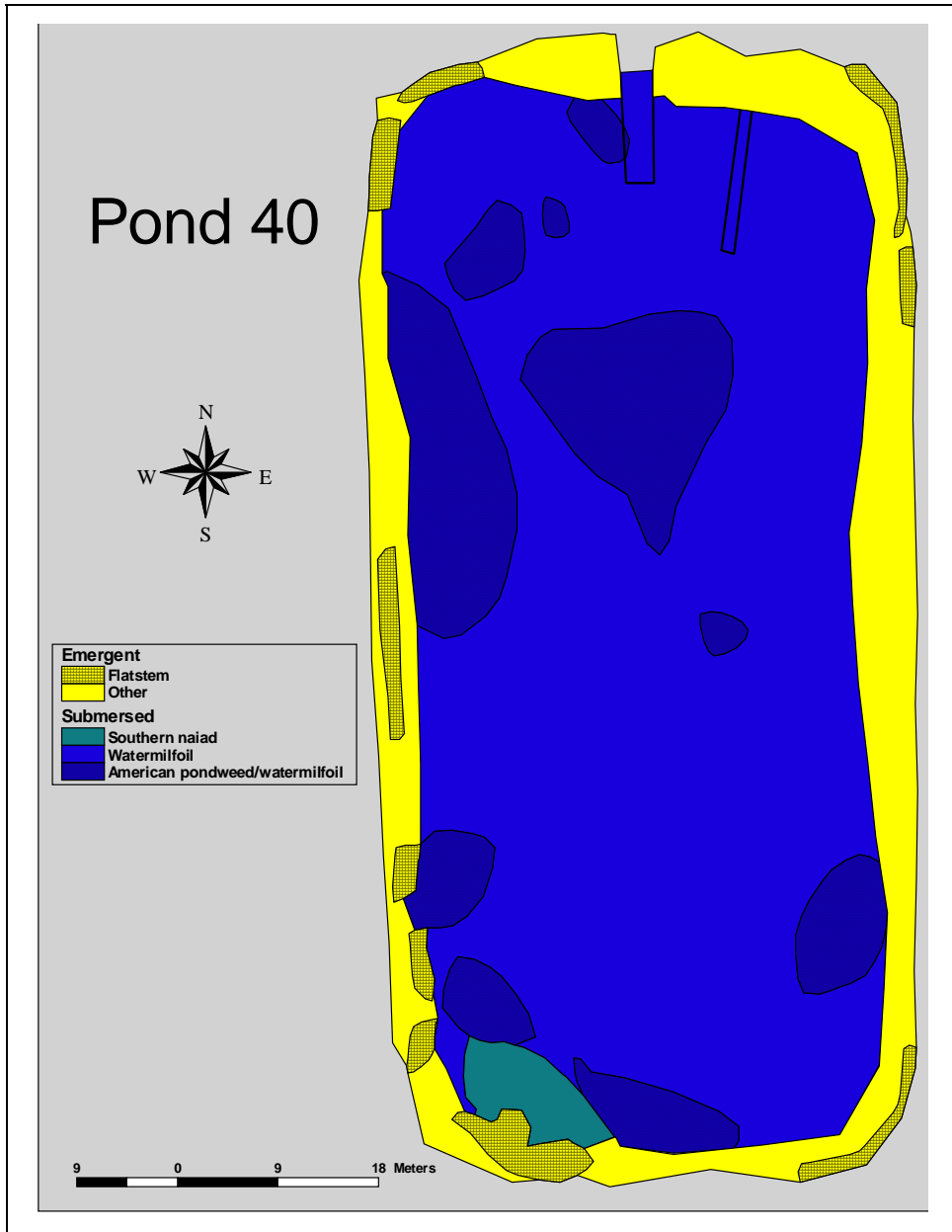
Pond 20 was managed to support an aquatic plant community dominated by hydrilla (*Hydrilla verticillata*). This objective was achieved during the study period.



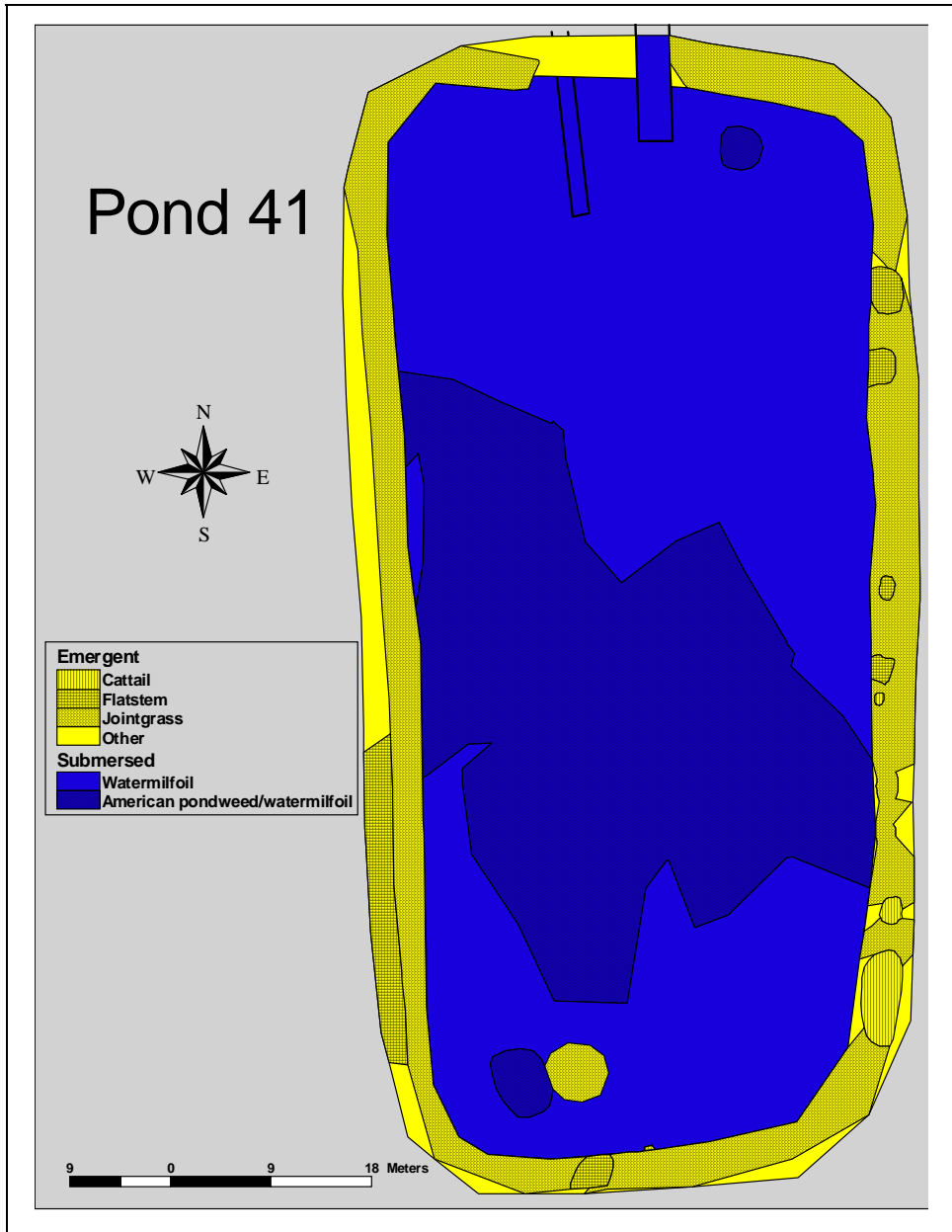
Pond 28 was managed to support an aquatic plant community dominated by native species. This objective was achieved during the study period.



Pond 39 was managed to support an aquatic plant community dominated by Eurasian watermilfoil (*Myriophyllum spicatum*). American pondweed (*Potamogeton nodosus*) from the pond bottom seedbank and infestation by hydrilla (*Hydrilla verticillata*) prevented dominance by Eurasian watermilfoil by the end of the study.

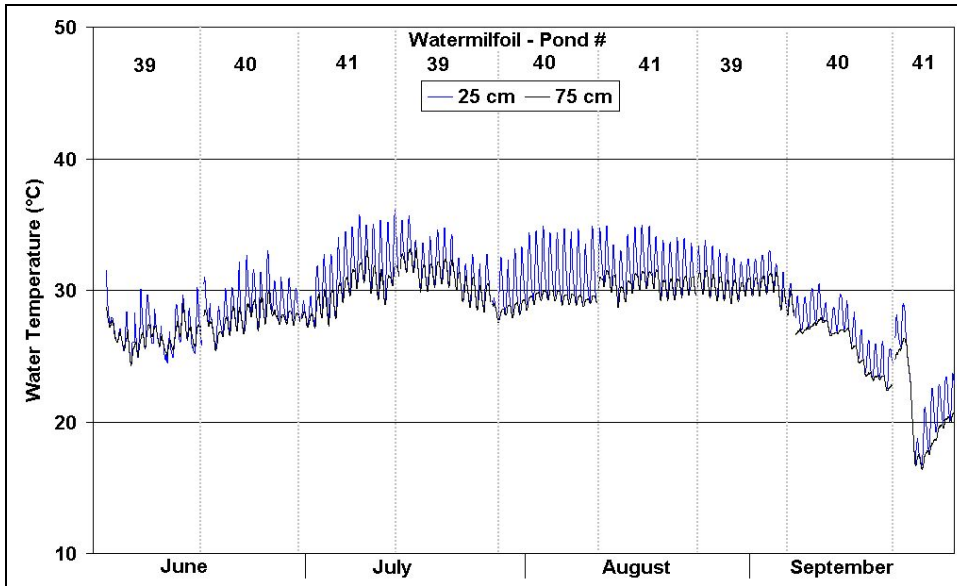


Pond 40 was managed to support an aquatic plant community dominated by Eurasian watermilfoil (*Myriophyllum spicatum*). This objective was achieved during the study period.

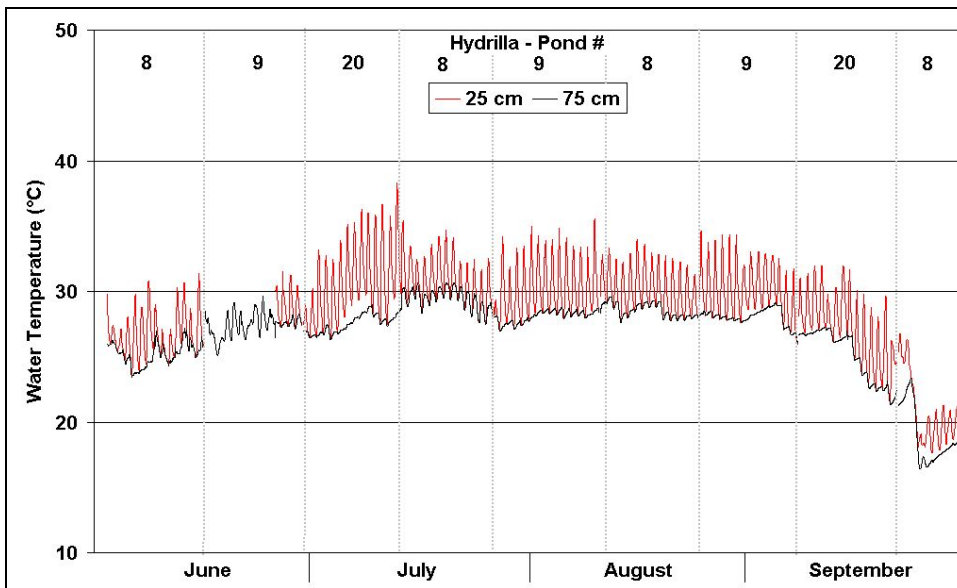


Pond 41 was managed to support an aquatic plant community dominated by Eurasian watermilfoil (*Myriophyllum spicatum*). This objective was achieved during the study period.

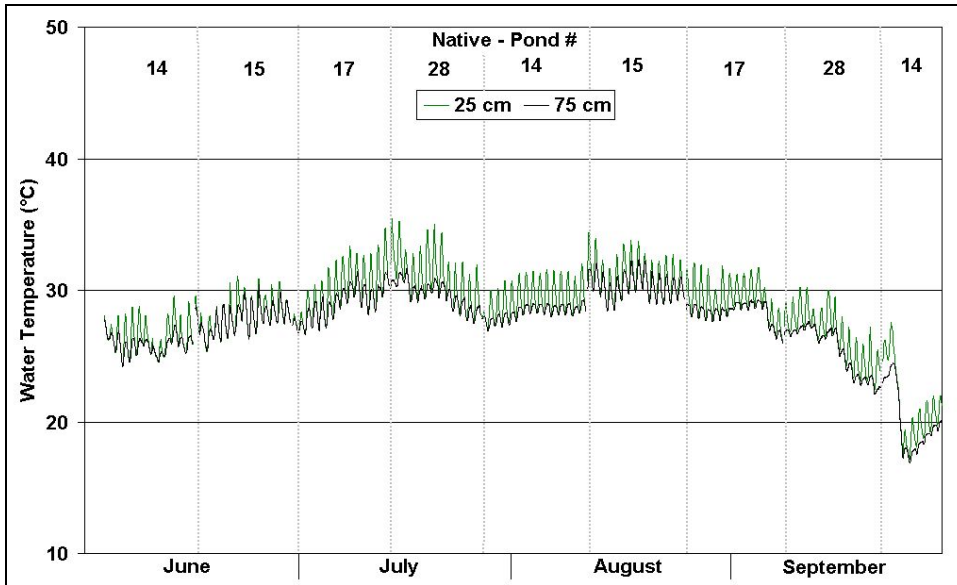
Appendix B: Water Quality



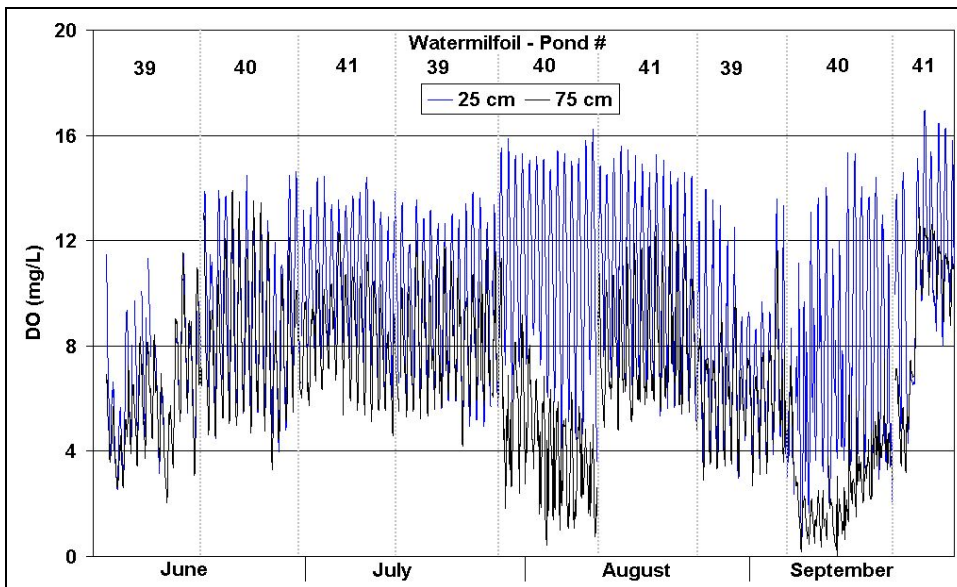
Hourly water temperature at two depths in ponds manipulated to support a dominant canopy of Eurasian watermilfoil.



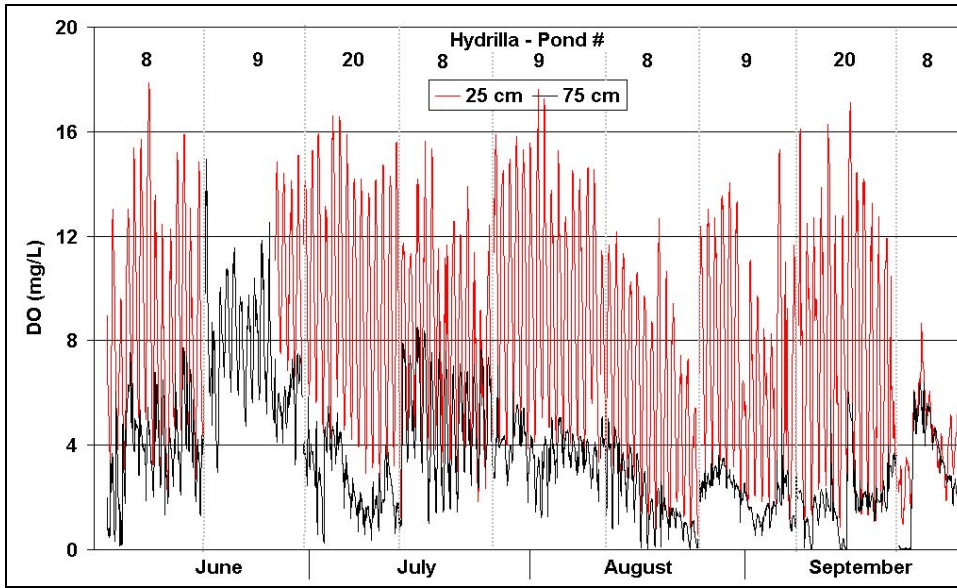
Hourly water temperature at two depths in ponds manipulated to support a dominant canopy of hydrilla.



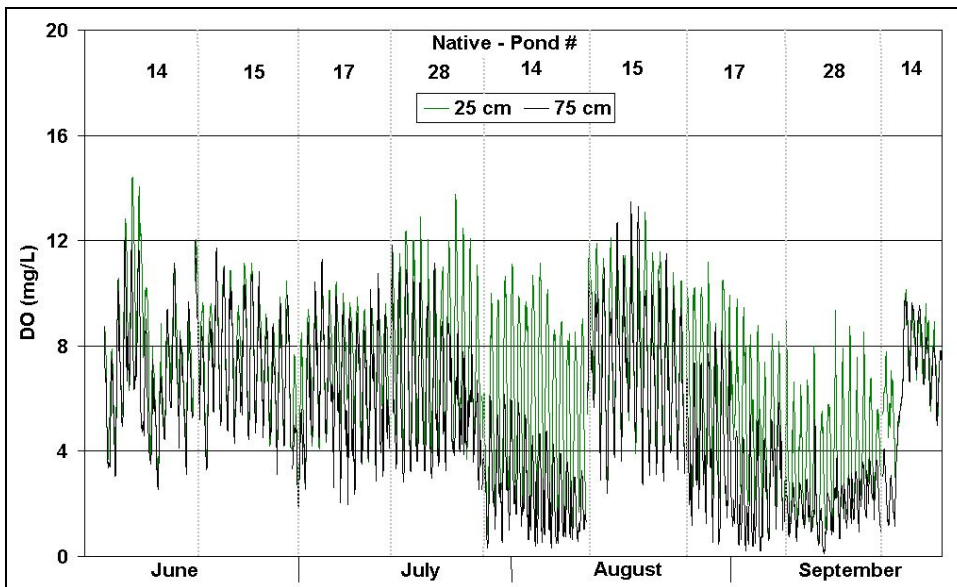
Hourly water temperature at two depths in ponds manipulated to support a dominant canopy of native plants.



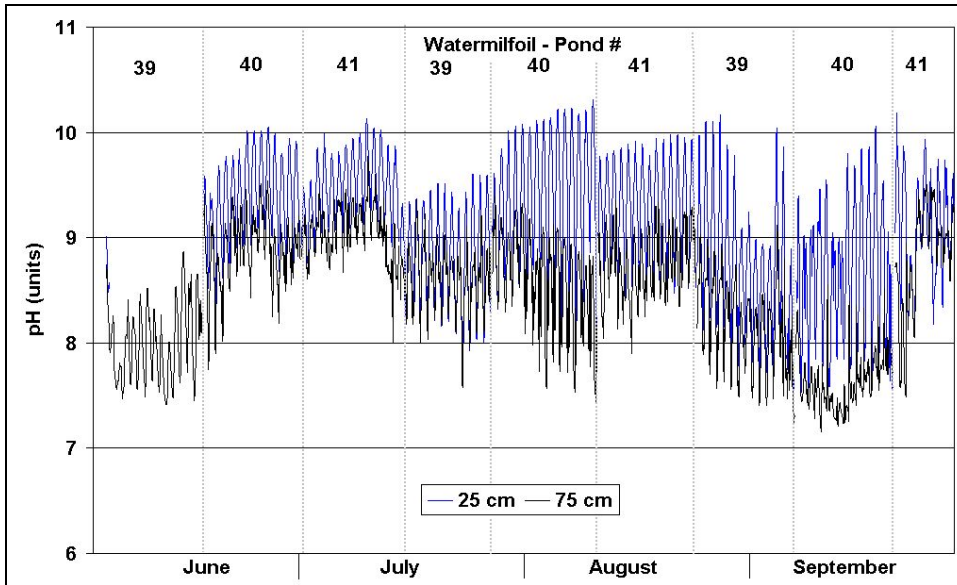
Hourly dissolved oxygen at two depths in ponds manipulated to support a dominant canopy of Eurasian watermilfoil.



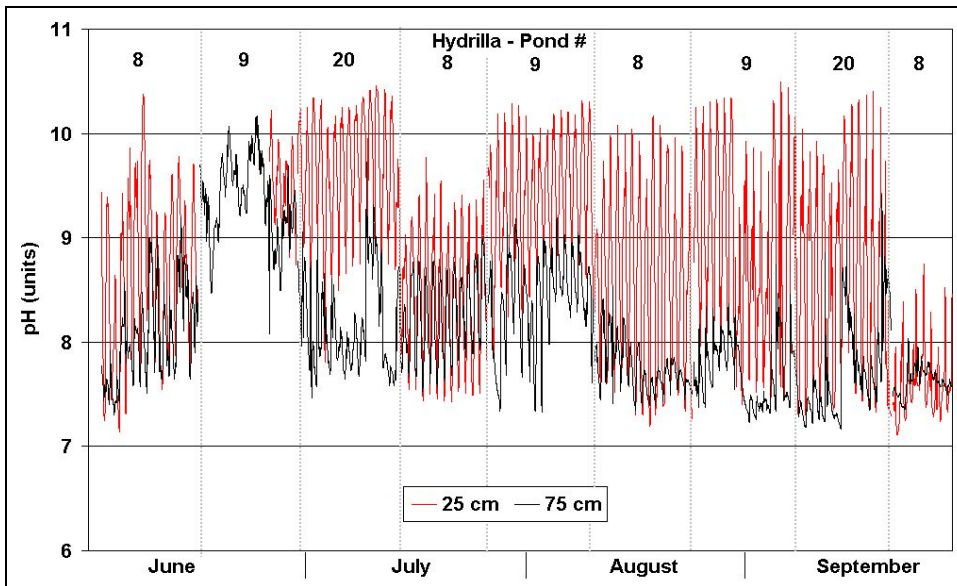
Hourly dissolved oxygen at two depths in ponds manipulated to support a dominant canopy of hydrilla.



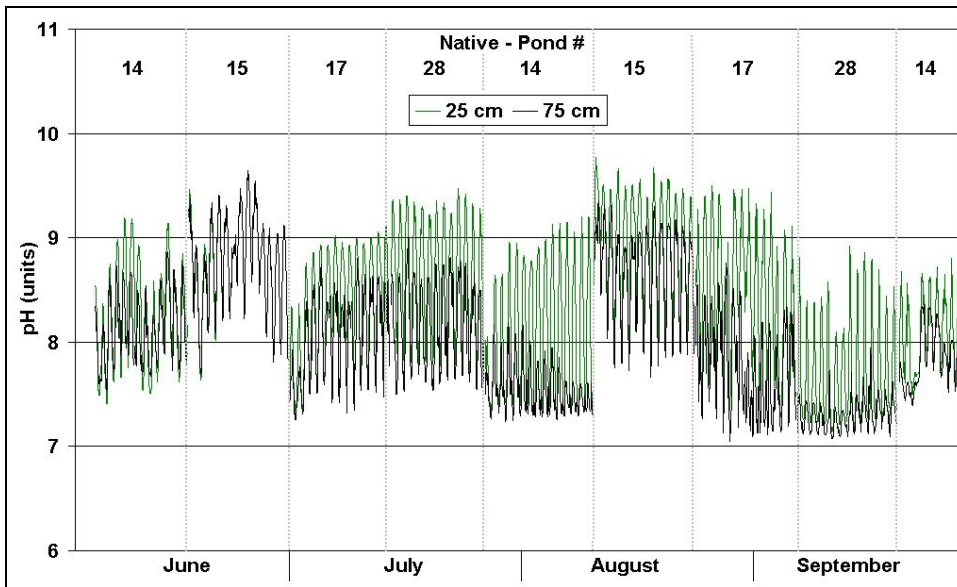
Hourly dissolved oxygen at two depths in ponds manipulated to support a dominant canopy of native plants.



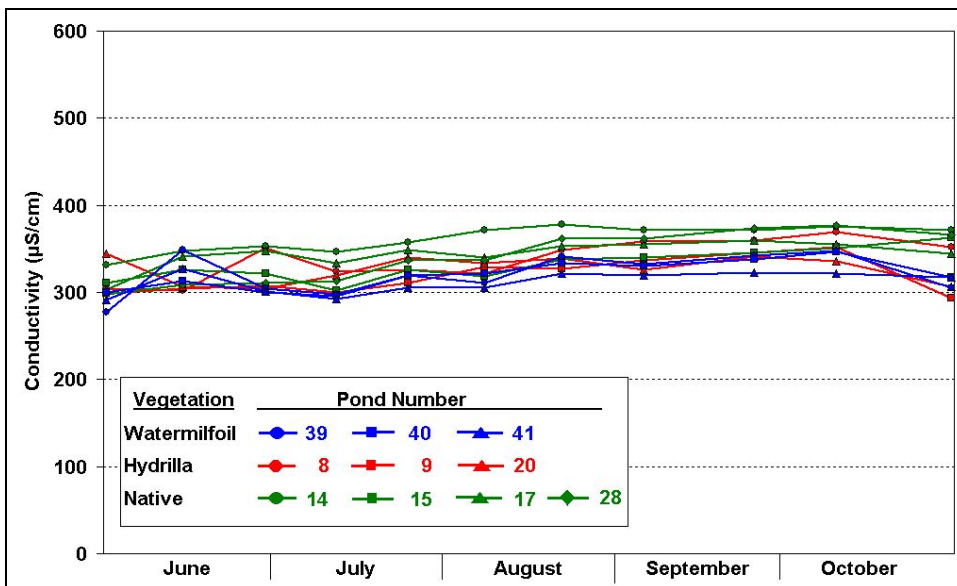
Hourly pH at two depths in ponds manipulated to support a dominant canopy of Eurasian watermilfoil. Watermilfoil dominance in pond 39 was not achieved. Datasondes were randomly moved between ponds every two weeks.



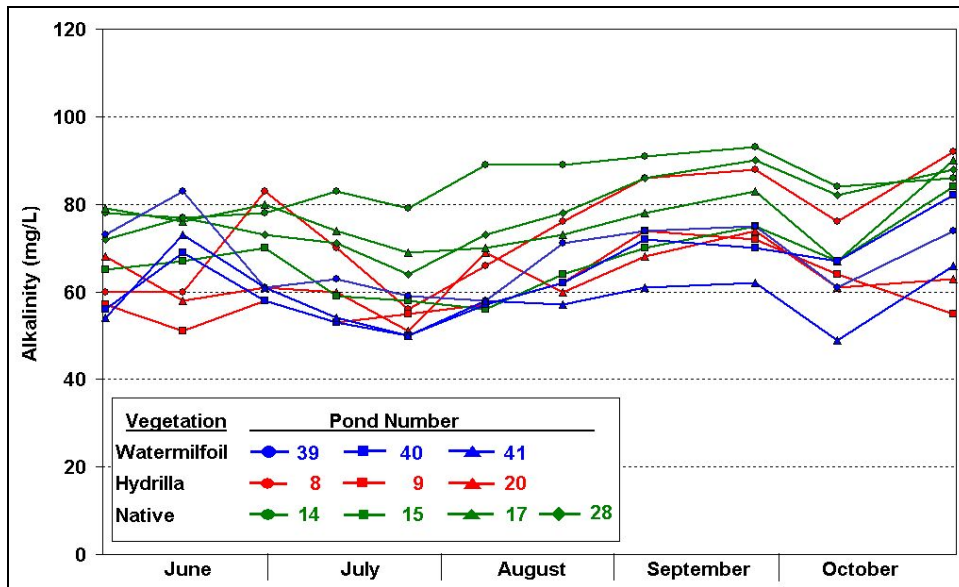
Hourly pH at two depths in ponds manipulated to support a dominant canopy of hydrilla. Datasondes were randomly moved between ponds every two weeks.



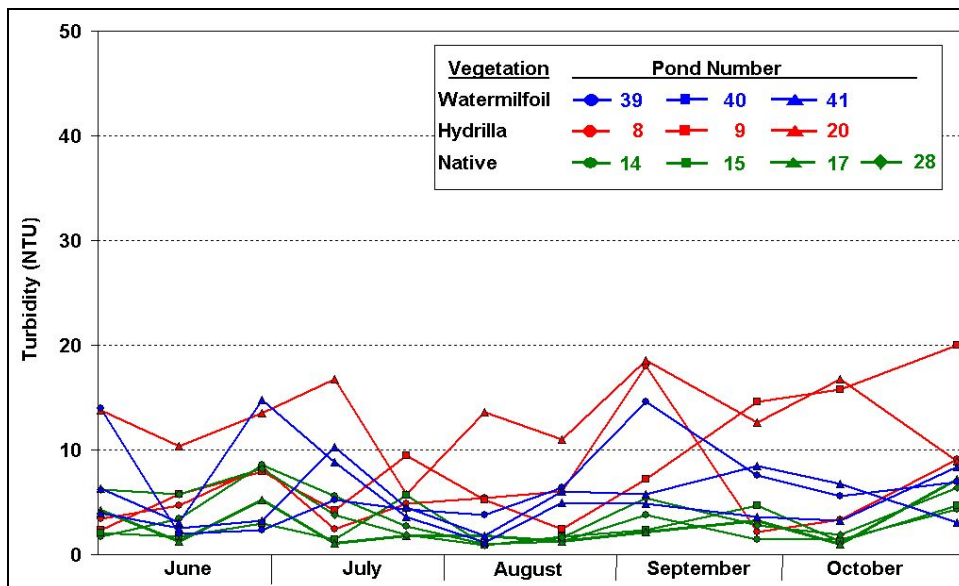
Hourly pH at two depths in ponds manipulated to support a dominant canopy of native plants. Native dominance in pond 17 was not achieved. Datasondes were randomly moved between ponds every two weeks.



Conductivity ($\mu\text{S}/\text{cm}$) measured biweekly from integrated samples averaged 317 in watermilfoil ponds, 328 in hydrilla ponds, and 344 in native ponds.

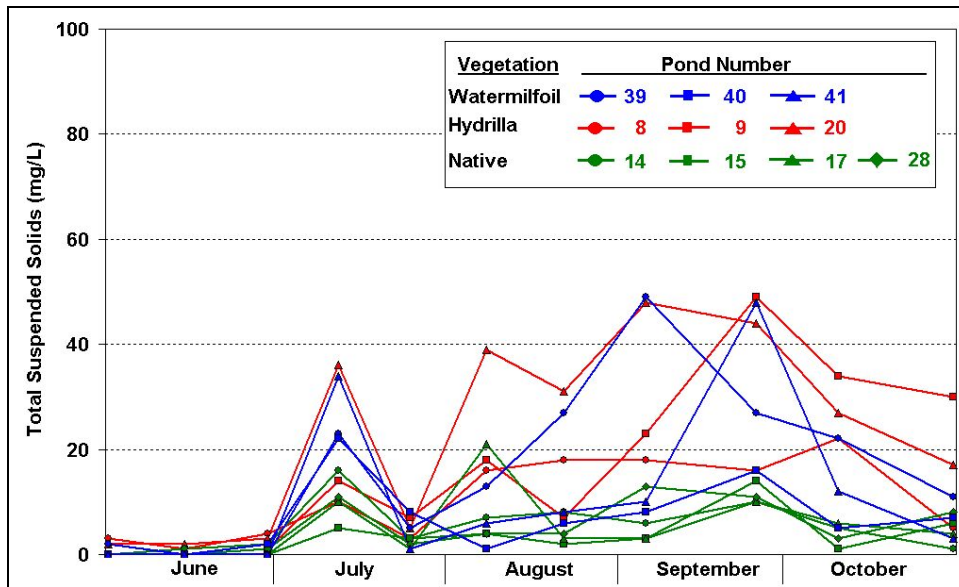


Alkalinity (mg/L as CaCO₃) measured biweekly from integrated samples averaged 63 mg/L in watermilfoil ponds, 66 mg/L in hydrilla ponds, and 76 mg/L in native ponds.

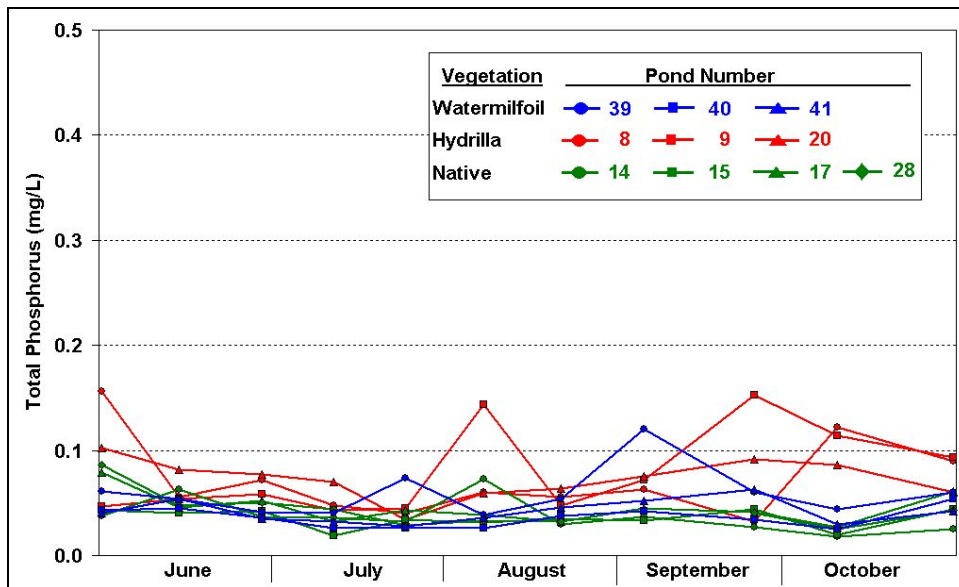


Turbidity measured biweekly from integrated samples averaged 5.8 NTU in watermilfoil ponds, 9.2 NTU in hydrilla ponds, and 3.2 NTU in native ponds.

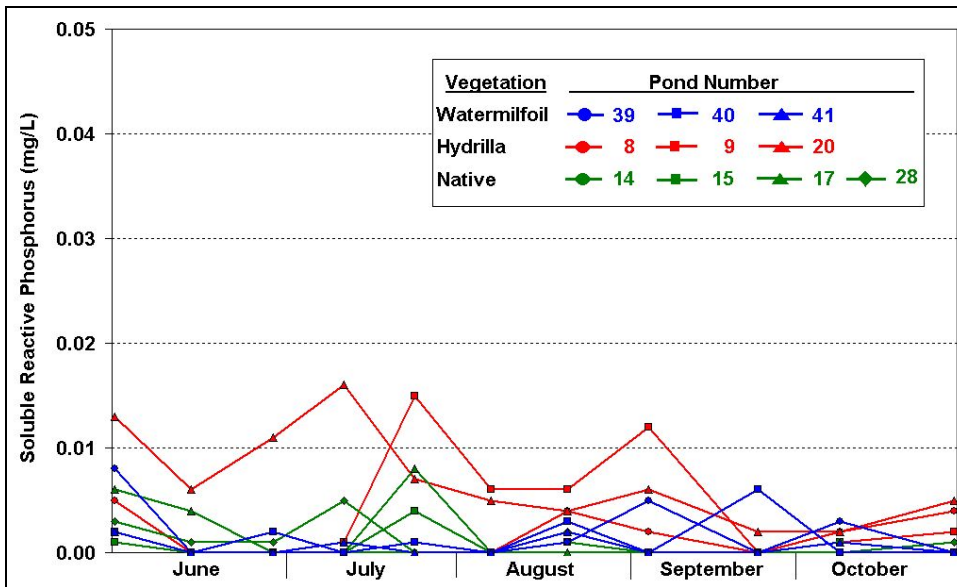
Generally, plants serve to clear water by reducing contributors to turbidity: phytoplankton (nutrient competition) and particulate matter (ionic “binding” by leaf surfaces). Sample collection may have contributed to higher turbidities in hydrilla and watermilfoil ponds: deployment of the integrated sampler disturbed the canopy, knocking particulate matter from stems and leaves.



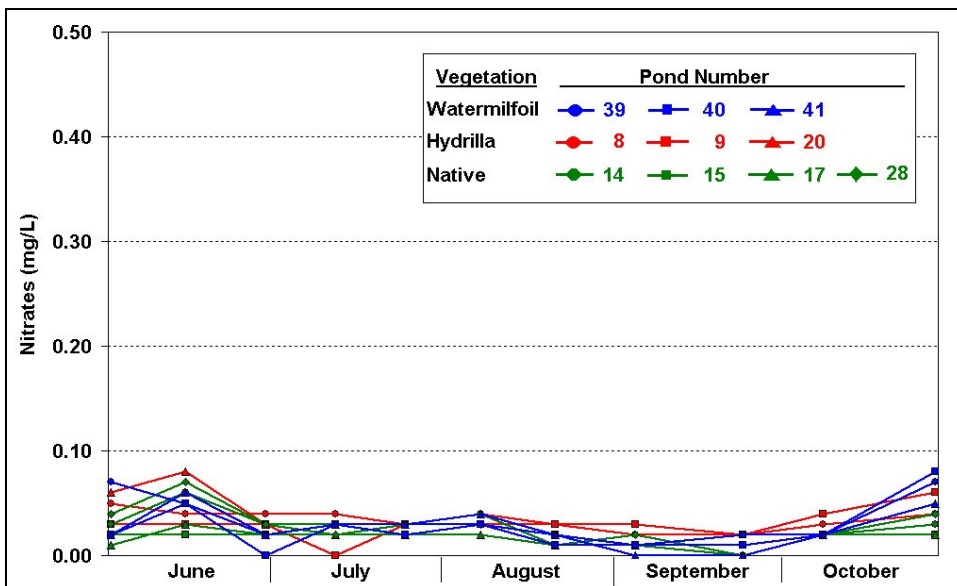
Total suspended solids (TSS) measured biweekly from integrated samples averaged 11 mg/L in watermilfoil ponds, 17 mg/L in hydrilla ponds, and 5 mg/L in native ponds. Sample collection may have contributed to higher TSS in hydrilla and watermilfoil ponds: deployment of the integrated sampler disturbed the canopy, knocking particulate matter from stems and leaves.



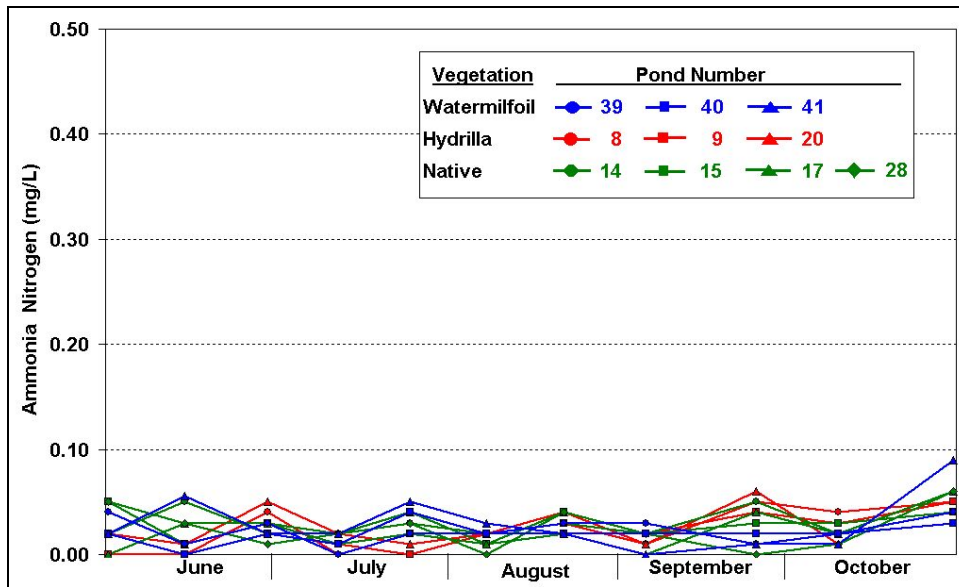
Total phosphorus measured biweekly from integrated samples averaged 0.045 mg/L in watermilfoil ponds, 0.075 mg/L in hydrilla ponds, and 0.04 mg/L in native ponds.



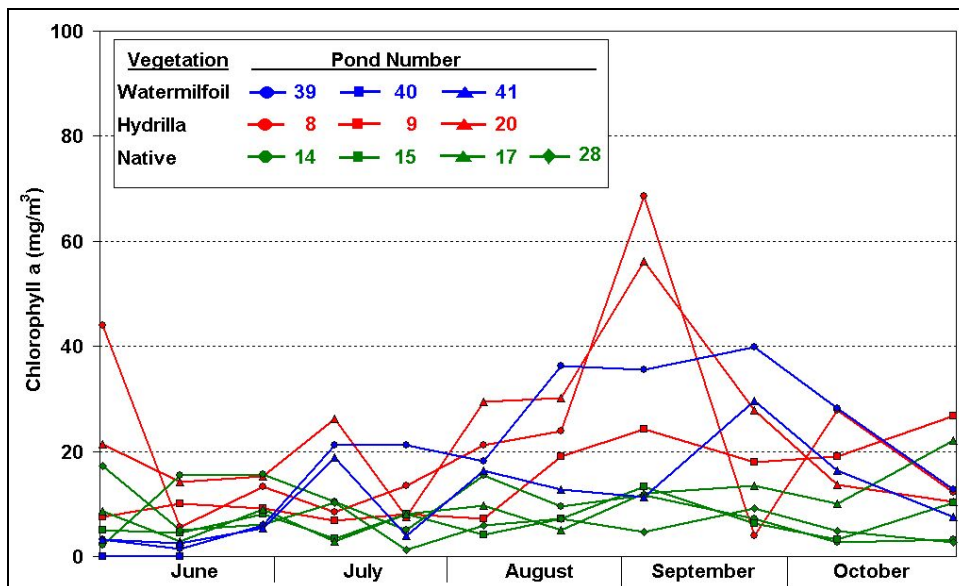
Soluble reactive phosphorus (SRP) measured biweekly from integrated samples averaged 0.001 mg/L in watermilfoil ponds, 0.004 mg/L in hydrilla ponds, and 0.001 mg/L in native ponds.



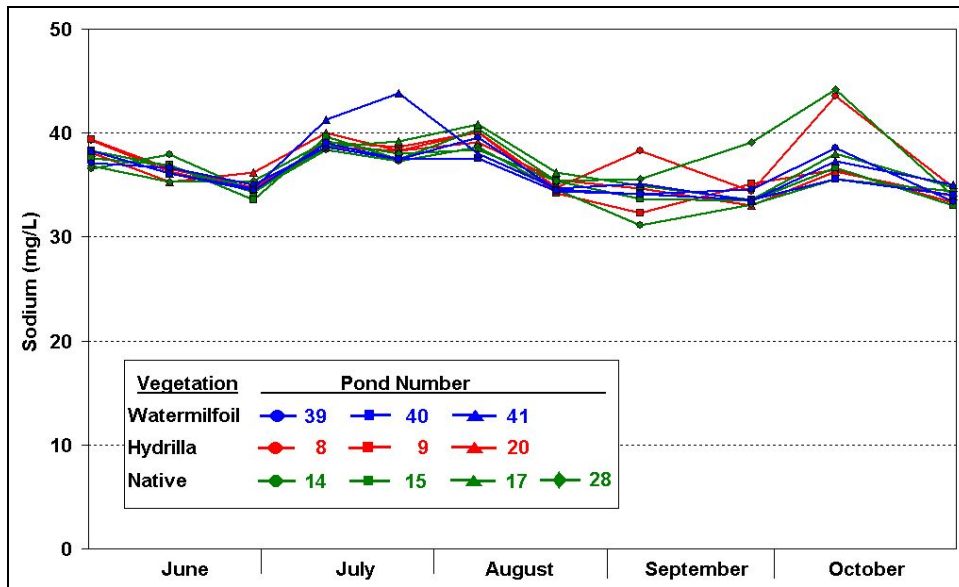
Nitrate-nitrogen measured biweekly from integrated samples was similar in all ponds, and averaged 0.03 mg/L in watermilfoil ponds, 0.03 mg/L in hydrilla ponds, and 0.02 mg/L in native ponds.



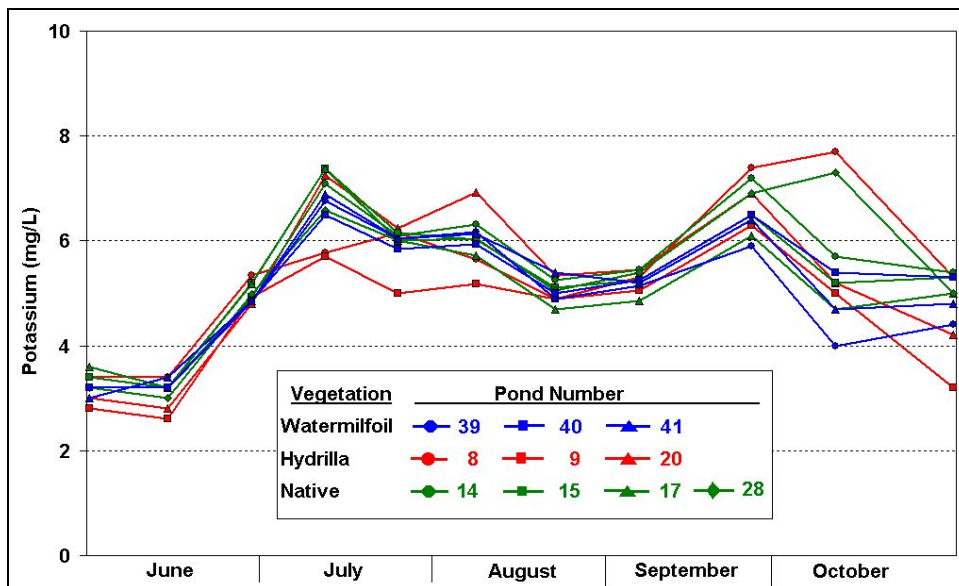
Ammonia nitrogen measured biweekly from integrated samples was similar in all ponds, and averaged 0.02 mg/L in watermilfoil ponds, 0.04 mg/L in hydrilla ponds, and 0.03 mg/L in native ponds.



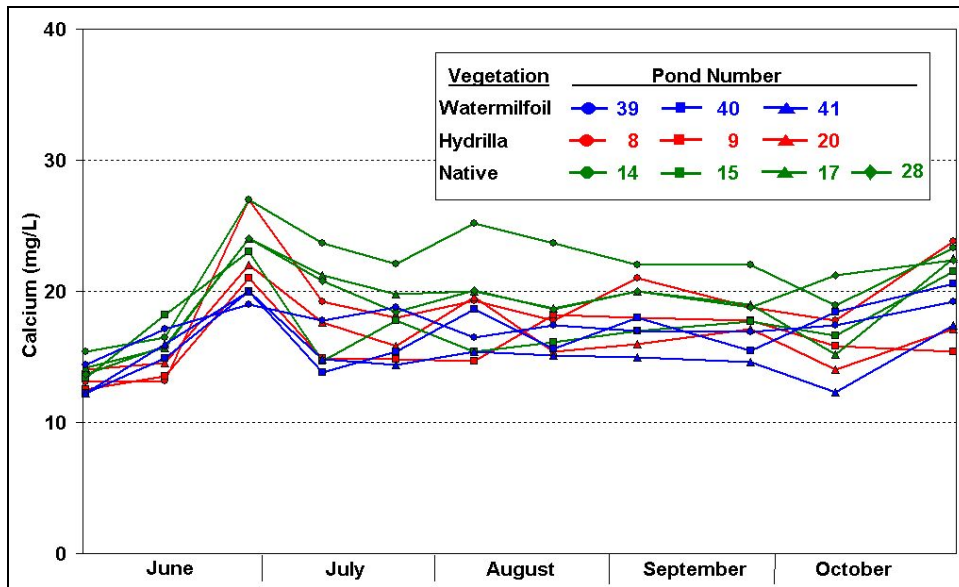
Chlorophyll a measured biweekly from integrated samples averaged 14.0 mg/L in watermilfoil ponds, 19.7 mg/L in hydrilla ponds, and 7.94 mg/L in native ponds. Higher concentrations in watermilfoil and hydrilla ponds was likely due to particulate matter and plant material being knocked free from plants during sample collection.



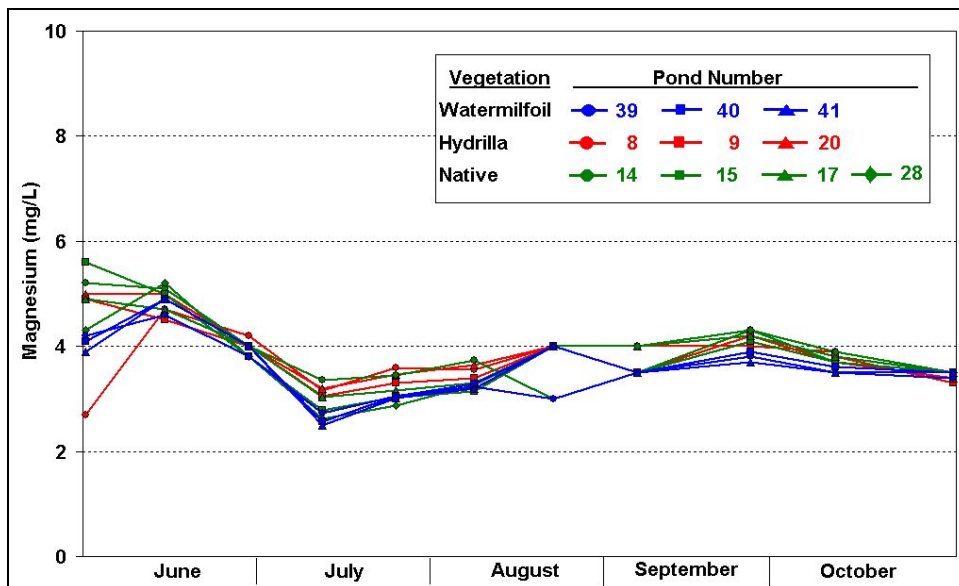
Sodium measured biweekly from integrated samples was similar in all ponds, and averaged 36.4 mg/L in watermilfoil ponds, 36.8 mg/L in hydrilla ponds, and 36.5 mg/L in native ponds.



Potassium measured biweekly from integrated samples was similar in all ponds, and averaged 5.10 mg/L in watermilfoil ponds, 5.12 mg/L in hydrilla ponds, and 5.33 mg/L in native ponds.



Calcium measured biweekly from integrated samples was similar in all ponds, and averaged 16.4 mg/L in watermilfoil ponds, 17.2 mg/L in hydrilla ponds, and 19.4 mg/L in native ponds.



Magnesium measured biweekly from integrated samples was similar in all ponds, and averaged 3.60 mg/L in watermilfoil ponds, 3.83 mg/L in hydrilla ponds, and 3.85 mg/L in native ponds.

