THE AQUATIC PLANT COMMUNITY OF PEPPERMILL LAKE, ADAMS COUNTY, WISCONSIN
2001-2012

Presented by Reesa Evans
Certified Lake Manager, Lake Specialist
Adams County Land & Water Conservation Department
P.O. Box 287, Friendship, WI 53934
608-339-4268

Executive Summary

I. INTRODUCTION

A study of the aquatic macrophytes (plants) in Peppermill Lake was conducted during the summer of 2012 by the Adams County Land and Water Conservation and a volunteer from the Peppermill Lake District. Two aquatic surveys were done during the summer of 2012: one by the transect method, in order to match changes from prior transect survey results, and one by the point intercept method for comparison to prior point intercept surveys.

A study of the diversity, density, and distribution of aquatic plants is an essential component of understanding a lake ecosystem due to the important ecological role of aquatic vegetation in the lake and the ability of the vegetation to characterize the water quality (Dennison et al. 1993).

Ecological Role: All other life in the lake depends on the plant life - the beginning of the food chain. Aquatic plants and algae provide food and oxygen for fish, wildlife, and the invertebrates that in turn provide food for other organisms. Plants provide habitat, improve water quality, protect shorelines and lake bottoms, add to the aesthetic quality of the lake and impact recreation.

Characterize Water Quality: Aquatic plants serve as indicators of water quality because of their sensitivity to water quality parameters, such as water clarity and nutrient levels (Dennison et. al. 1993).

The present study will provide ongoing information that is important for effective management of the lake, including fish habitat improvement, protection of sensitive habitat, aquatic plant management and water quality protection. It will also allow tracking of any significant changes in the aquatic plant community that may indicate changes in the lake's overall health, as well as permit evaluation of the management strategies set out in the approved lake management plan.

Background and History: Peppermill Lake is located in the Town of Jackson. The impoundment is 65 surface acres in size. Maximum depth is 14 feet, with an average depth of about 5 feet. During the summer of 2012 when this aquatic plant survey was conducted, the lake was at slightly lower level than usual due to drought and very hot weather. There is a public boat ramp located on northeast end of the lake owned by the Town of Jackson. By the boat ramp is the Peppermill Dam, owned by Adams County, and managed by the Adams County Land & Water Conservatism Department. The Peppermill Lake District completed a lake management plan that was approved by the Wisconsin Department of Natural Resources. This plan is reviewed annually for needed updates.

Residential development around the lake is found along most of the lakeshore, except the northwest end, which is in conservancy. The surface watershed is 36.2% residential, 3.5% non-irrigated agriculture, 53.4% woodlands, and 2.58% water. The ground watershed, which extends north and west of the lake, contains 13.26% non-irrigated agriculture, 9.69% irrigated agriculture, 52.02% woodlands, 14.22% residential, 2.75% governmental (a federal prison), 0.48% open grassland, and 2.58% water. There are no known endangered or threatened aquatic and terrestrial resources in or directly around the lake. There are no identified archeological or historical sites in either the surface or ground watersheds.

Fish stocking records in the 1990s show that northern pike (*Esox lucius)* and largemouth bass (*Micropterus salmoides)* were stocked by the Wisconsin Department of Natural Resources. Fish inventory in 1970 found that largemouth bass, bluegills (*Lepomis macrochrius)*, pumpkinseeds (*Lepomis gibbosus)*, and white suckers (*Catostomus commersonii)* were common, northern pike was present and rock bass (*Amblophites rupestris)* was scarce. Through several other fish inventories, largemouth bass and bluegills tended to be abundant. A fish inventory in October 2006 revealed that the following fish were found in the lake (a full report is not yet available): northern pike; largemouth bass; bluegill; pumpkinseed; yellow perch (*Perca flavescens)*; black crappie (*Pomoxis nigromaculatus)*; bullhead (*Ameiurus* spp); white sucker; and rock bass.

In 2009, Peppermill Lake suffered a winter fish kill. After investigation by the Wisconsin Department of Natural Resources, it was determined that the fish population was likely to recover on its own without any additional fish stocking. The Peppermill Lake District does run aerators throughout most of each winter to help maintain oxygen for the fish.

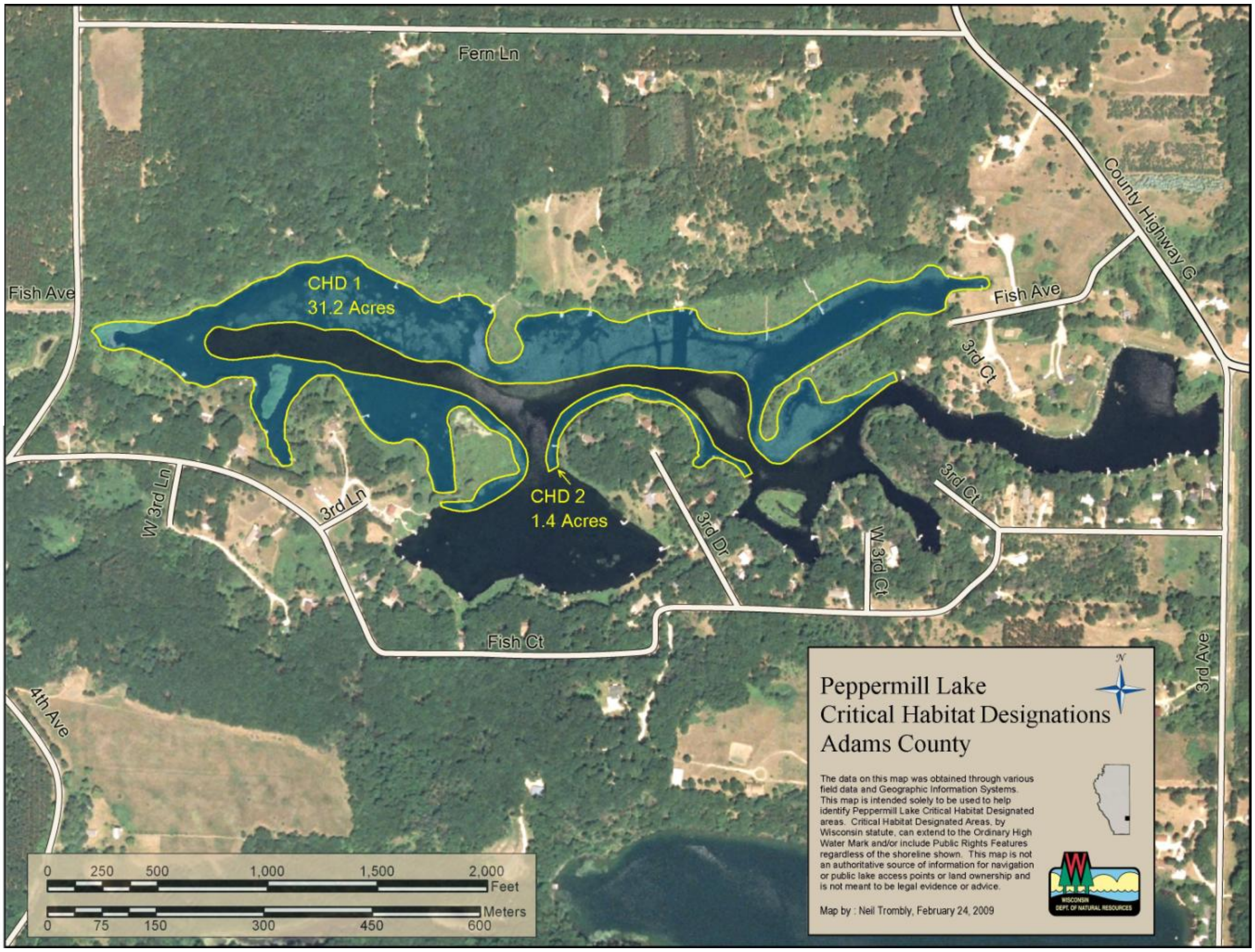
Soils directly around Peppermill Lake tend to be sand or loamy sand of less than 12% slope, except for some eroded silt loam with 12% to 29% slope at the far east end of the lake. Those in the surface and ground watersheds are also sands and loamy sands. Such soils tend to be excessively-drained, with infiltration of water being rapid to very rapid, and permeability also high. Such soils also usually have low water-holding and low organic matter content, thus making them difficult to establish vegetation on. These soils tend to be easily eroded by both water and wind.

In the past, efforts at controlling aquatic plant growth have included both chemical treatments and mechanical harvesting. Chemical treatment records go back to 1999. However, no chemical treatment has been done in Peppermill Lake for at least five years, as the population of Eurasian Watermilfoil diminished after several years of regular chemical treatment. The lake is evaluated each spring and fall for any re-establishment of Eurasian Watermilfoil. One other invasive aquatic plant has been found in Peppermill Lake, but has remained in low frequency occurrence: Reed Canarygrass (*Phalarais arundinacea*).

Mechanical harvesting is done one to three times per summer, depending on aquatic plant growth, and is confined to making sure that navigational channels are open throughout the lake.

Two areas in Peppermill Lake have been designated as “critical habitat areas”. Designation of critical habitat areas within lakes provides a holistic approach for assessing the ecosystem and for protecting those areas in and near a lake that are important for preserving the qualities of the lake. Wisconsin Rule 107.05(3)(i)(I) defines a “sensitive areas” as: “areas of aquatic vegetation identified by the department as offering critical or unique fish & wildlife habitat or offering water quality or erosion control benefits to the body of water. Thus, these sites are essential to support the wildlife and fish communities. They also provide mechanisms for protecting water quality within the lake, often containing high-quality plant beds. Finally, sensitive areas often can provide the peace, serenity and beauty that draw many people to lakes in the first place.

Figure 1: Critical Habitat Map for Peppermill Lake



Area CH1

This area extends along approximately 7000 feet of the shoreline up to the ordinary high water mark, comprised of about 2/3 of the northern shore of the lake and the southwest shore of the lake. 12% of the shore is wooded; 61% has shrubs; 27% is native herbaceous cover. Shrub-carr is found along part of the shore. Large woody cover is common for habitat. With minimal human disturbance along this shoreline, the area has natural scenic beauty. Since human disturbance is light in PE1, it provides quality habitat for many types of wildlife. The WDNR wildlife biologist indicated that should this shoreline become more developed, its habitat value will be limited.

Figure 2: Photo of Middle Section of CH1

Maximum rooting depth of aquatic vegetation in PE1 was 7.5 feet. Ten types of emergent aquatic plants were found in this area. Emergents provide important fish habitat and spawning areas, as well as food and cover for wildlife. Two species of free-floating plants were also present. These provide cover for fish and invertebrates and are eaten by fish and waterfowl. Three types of rooted, floating-leaf plants were also found here. Rooted floating-leaf vegetation provides cover and dampens waves, protecting the shore. A variety of twelve species submergent aquatics characterized this area. A diverse submergent community provides many benefits.

The only exotic invasive plant found in this area was Eurasian Watermilfoil. Most of the aquatic vegetation in this area has multiple uses for fish and wildlife (see Figure 3). Because this site provides all three structural types of vegetation, the community has a diversity of structure and species that supports even more diversity of fish and wildlife.

Figure 3: Fish & Wildlife Uses of Aquatic Plants

	Fish	Water	Shore	Upland	Muskrat	Beaver	Deer
		Fowl	Birds	Birds			
Carex spp		F	F,I	-			
Chara	F,S	F,I,C					
Lemna minor	F,I,C,S	F	F		F	F	
Myriophyllum spp	F,I,C,S	F,I	F		F		
Najas spp	F,C,I	F	F	F	F		
Nuphar variegataa	F,I,C,S	F	F		F	F	F
Nymphaea odoratoa	F,I,C,S	F	F		F	F	
Potamogeton spp	F,I,C.S	F,I	F		F	F	F
Scirpus spp	F,C,I	F,C	F,C,N	F	F	F	F
Spirodela polyrhiza	F,I,C,S	F	F		F	F	
Sparganium spp	F,I,C,S	F,C,N	F,C,N		F		F

F = Food; I = Shelters Invertebrates; C = Cover; S = Spawning; N = Nesting

Area CH2

This area extends along approximately 800 feet of the shoreline along the middle south part of the lake. 35% of the shore is wooded; 10% is native herbaceous cover; the remaining shore is cultivated lawn and a little hard structure. Shallow marsh covers part of the shore. Large woody cover is common for habitat. Maximum rooting depth in PE2 was 8 feet. No threatened or endangered species were found in this area. One exotic invasive, *Myriophyllum spicatum* (Eurasian watermilfoil), was found in this area. . Only two types of emergents were found here. Two floating-leaf rooted plants were present. Two free-floating plants were also at this site. The remaining aquatic plants were five submergent species.

Figure 4: Photo of Part of CH2

II. METHODS

Field Methods

The transect study design was based on the rake-sampling method developed by Jessen and Lound (1962), using stratified random placement of the transect lines. The shoreline was divided into several equal segments, and a transect line, perpendicular to the shoreline, was randomly placed within each segment, using a random numbers table.

One sampling site was randomly located in each depth zone (0-1.5ft, 1.5-5ft, 5-10ft and 10-20ft) along each transect. Using a long-handled steel thatching rake or a thatching rake on a rope, four rake samples were taken at each sampling site, one from each quarter of a 6-foot diameter quadrat. The aquatic plant species that were present on each rake sample were recorded. Each species was given a density rating (0-5), the number of rake samples on which it was present at each sampling site.

A rating of 1= the species was present on one rake sample at that site;
A rating of 2 = the species was present on two rake samples at that site;
A rating of 3 = it was present on three rake samples;
A rating of 4 = it was present on all four rake samples;
A rating of 5 = it was abundant on all four rake samples.

Visual inspection and periodic samples were taken between transect lines to record the presence of any species that did not occur at the sampling sites. Specimens of all plant species present were collected and saved in a cooler for later preparation of voucher specimens. Nomenclature was according to Gleason and Cronquist (1991).

The type of shoreline cover was recorded at each transect. A section of shoreline, 50 feet on each side of the transect intercept with the shore and 30 feet landward, was evaluated. The percent cover of each land use category within this 100' x 30' rectangle was visually estimated and recorded on a data sheet.

The second method used was the Point Intercept Method. This method involves calculating the surface area of a lake and dividing it (using a formula developed by the WDNR) into a grid of several points, always placed at the same interval from the next one(s). These points are related to a particular latitude and longitude reading. At each geographic point, the depth is noted and one rake is taken, with a score given between 1 and 3 to each species on the rake.

A rating of 1 = a small amount present on the rake;
A rating of 2 = moderate amount present on the rake;
A rating of 3 = large amount present on the rake.

A visual inspection was done between points to record the presence of any species that didn't occur at the raking sites. Gleason and Cronquist (1991) nomenclature was used in recording plants found.

Data Analysis

The percent frequency of each species was calculated (number of sampling sites at which it occurred/total number of sampling sites). Relative frequency was calculated (number of occurrences of a species/sum of all species occurrences) .The mean density was calculated for each species (sum of a species' density ratings/number of sampling sites). Relative density was calculated (sum of a species density/sum of all plant densities). "Mean density where present" was calculated for each species (sum of a species' density ratings/number of sampling sites at which the species occurred). The relative frequency and relative density of each species were summed to obtain a dominance value for each species. Species diversity was measured by Simpson's Diversity Index.

The Aquatic Macrophyte Community Index (AMCI) developed by Nichols (Nichols, et al., 2000) was applied to Peppermill Lake results. Measures for each of seven categories that characterize a plant community are converted to values between 0 and 10 and summed to measure the quality of the plant community.

The Average Coefficient of Conservatism and Floristic Quality Index were calculated, as outlined by Nichols (1998), to measure disturbance in the plant community. A coefficient of conservatism is an assigned value, 0-10, the probability that a species will occur in an undisturbed habitat. The Average Coefficient of Conservatism is the mean of the coefficients for all species found in the lake. The Floristic Quality Index is calculated from the Coefficient of Conservatism (Nichols 1998) and is a measure of a plant community's closeness to an undisturbed condition.

III. RESULTS

PHYSICAL DATA

Many physical parameters impact the aquatic plant community. Water quality (nutrients, algae, water clarity and water hardness) influence the plant community as the plant community can in turn modify these parameters. Lake morphology, sediment composition and shoreline use also impact the aquatic plant community.

WATER QUALITY - The trophic state of a lake is a classification of its water quality. Phosphorus concentration, chlorophyll concentration and water clarity data are collected and combined to determine the trophic state.

- Eutrophic lakes are high in nutrients and support a large biomass.
- Oligotrophic lakes are low in nutrients and support limited plant growth and smaller populations of fish.
- Mesotrophic lakes have intermediate levels of nutrients and biomass.

Peppermill Lake has water quality records for a number of years. Water clarity, total phosphorus, and chlorophyll-a readings go back to 1992. There was then a gap of several years with no data collected. Regular collection began again in 1999 and has continued through 2012.

Figure 5: Trophic Status of Peppermill Lake

	Quality Index	Phosphorus ug/l	Chlorophyll ug/l	Secchi Disc ft.
Oligotrophic	Excellent	<1	<1	> 19
	Very Good	1-10	1-5	**8-19**
Mesotrophic	Good	**10-30**	**5-10**	6-8
	Fair	30-50	10-15	5-6
Eutrophic	Poor	50-150	15-30	3-4
Peppermill Lake Growing Season 2001-2012		**26.5**	**6.5**	**9.3**

Nutrients

Phosphorus is a limiting nutrient in many Wisconsin lakes, including Peppermill Lake, and is measured as an indication of nutrient enrichment in a lake. Increases in phosphorus in a lake can feed algae blooms and, occasionally, excess plant growth. Starting from 1990, the average growing season (May through September) for total phosphorus levels is 26.5 micrograms/liter, which is in the "good" category (see Figure 6). The lowest growing season total phosphorus average was 16 micrograms/liter in 1992; the highest average, 45.3 micrograms/liter, occurred in 2012.

Algae/Chlorophyll-a

Chlorophyll-a concentrations provide a measure of the amount of algae in lake water. Algae are natural and essential in lakes, but high algae populations can increase turbidity and reduce the light available for plant growth. The 1992-2012 Mean summer chlorophyll-a concentration in Peppermill Lake was 6.5 micrograms/liter, in the "good" range for chlorophyll-a levels (see Figure 7). The lowest average chlorophyll-a was 1.4 (in 2000); the highest average was 19.6 micrograms/liter in 2012.

Figure 6: Average Total Phosphorus Levels in Peppermill Lake 1992-2012

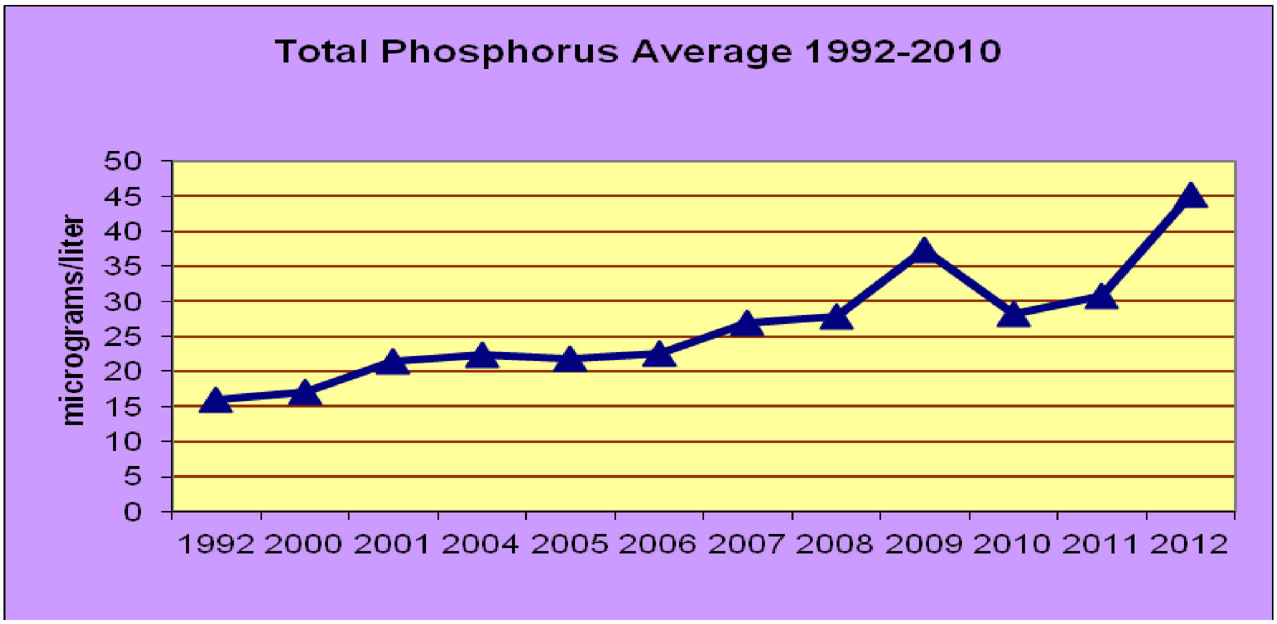
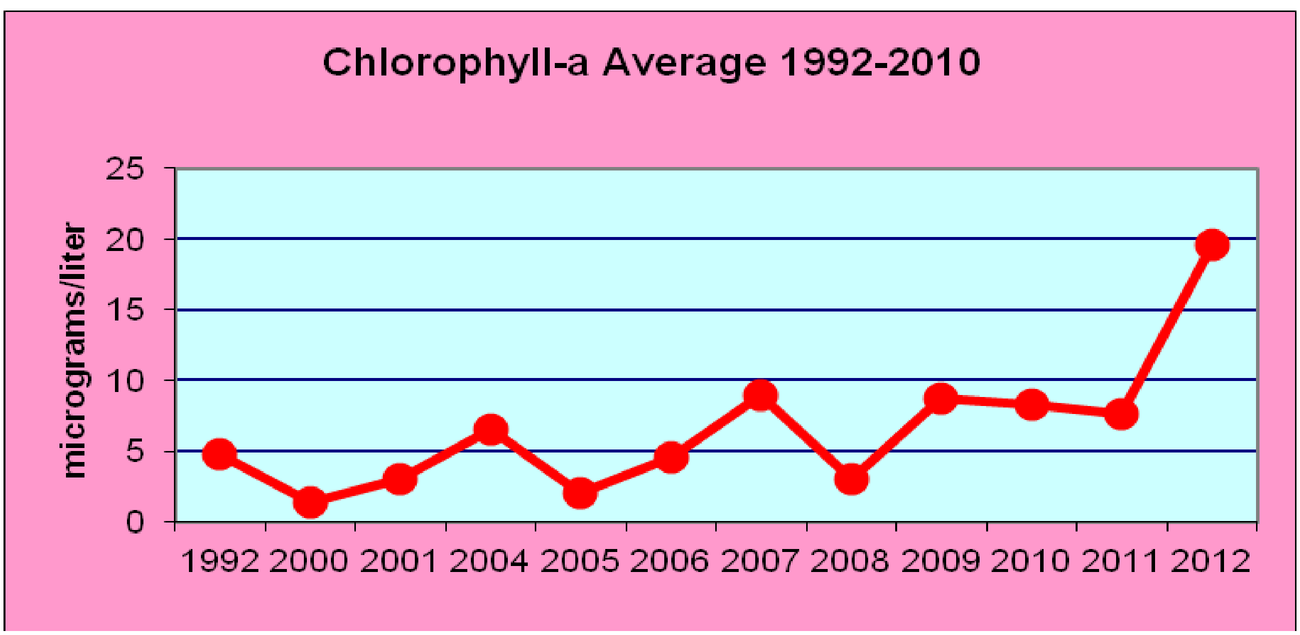


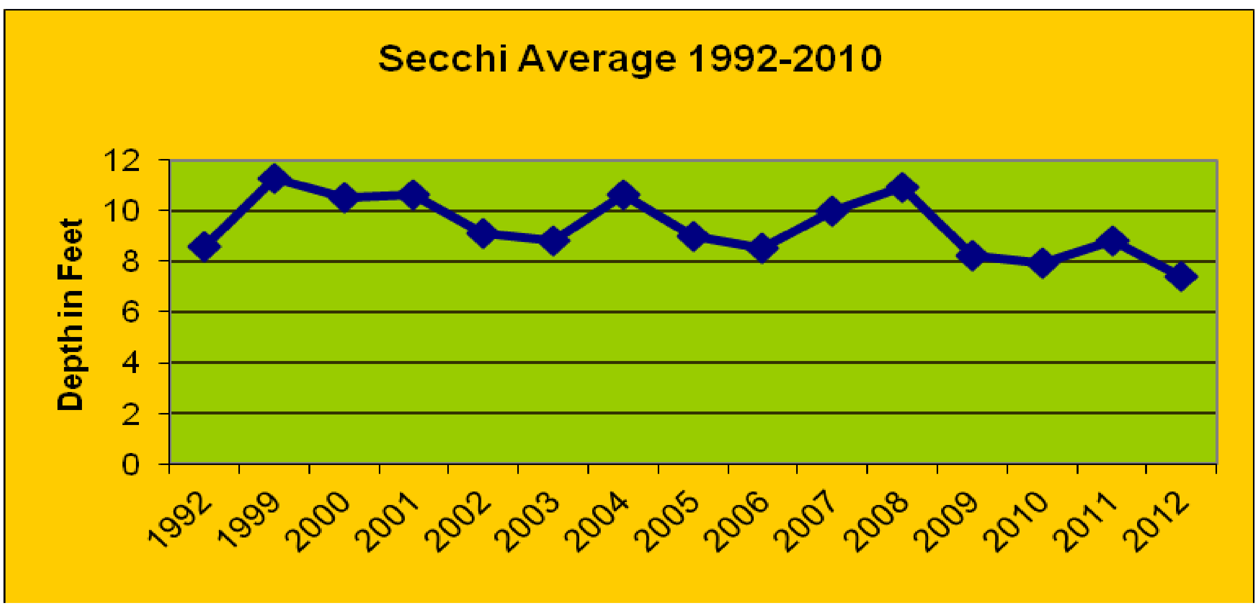
Figure 7: Average Chlorophyll-a Levels in Peppermill Lake 1992-2012



Water Clarity

Water clarity is a critical factor for aquatic plants, because if they don't get more than 2% of surface illumination, they won't survive (Chambers and Kalff 1985, Duarte et. al. 1986, Kampa 1994). Water clarity is reduced by turbidity (suspended materials such as algae and silt) and dissolved organic chemicals that color the water. Water clarity is measured with a Secchi disc that shows the combined effect of turbidity and color. The 1992-2012 Average Summer Secchi Disc clarity in Peppermill Lake was 9.3 feet. This falls in the "very good" category (see Figure 8). The lowest growing season average was 7.9 feet in 2010; the highest was 11.3 feet in 1999.

Figure 8: Average Growing Season Secchi Depth 1992-2012



Overall Water Quality

The combination of phosphorus concentration, chlorophyll-a concentration and water clarity indicate that Peppermill Lake is a borderline oligotrophic/mesotrophic lake with good-to-very good water quality and clarity. This trophic state should favor only moderate plant growth and occasional localized summer algal blooms.

Hardness

The hardness or mineral content of lake water also influences aquatic plant growth. The 1999-2006 hardness values in Peppermill Lake ranged from of 185 to 212 milligrams/liter $CaCO_3$, with an average of 198.7 micrograms/liter $CaCO_3$. This is very hard water. Hard water lakes tend to support more plant growth than soft water lakes (B.Shaw, et al, p.13). While marl (calcium carbonate) in a lake precipitates and falls to the lake bottom, some of the marl in hard water lakes often coats the external surfaces of submersed plants (C.E.Boyd, p. 112). Marl formations absorb phosphorus, reducing its overall concentration and decreasing algal growth (B. Shaw et al, p. 7). Such coating can be found on some of the plants in Peppermill Lake.

LAKE MORPHOMETRY - The morphometry of a lake is an important factor in determining the distribution of aquatic plants. Duarte and Kalff (1986) found that the slope of the littoral zone could explain 72% of the observed variability in the growth of submerged plants. Gentle slopes support more plant growth than steep slopes (Engel 1985).

Peppermill Lake is a man-made lake with a middle “channel” area and several lobes around the lake. There are no steep slopes; instead, the littoral area tends to be the entire lake, with gradual slopes. These gradual slopes provide a stable rooting base and a broad area of shallow water that can be reached by the sun. These factors favor aquatic plant growth, which may account for the aquatic vegetation rate for Peppermill Lake at 100% for all of the recorded aquatic plant surveys.

INFLUENCE OF SEDIMENT COMPOSITION

Some plants depend on the sediment in which they are rooted for their nutrients. The richness or sterility and texture of the sediment will determine the type and abundance of plant species that can survive in a location. The availability of mineral nutrients for growth is highest in sediments of intermediate density, such as silt, so these sediments are considered most favorable for plant growth (Barko and Smart 1986). Mineral availability in sediments such as sand is often considerably reduced. The most common sediment in Peppermill Lake was muck (see Figure 9). Muck soil has a nutrient-rich content, “perfect” for growing plants (Thompson 2010).

Figure 9: Peppermill Lake Bed Sediments

Sediment	Type	Zone 1 (0-1.5 ft)	Zone 2 (1.5-5 ft)	Zone 3 (5-10 ft)	Overall
Hard	Sand	5.26%			1.85%
Mixed	Muck/Gravel	10.53%	5.26%		5.56%
	Sand/Silt	5.26%			1.85%
Soft	Marl/Muck	5.26%		6.25%	3.70%
	Marl/Peat		5.26%	6.25%	3.70%
	Marl/Silt		10.53%	12.50%	7.41%
	Muck	63.17%	47.37%	18.75%	44.45%
	Muck/Peat		5.26%		1.85%
	Peat		15.79%	50.00%	20.37%
	Silt	5.26%	10.53%		5.56%
	Silt/Muck	5.26%		6.25%	3.70%

SHORELINE LAND USE

Land use can strongly impact the aquatic plant community and therefore the entire aquatic community. Land use can directly impact the plant community through increased erosion and sedimentation and increased run-off of nutrients, fertilizers and toxics applied to the land. These impacts occur in both rural and residential settings.

Native herbaceous plant cover was the most frequently occurring shoreline cover at the transect sites in 2006, and it remained high in 2012. Cultivated lawn and hard structure (boat docks, patios, retaining walls, etc.) also were frequently occurring (see Figure 10).

Figure 10: Percent Frequency of Occurrence of Shore Types

	2006	2012
Herbaceous Vegetation	100.0%	95%
Shrub Vegetation	73.7%	95%
Wooded Vegetation	63.2%	90%
Cultivated Lawn	42.1%	21%
Hard Structure (piers, patios, boatlifts, etc.)	36.8%	32%

Frequency of occurrence does not always translate into amount of actual cover a shore type provides. For example, in 2012, although one of the most frequently-occurring shore types was herbaceous vegetation (94.7%), it only covered 26.1% of the shore (see Figure 11).

Figure 11: Comparison of Shore Type Coverage by Percent Cover

	2006	2012
Herbaceous Vegetation	22.6	26.1
Shrub Vegetation	38.8	33.4
Wooded Vegetation	15.3	25.3
Cultivated Lawn	19.4	11.3
Hard Structure	3.9	3.9

Several landowners on Peppermill Lake have been working with the Adams County Land & Water Conservation Department to improve and/or expand their buffer areas. This probably contributed to the increase of vegetated shore cover from 76.7% to 84.5%.

MACROPHYTE DATA

SPECIES PRESENT

In the 2012 transect survey, forty-one (41) species of aquatics were found. Of these, thirty-nine (39) were native: nineteen (19) emergent species, two free-floating species, three rooted floating-leaf plants, and fifteen (15) submergents. Fifty-one (51) species were found in the 2012 PI survey, forty-nine of which were native. This included twenty-seven (27) emergents, two free-floating species, four rooted floating-leaf plants, and sixteen (16) submergents. In both surveys, two invasive aquatic plants were found: the emergent Reed Canarygrass (*Phalaris arundinacea*) and the submergent Eurasian Watermilfoil (*Myriophyllum spicatum*).

Figure 12: Peppermill Lake Aquatic Plant Species in 2012

Scientific Name	Common Name	2012(t)	2012(pi)	Plant Type
Acorus americana	Sweet Flag		x	E
Angelica atropurpurea	Angelica		x	E
Ascelpias incarnata	Swamp Milkweed	x	x	E
Bidens frondosus	Common Beggar's Tick		x	E
Bromus ciliatus	Fringed Brome		x	E
Calamagrostis canadensis	Canada Blue-Joint Grass	x	x	E
Carex spp	Sedge	x	x	E
Carex aquatilis	Lake Sedge	x		E
Carex comosa	Porcupine Sedge		x	E
Carex prairea	Prairie Sedge		x	E
Cornus stolonifera	Buttonbush		x	E
Ceratophyllum demersum	Coontail	x	x	S
Chara spp	Muskgrass	x	x	S
Chelone glabra	Turtlehead	x		E
Cicuta bulbifera	Bulb-Bearing Water Hemlock	x	x	E
Cornus stolonifera	Red-Osier Dogwood	x	x	E
Eleocharis erythropoda	Bald Spikerush		x	E
Elodea canadensis	Common Waterweed	x	x	S

Eupatorium maculatum	Joe Pye Weed	x	x	E
Eupatorium perfoliatum	Boneset	x	x	E
Galium asperellum	Rough Bedstraw		x	E
Impatiens capensis	Jewelweed	x	x	E
Iris versicolor	Blue-Flag Iris	x	x	E
Lemna minor	Lesser Duckweed	x	x	FF
Lycopus uniflorus	Northern Bugleweed	x	x	E
Myriophyllym heterophyllum	Various-Leaved Milfoil	x	x	S
Myriophyllum sibiricum	Northern Milfoil	x	x	S
Myriophyllum spicatum	Eurasian Watermilfoil	x	x	S
Myriophyllum verticillatum	Whorled Watermilfoil	x	x	S
Najas flexilis	Bushy Pondweed	x	x	S
Nuphar variegata	Yellow Pond Lily	x	x	FL
Nymphaea odorata	White Water Lilly	x	x	FL
Onoclea sensibilis	Sensitive Fern		x	E
Phalaris arundinacea	Reed Canarygrass	x	x	FL
Polygoncum amphibium	Water Smartweed		x	S
Potamogeton amplifolious	Large-Leaf Pondweed	x	x	S
Potamogeton foliosus	Leafy Pondweed	x	x	S
Potamogeton friesii	Fries's Pondweed	x	x	S
Potamogeton illinoensis	Illinois Pondweed	x	x	S
Potamgeton natans	Floating-Leaf Pondweed	x	x	FL
Potamogeton praelongus	White-Stemmed Pondweed	x	x	S
Potamogeton richardsonii	Clasping-Leaf Pondweed		x	S
Potamogeton zosteriformis	Flat-Stemmed Pondweed		x	S
Sagittaria spp	Arrowhead	x	x	E
Salix spp	Willow	x	x	E
Schoenoeplectus tabernaemontani	Soft-Stemmed Bulrush	x	x	E
Scirpus cyperinus	Woolgrass		x	E
Sium suave	Hemlock Water Parsnip		x	E
Solanum dulcamara	Bittersweet Nightshade	x		E
Sparganium eurycarpum	Common Bur Reed	x	x	E
Spirodela polyrhiza	Greater Duckweed	x	x	FF
Stuckenia pectinata	Sago Pondweed	x	x	S
Typha spp	Cattails	x	x	E
Utricularia gemniscapa	Twin-Stemmed Bladderwort		x	S
Utricularia gibba	Creeping Bladderwort		x	S
Utricularia vulgaris	Greater Bladderwort		x	S
Zosterella dubia	Water Stargrass	x	x	S

FREQUENCY OF OCCURRENCE

In both 2012 surveys, Muskgrass (*Chara* spp.), a plant-like algae, was the most frequently-occurring species. Northern Milfoil was also very frequent. In both surveys, Eurasian Watermilfoil was the most frequently-occurring invasive, occurring 5.5% of the time in the PI survey and 13.2% in the transect survey.

There are two ways of looking at frequency in these surveys. One is the frequency of occurrence in the aquatic plant community overall. The second way is to evaluate the relative frequency of a plant overall, i.e., what frequency percent is it relative to all the other plants in the aquatic plant community? Figures 13a and 13b show the frequency of occurrence for both surveys in 2012. Relative frequency will be discussed later in this report.

Figure 13a: Percent Frequency of Occurrence Overall (T)

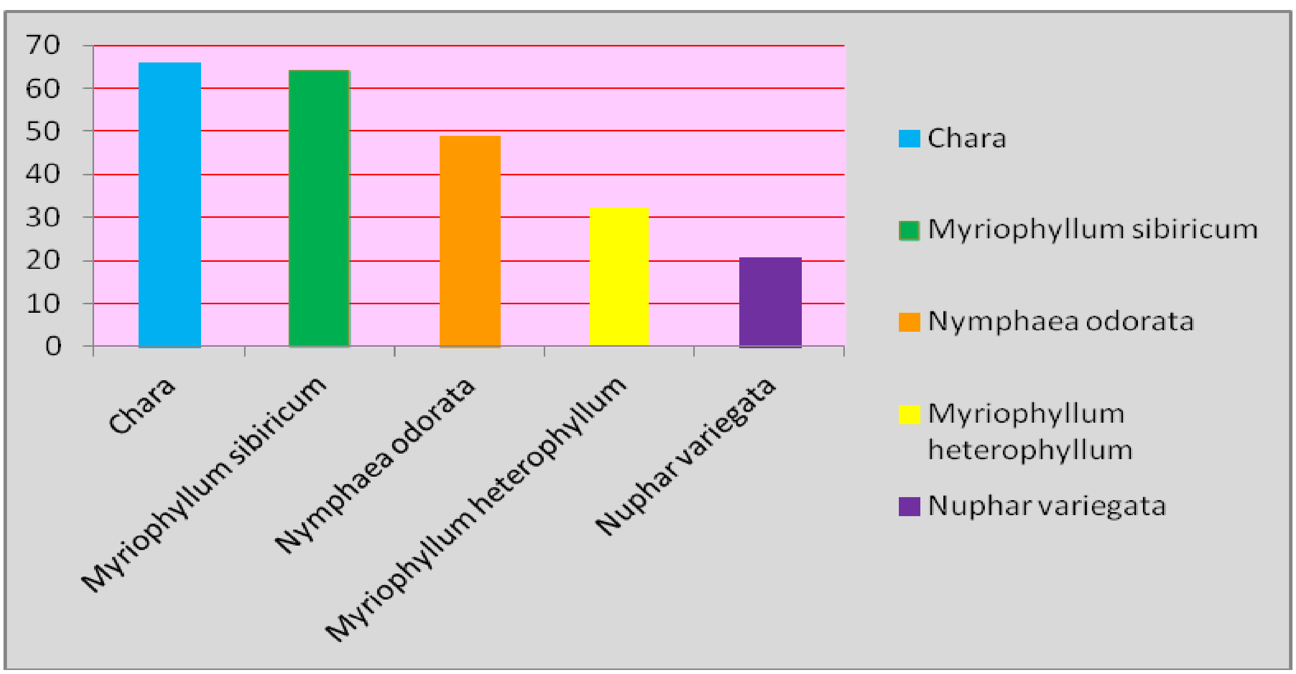
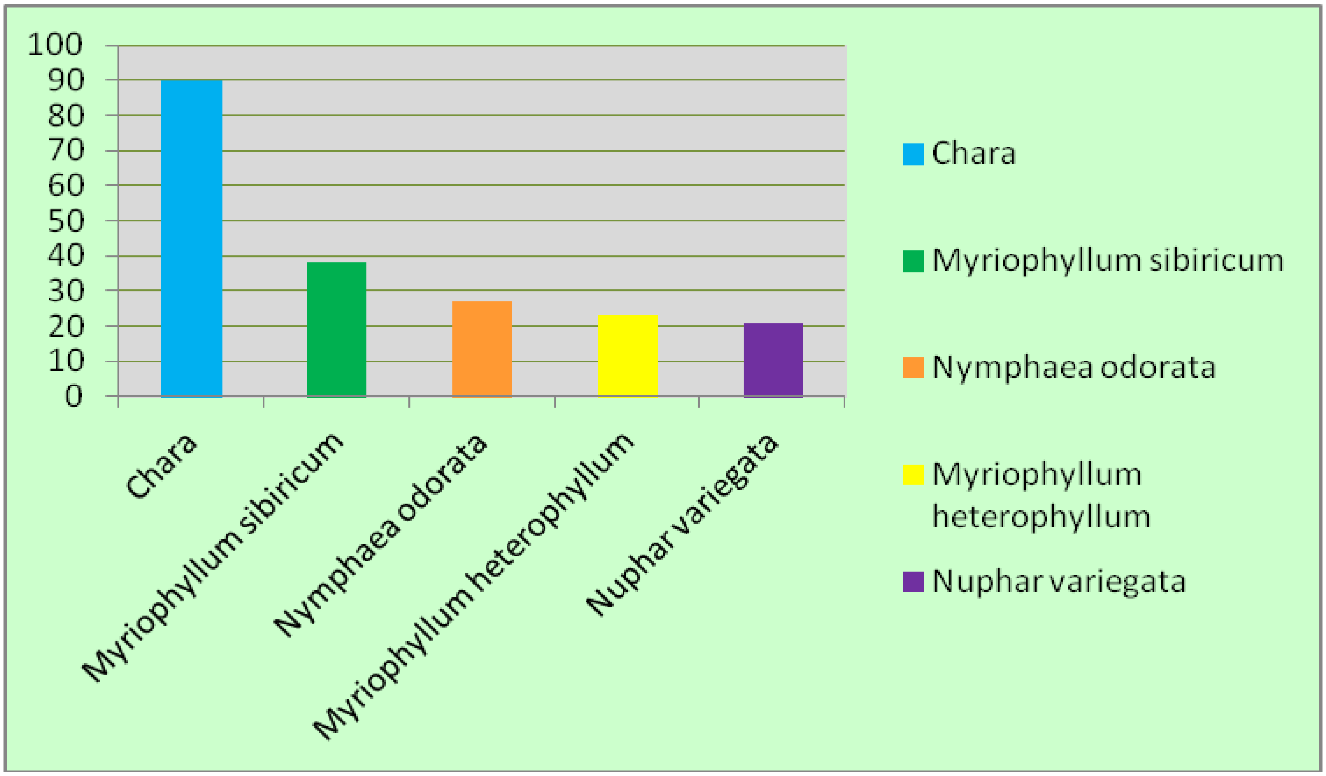


Figure 13b: Percent Frequency of Occurrence Overall (PI)



DENSITY

Besides the frequency at which particular species occurs, the density of growth for each plant type is also evaluated. Some plants occur mostly in beds of growth with their own kind—those would have a considerably higher growth density where present than in the lake overall. In other instances, a specie is found scattered throughout the lake, mixed with other species. The most densely-growing aquatic species in the lake overall, in both 2012 surveys, was Muskgrass (*Chara* spp.). This had a fairly high consistent density of growth throughout the lake, often occurring in large beds several inches or even feet deep. These "balls" sometimes float to the surface on Peppermill Lake and have to be removed to prevent interference with navigation.

DOMINANCE

Combining the relative frequency and relative density of a species into a Dominance Value illustrates how dominant that species is within the aquatic plant community. Based on the Dominance Value, Muskgrass was the dominant aquatic species in Peppermill Lake in 2012 (Figures 14a and 14b). In both 2012 surveys, the subdominant species was Northern Milfoil.

Figure 14a: Dominance in 2012 (T)

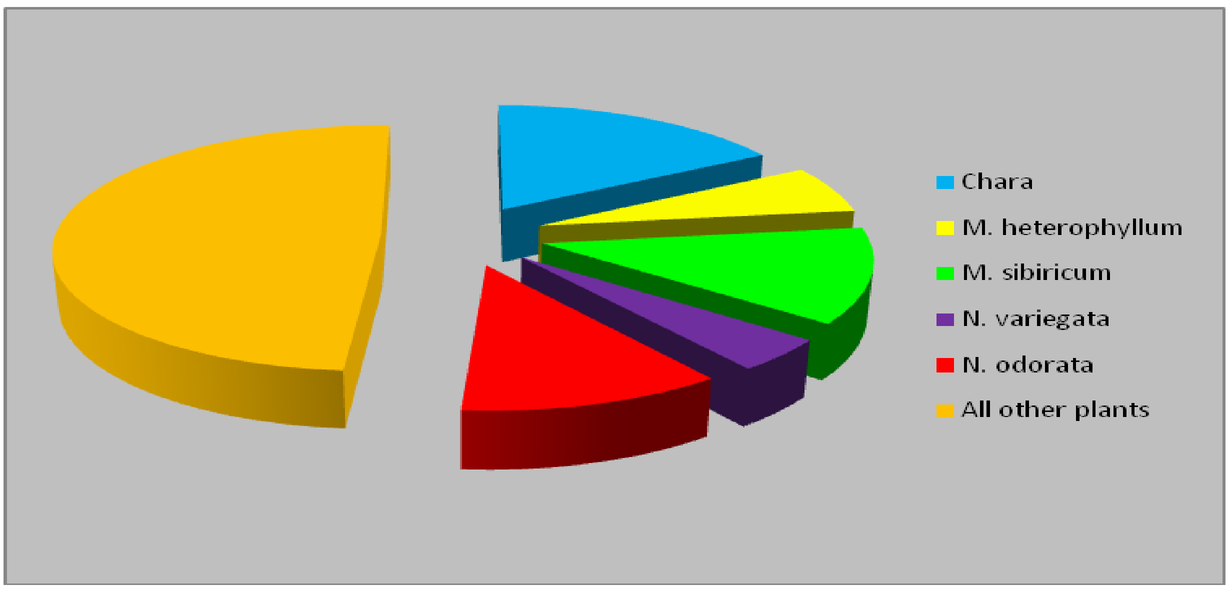
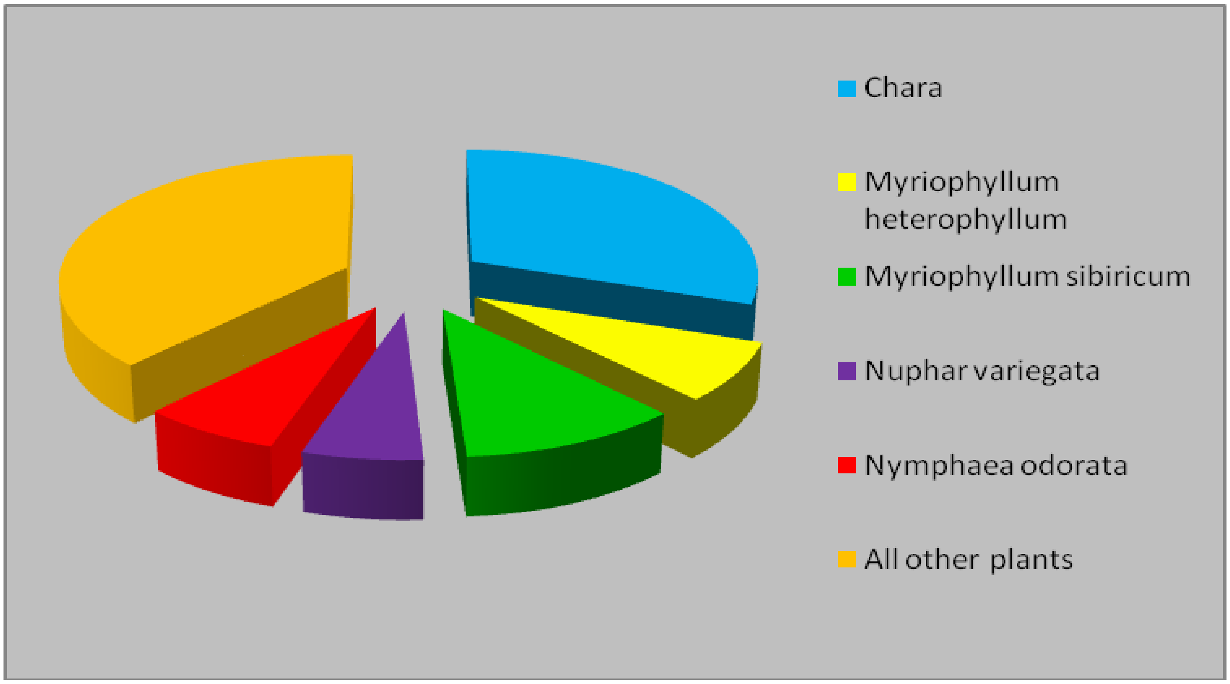


Figure 14b: Dominance in Peppermill Lake 2012 (PI)



In looking at dominance, it may also be relevant to look at what type of aquatic species dominates the "plant" community in a lake. In both 2012 surveys, submergent plants dominate the lake. Emergent species are the second most common plant type, with rooted floating-leaf plants the least common (Figures 15a and 15b).

Figure 15a: **Dominance by Plant Type (T)**

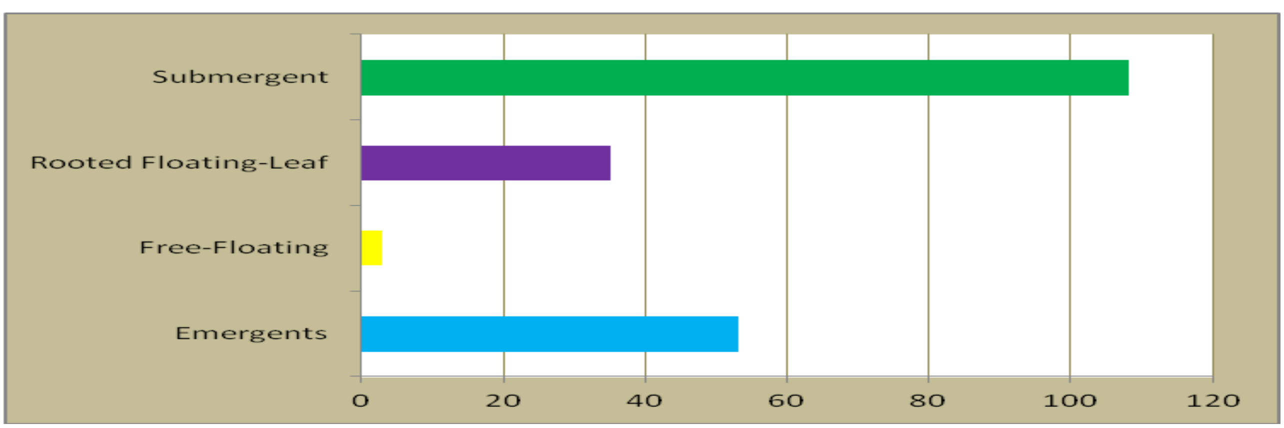
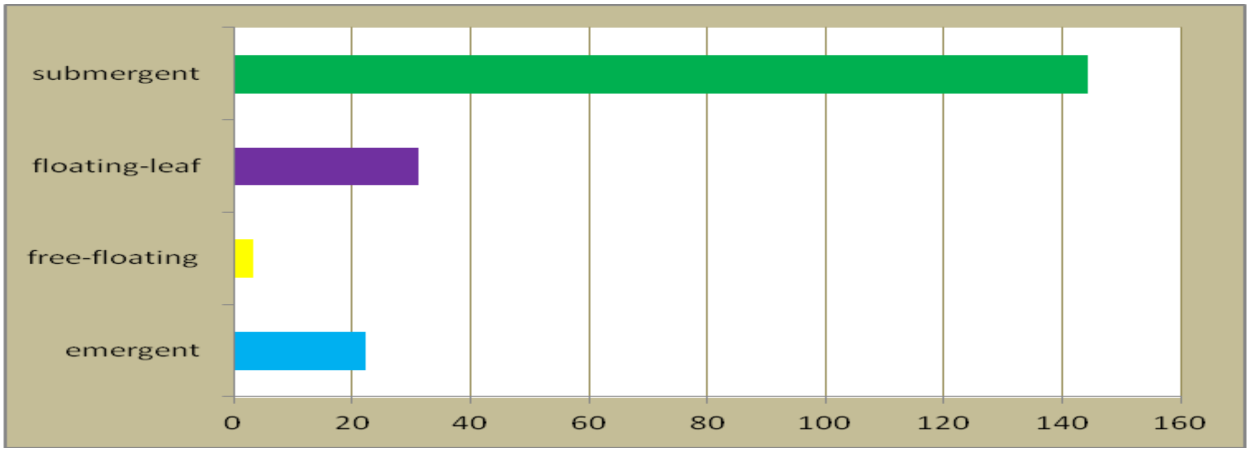


Figure 15b: Dominance by Plant Type (PI)



DISTRIBUTION

Aquatic plants were found throughout Peppermill Lake in all the recorded surveys. Although plants were found all through the lake, not all plant types or species were found everywhere. Figures 16a and 16b show the distribution of emergent, free-floating, and rooted floating-leaf aquatics. Submergent plants covered the entirety of Peppermill Lake.

Eurasian Watermilfoil was consistently found in Peppermill Lake for many years. After several years of chemical treatment, it seemed to disappear from the lake for a while. The lake has been monitored every year spring and fall by Adams County Land & Water Conservation Department and Peppermill Lake volunteers for any recurrence. In the last four years, it has only been found as isolated plants. Spring and fall monitoring will continue for the near future. Figure 17 is a map showing where invasives were found in 2012.

Figure 16a: Distribution of Emergent Plants 2012

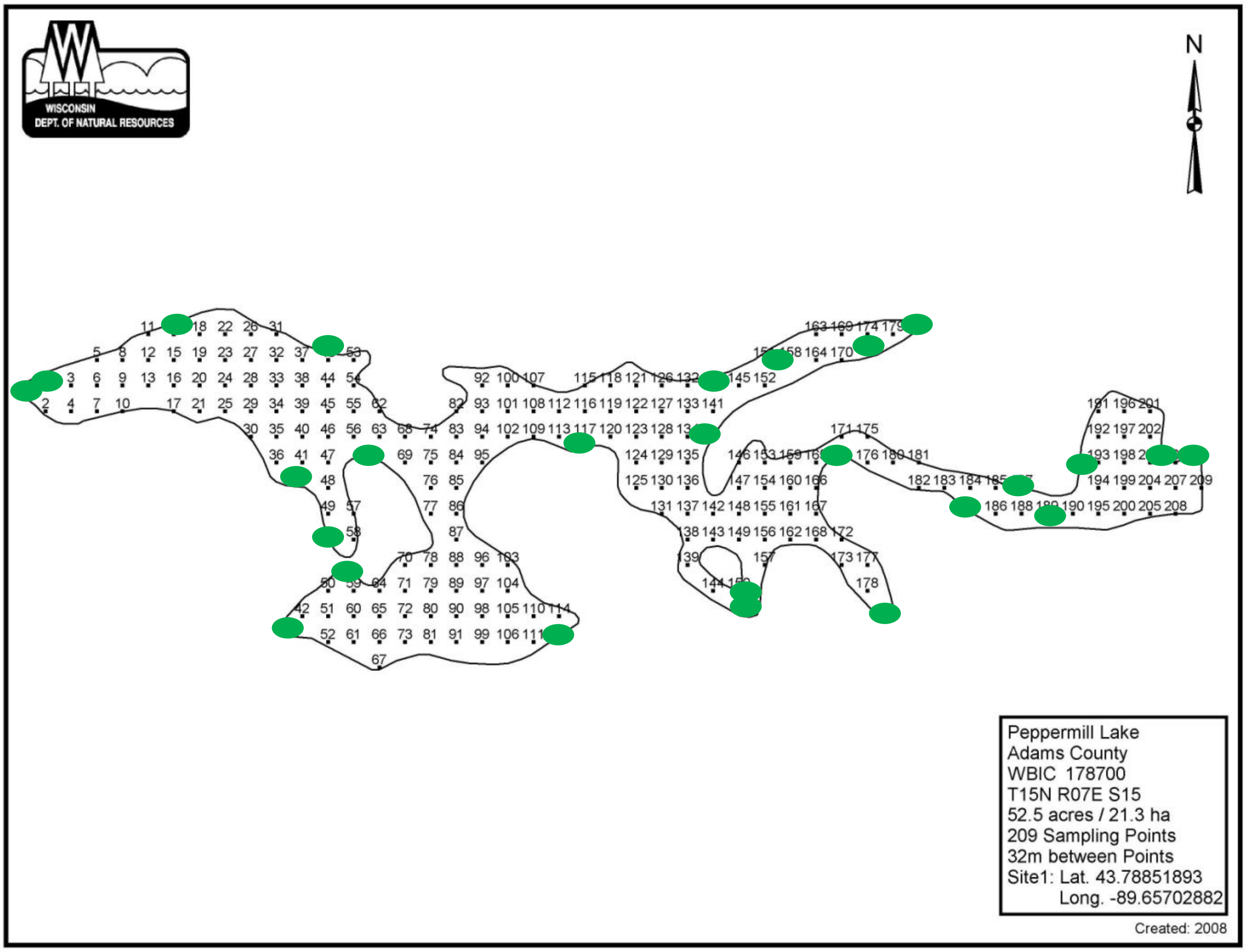


Figure 16b: Distribution of Free-Floating and Rooted Floating-Leaf Plants

Both Types **Free-Floating Only** **Floating-Leaf Only**

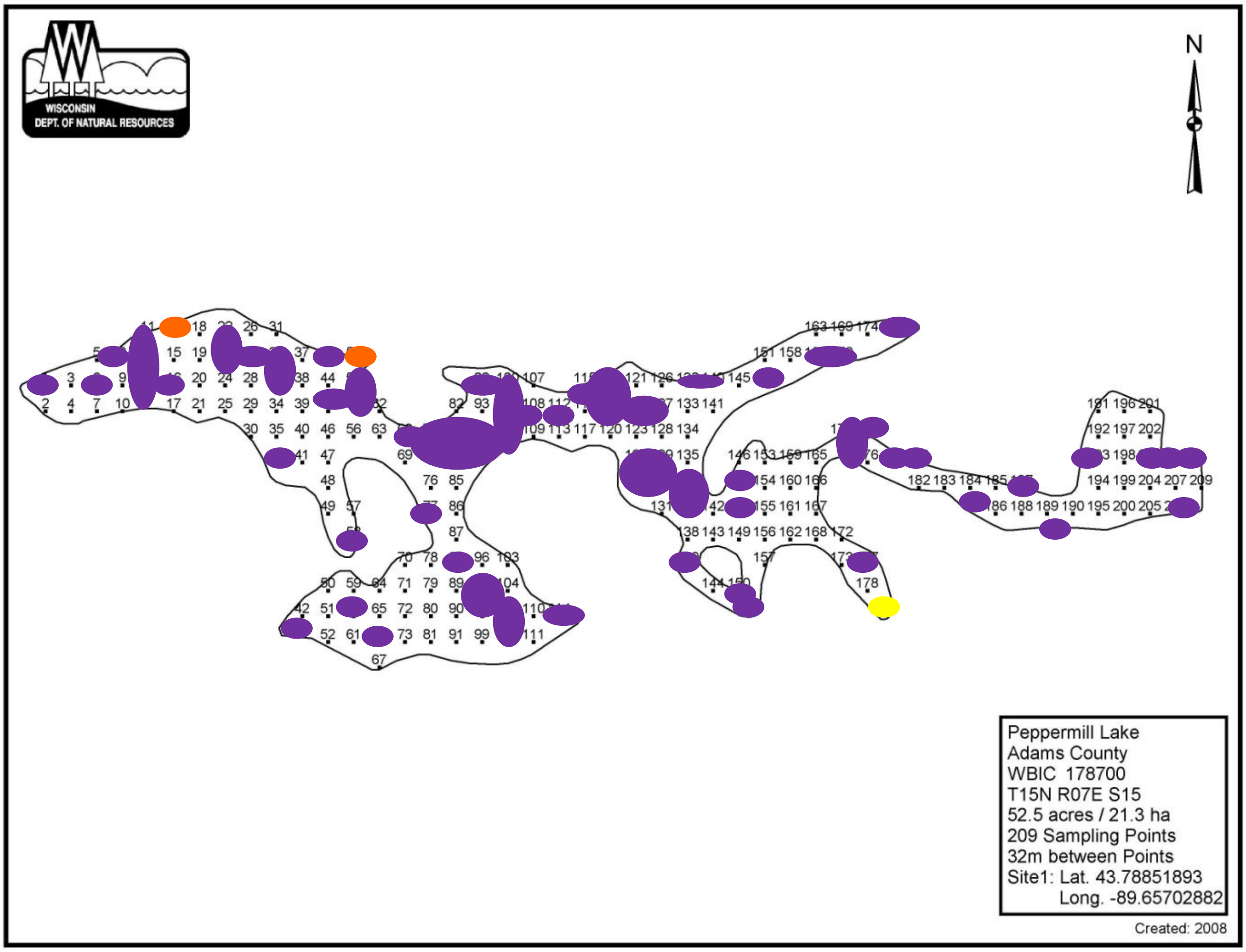
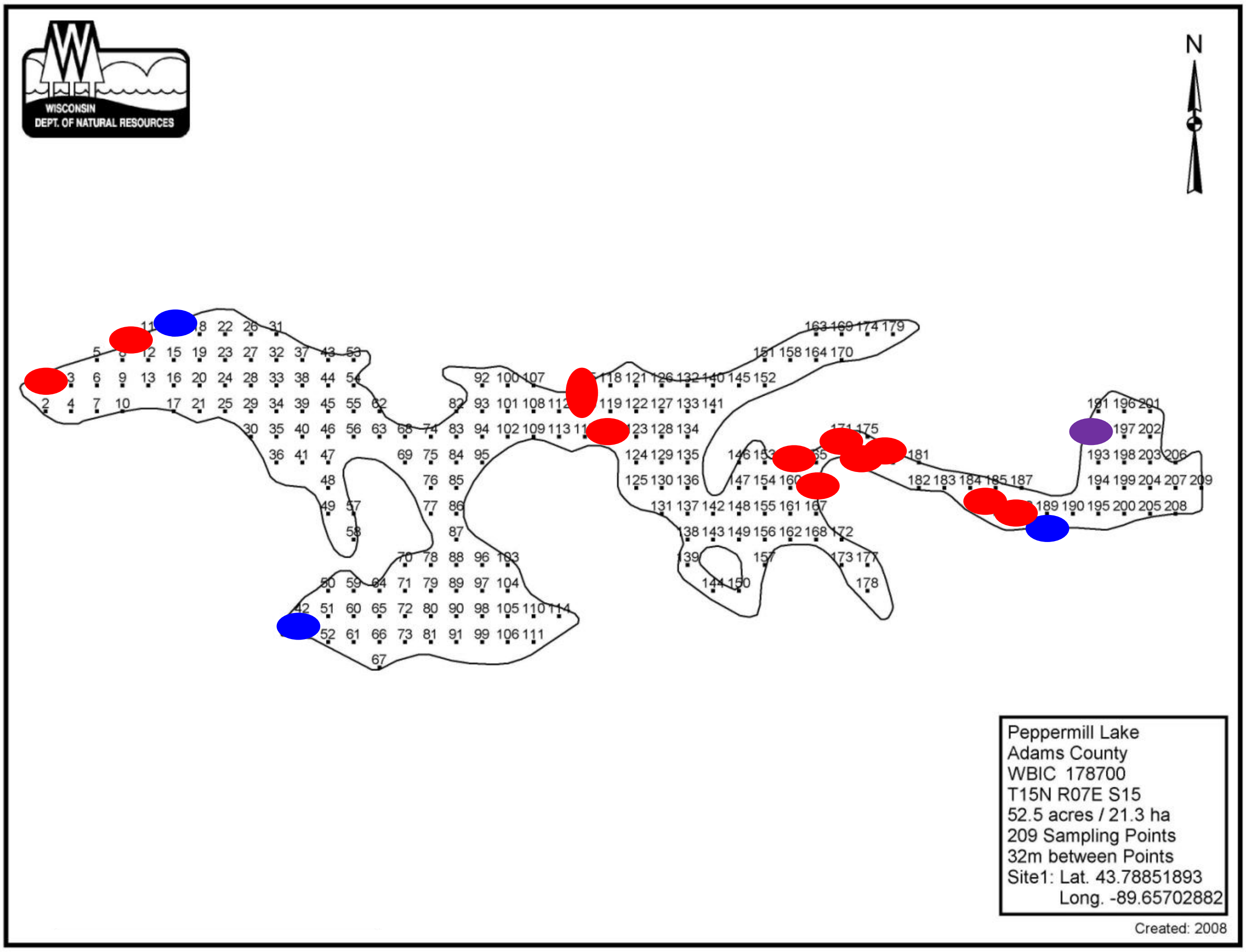


Figure 17: Location of Invasives 2012

Eurasian Watermilfoil **Reed Canarygrass** **Both Plants**



In 2007, a survey was done to look for the native weevil known to damage Eurasian watermilfoil, *Euhrychiopsis lecontei*, in Peppermill Lake. 14% of the milfoil collected showed significant damage to stems that could be attributed to weevil presence. Although the Peppermill Lake District has expressed some interest in raising the weevils to increase the numbers present, the current protocol is extremely labor-intensive. Thus far, there are insufficient volunteers available to engage in a rearing project.

The Peppermill Lake District has actively pursued hand-pulling Eurasian Watermilfoil in areas that can be reached by wading or snorkeling. This has focused on the removal of individual plants or small isolated populations and continues each year. In the 2006 transect survey, Eurasian Watermilfoil comprised 10% of the aquatic plant community. By 2012, it had decreased to 3% in the transect survey and 1.5% in the PI survey.

Reed Canarygrass, the other invasive found at Peppermill Lake, has never comprised a large part of the aquatic community. Although it has been found for many years at Peppermill Lake, it continues to be found in low frequency of occurrence and low density of growth, comprising less than 1% of the aquatic plant community.

As Figure 18 shows, the transect survey results showed the greatest frequency of occurrence in Zone 1 (0 to 1.5 feet depth), with the least frequency of occurrence in the water 5 to 10 feet deep. The same was true in 2006.

Figure 18: Frequency of Occurrence by Zone in 2012 (T)

No similar conclusions can be drawn from the PI results, since the data collection method differs. In many instances, the greatest diversity of aquatic plants is found in less than 5 feet of water.

THE COMMUNITY

The Simpson's Diversity Index (SI) for the transect 2012 survey was .93 and .87 for the 2012 PI method. A rating of 1.0 would mean that each plant in the lake was a different species (the most diversity achievable). The transect .93 score would place Peppermill Lake in the upper quartile for diversity for all the lakes in Wisconsin and for the North Central Hardwoods Region. The PI SI score of .87 places Peppermill Lake in the median category for lakes in Wisconsin and in the North Central Hardwoods Region.

Species richness is the number of species in a given area. When looking at aquatic survey results, higher species richness usually indicates a higher quality aquatic plant community. The overall 2012 transect species richness (See figure 19) was 4.7. Zone 1 (0-1.5 feet deep) had the highest species richness at 7.9, followed by Zone 2 (1.5-5 feet deep) with a species richness of 3.5. Species richness dropped to 2.2 in Zone 3 (5 to 10 feet deep).

Figure 19: Species Richness Comparison 2006 to 2012

	2006(T)	2012(T)
Overall	5.5	4.7
Zone 1	7.4	7.9
Zone 2	4.7	3.5
Zone 3	2.8	2.2

Since the PI method doesn't use depth zones for surveying, species richness calculations were done looking at overall species richness (all sample sites). The 2012 PI score was 3.2 overall.

The Average Coefficient of Conservation and Floristic Quality Index were calculated as outlined by Nichols (1998) to measure plant community disturbance (see Figure 20). A coefficient of conservation is an assigned value between 0 and 10 that measures the probability that the species will occur in an undisturbed habitat. The Average Coefficient of Conservationism is the mean of the coefficients for the species found in the lake.

The Average Coefficient of Conservatism for Peppermill Lake in 2012 was 4.8 for the transect method in 2012. The transect 4.8 Average Coefficient of Conservatism places Peppermill Lake in the lower quartile of lakes for Average Coefficient of Conservatism for lakes in Wisconsin overall and the North Central Hardwoods Region. The results of the PI survey were slightly higher, with an Average Coefficient of Conservatism at 5.3. This figure would put Peppermill Lake in the median of lakes in Wisconsin and in median range for the North Central Hardwoods Region.

The coefficient of conservatism is used to calculate the Floristic Quality Index (FQI), a measure of a plant community's closeness to an undisturbed condition. The Floristic Quality Index is also a tool that can be used to identify areas of high conservation value, monitor sites over time, assess the anthropogenic (human-caused) impacts affecting an area and measure the ecological condition of an area (M. Bourdaghs, 2006).

Figure 20: Floristic Quality and Coefficient of Conservatism of Peppermill Lake, Compared to Wisconsin Lakes and Northern Wisconsin Lakes.

	Average Coefficient of Conservatism †	Floristic Quality ‡
Wisconsin Lakes	5.5, 6.0, 6.9 *	16.9, 22.2, 27.5
NCHR	5.2, 5.6, 5.8 *	17.0, 20.9, 24.4
Peppermill Lake 2012	5.6 (T), 4.1 (PI)	31.8 (T), 29.7 (PI)

* - Values indicate the highest value of the lowest quartile, the mean and the lowest value of the upper quartile.

† - Average Coefficient of Conservatism for all Wisconsin lakes ranged from a low of 2.0 (the most disturbance tolerant) to a high of 9.5 (least disturbance tolerant).

‡ - lowest Floristic Quality was 3.0 (farthest from an undisturbed condition) and the high was 44.6 (closest to an undisturbed condition).

The 2012 FQI from the transect method was 29.52. The FQI for the PI survey was 36.81. The transect Floristic Quality Index of the aquatic plant community in Peppermill Lake was in the highest quartile for Wisconsin lakes and the North Central Hardwood Region lakes. These figures indicate that the plant community in Peppermill Lake is closer to an undisturbed condition than the average lake in Wisconsin and within the group of lakes in the region closest to an undisturbed condition.

Disturbances can be of many types:

1) Physical disturbances to the plant beds result from activities such as boat traffic, plant harvesting, chemical treatments, the placement of docks and other structures and fluctuating water levels.
2) Indirect disturbances come from factors that impact water clarity and stress species that are more sensitive: resuspension of sediments, sedimentation from erosion, or increased algae growth due to nutrient inputs.

3) Biological disturbances include competition from the introduction of a non-native or invasive plant species, grazing from an increased population of aquatic herbivores and destruction of plant beds by a fish or wildlife population.

The major disturbances in Peppermill Lake are likely:

1) the introduction of non-native aquatic plant species;
2) damage by motor boats in the shallow water areas.

The Aquatic Macrophyte Community Index (AMCI) for Peppermill Lake varies from 51 (PI survey) to 49 (transect survey), depending on the particular survey results used. Both these values are above average for lakes in the North Central Hardwoods Region (48 to 57) and Wisconsin (45 to 57) and indicate that the aquatic plant community in Peppermill Lake is of above average quality.

COMPARISON TO PRIOR RESULTS

In 2006, 31 aquatic species were found in Peppermill Lake, using the transect method. In 2012, the transect survey method found 41 species and the PI survey yielded 51 species. During the summer of 2012, the lake level of Peppermill Lake was reduced, down in depth due to the hot dry weather and drought. Despite this variance in water level, the aquatic plant community found in the 2012 transect community was much the same as that in the 2006 survey, with a small change in percentages between emergent, rooted floating-leaf, and submergent species.

There were also transect surveys done on Peppermill Lake before 2006, using the same transects. A look at some points of comparison between the 2012 transect survey results and those before suggest that in some ways, the aquatic plant community in Peppermill Lake has remained somewhat stable, while in other ways, it has varied.

Figure 21: Macrophyte Community Changes

Peppermill	2001(T)	2006(T)	2012(T)	2012(PI)
Number of Species	19	31	39	49
Maximum Rooting Depth	10.0	8.0	7.5	9.5
% of Littoral Zone Unvegetated	0	0	0	0
%Emergents	14%	11%	26%	10%
%Free-floating	8%	2%	0%	0%
%Submergents	69%	72%	59%	74%
%Floating-leaf	9%	15%	15%	16%
Simpson's Diversity Index	0.90	0.93	0.93	0.87
Species Richness	3.50	5.05	4.7	3.2
Floristic Quality	36.02	28.28	29.52	36.81
Average Coefficient of Conservatism	4.8	5	4.8	5.3
AMCI Index	43	56	49	51

The transect plant communities of 2006 and 2012 were compared by calculating coefficients of similarity (developed by Jaccard in 1901), using both actual frequency of occurrence and relative frequency of occurrence. Based on actual frequency of occurrence for the two transect methods, the 2006 and 2012 aquatic plant communities were 96.8% similar. Based on relative frequency, they were 93.8% similar. Coefficients of similarity over 75% suggest that the plant community is substantially the same, despite any difference in numbers of species. When the 2006 and 2001 communities were compared, they were 89.7% similar based on frequency of occurrence and 92.2% similar based on relative frequency. These figures suggest that the aquatic plant community at Peppermill Lake has remained relatively stable in the last ten years, despite some variances in species or species occurrence.

New plants found in 2012 surveys that were not found previously in Peppermill Lake included: Angelica (*Angelica atropurpurea),* Common Beggar's Tick (*Bidens frondosus),* Fringed Brome (*Bromus ciliatus*), Prairie Sedge (*Carex prairea),* Turtlehead (*Chelone glabra)*, Bald Spikerush (*Eleocharis erthyropoda),* Joe Pye Weed (*Eupatorium maculatum)*, Boneset (*Eupatorium perfoliatum)*, Whorled Milfoil (*Myriophyllum verticillatum)*, White-Stemmed Pondweed (*Potamogeton praelongus*), Willow (*Salix* spp), Woolgrass (*Scirpus cyperinus*), Water Hemlock (*Sium suave)*, Bittersweet Nightshade (*Solanum dulcamara)*, Twin-Stemmed Bladderwort (*Utricularia gemniscapa),* and Creeping Bladderwort (*Utricularia gibba).*

2012 was the first PI survey on Peppermill Lake, so there is no basis for a prior comparison.

V. DISCUSSION

Based on water clarity, chlorophyll-a, and phosphorus data, Peppermill Lake is a borderline oligotrophic/mesotrophic lake with very good water clarity and good water quality. Adequate nutrients (including sediments), good water clarity, hard water, and the large shallow areas in the lake would favor plant growth. Fairly high traffic and a significant presence of aquatic invasive plants, especially Eurasian Watermilfoil, have disturbed the aquatic plant community in the past, although overall the aquatic plant community has remained fairly stable. When the Eurasian Watermilfoil (EWM) was significantly reduced, *Chara* (muskgrass) moved in to many of the areas formerly occupied by EWM.

Figure 22: Aquatic Plant List 2001-2012

		2001(t)	2006(t)	2012(t)	2012(pi)
Acorus americana	Sweet Flag		x		x
Angelica atropurpurea	Angelica				x
Ascelpias incarnata	Swamp Milkweed		x	x	x
Bidens frondosus	Common Beggar's Tick				x
Bromus ciliatus	Fringed Brome				x
Calamagrostis canadensis	Canada Blue-Joint Grass			x	x
Carex spp	Sedge		x	x	x
Carex aquatilis	Lake Sedge			x	
Carex comosa	Porcuplne Sedge		x		x
Carex prairea	Prairie Sedge				x
Cornus stolonifera	Buttonbush				x
Ceratophyllum demersum	Coontail	x	x	x	x
Chara spp	Muskgrass	x	x	x	x
Chelone glabra	Turtlehead			x	
Cicuta bulbifera	Bulb-Bearing Water Hemlock	x	x	x	x
Cornus stolonifera	Red-Osier Dogwood	x	x	x	x
Eleocharis erythropoda	Bald Spikerush				x
Elodea canadensis	Common Waterweed	x	x	x	x
Eupatorium maculatum	Joe Pye Week			x	x
Eupatorium perfoliatum	Boneset			x	x
Galium asperellum	Rough Bedstraw				x
Impatiens capensis	Jewelweed		x	x	x
Iris versicolor	Blue-Flag Iris			x	x
Leersia oryzoides	Rice-Cut Grass		x		
Lemna minor	Lesser Duckweed	x	x	x	x
Lycopus uniflorus	Northern Bugleweed			x	x
Myriophyllym heterophyllum	Various-Leaved Milfoil		x	x	x
Myriophyllum sibiricum	Northern Milfoil	x	x	x	x
Myriophyllum spicatum	Eurasian Watermilfoil	x	x	x	x
Myriophyllum verticillatum	Whorled Watermilfoil			x	x
Najas flexilis	Bushy Pondweed	x	x	x	x
Nuphar variegata	Yellow Pond Lily	x	x	x	x
Nymphaea odorata	White Water Lilly	x	x	x	x
Onoclea sensibilis	Sensitive Fern		x		x

Phalaris arundinacea	Reed Canarygrass		x	x	x
Physiocoarpus opulifolis	Common Ninebark		x		
Polygoncum amphibium	Water Smartweed		x		x
Potamogeton amplifolious	Large-Leaf Pondweed	x	x	x	x
Potamogeton foliosus	Leafy Pondweed		x	x	x
Potamogeton friesii	Fries's Pondweed		x	x	x
Potamogeton illinoensis	Illinois Pondweed	x	x	x	x
Potamgeton natans	Floating-Leaf Pondweed		x	x	x
Potamogeton praelongus	White-Stemmed Pondweed			x	x
Potamogeton richardsonii	Clasping-Leaf Pondweed	x			x
Potamogeton zosteriformis	Flat-Stemmed Pondweed		x		x
Rumex spp	Dock		x		
Sagittaria spp	Arrowhead		x	x	x
Salix spp	Willow			x	x
Schoenoeplectus tabernaemontani	Soft-Stemmed Bulrush	z	x	x	x
Scutellaria laterifolia	Mad-Dog Skullcap		x		
Scirpus cyperinus	Woolgrass				x
Sium suave	Hemlock Water Parsnip				x
Solanum dulcamara	Bittersweet Nightshade			x	
Sparganium eurycarpum	Common Bur Weed		x	x	x
Spirodela polyrhiza	Greater Duckweed		x	x	x
Stuckenia pectinata	Sago Pondweed	x	x	x	x
Typha spp	Cattails	x		x	x
Utricularia gemniscapa	Twin-Stemmed Bladderwort				x
Utricularia gibba	Creeping Bladderwort				x
Utricularia vulgaris	Greater Bladderwort	x	x		x
Zosterella dubia	Water Stargrass		x	x	x

V. CONCLUSIONS

Peppermill Lake is a mesotrophic/oligotrophic lake with aquatic plants all through the lake. Depths of less than 5 feet supported the most abundant aquatic plant growth. Rooted aquatic plants were found as deep as 9.5 feet. *Chara* spp. was the dominant species found in both of the aquatic plant surveys in 2012, dominating all depth zones. Northern Milfoil was sub-dominant in both 2012 surveys. Both of these are species native to Wisconsin. All other species were found much less frequently and occurred in relatively low density of growth. No endangered or threatened species were found in Peppermill Lake in 2012.

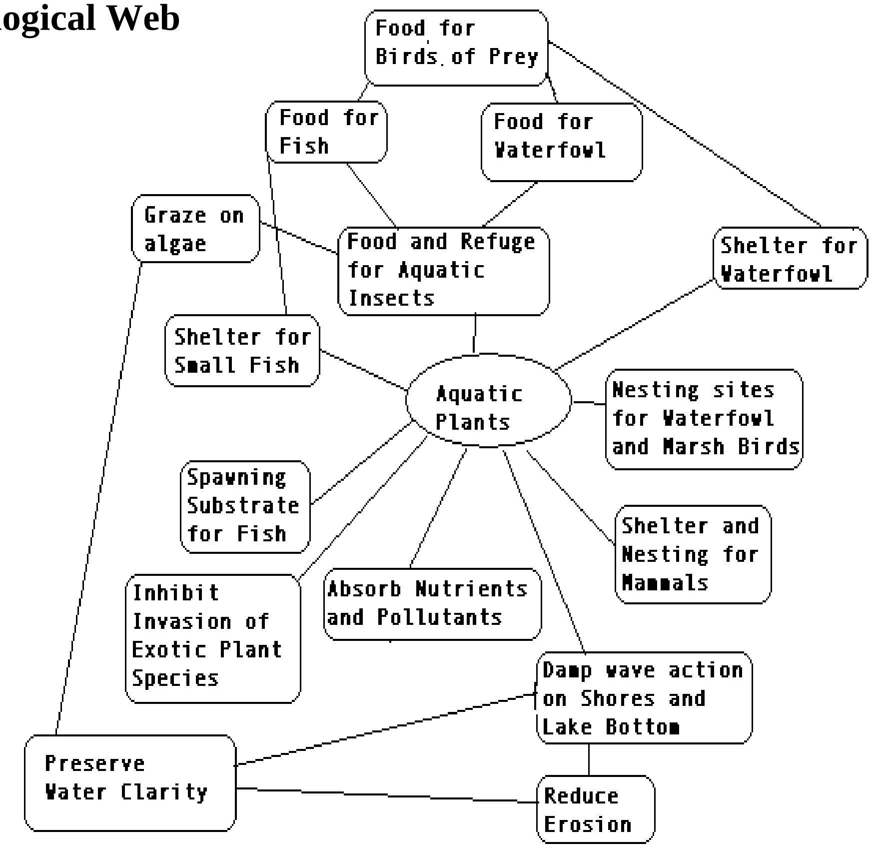
Two invasive aquatic plant species have been present in Peppermill Lake for some time. One of them, Reed Canarygrass, has continued to be present only in low numbers. However, the third, Eurasian Watermilfoil, has been a problem treated with chemicals in the past, but seems at least temporarily to be reduced in presence.

The Peppermill Lake aquatic plant community is characterized by at least average quality and good species diversity. Depending on the indices used, the plant community is either in the top quartile or median of lakes in the region, with an above average tolerance to disturbance.

A healthy aquatic plant community plays a vital role within the lake community. This is due to the role plants play in: 1) improving water quality; 2) providing valuable habitat resources for fish and wildlife; 3) resisting invasions of non-native species; and 4) checking excessive growth of tolerant species that could crowd out the more sensitive species, thus reducing diversity. Aquatic plant communities improve water quality in many ways (Engel 1985):

- they trap nutrients, debris, and pollutants entering a water body;
- they absorb and break down some pollutants;
- they reduce erosion by damping wave action and stabilizing shorelines and lake bottoms;
- they remove nutrients that would otherwise be available for algae blooms.

Figure 23: Aquatic Ecological Web



Aquatic plant communities provide important fishery and wildlife resources. Plants and algae start the food chain that supports many levels of wildlife, and at the same time produce oxygen needed by animals. Plants are used as food, cover and nesting/spawning sites by a variety of wildlife and fish and are an essential part of the ecological web of a lake (Figure 23).

Lakes with diverse aquatic plant beds support larger, more diverse invertebrate populations. These in turn support larger and more diverse fish and wildlife populations (Engel 1985). Additionally, mixed stands of aquatic plants support 3-8 times as many invertebrates and fish as monocultural stands (Engel 1990). Diversity in the plant community creates more microhabitats for the preferences of more species. Aquatic plant beds of moderate density support adequate numbers of small fish without restricting the movement of predatory fish (Engel 1990). Peppermill Lake, with a diversity of aquatic vegetation species and varied aquatic plant structure, should support diverse invertebrate and fish populations.

MANAGEMENT RECOMMENDATIONS

1) All lake residents should practice best management on their lake properties. Peppermill Lake is borderline between oligotrophic and mesotrophic. A small increase in nutrients could push the lake into another trophic state, resulting in noticeably worse water quality. Conversely, reducing nutrients could have a noticeable favorable impact on water quality.

- Keep septic systems cleaned and in proper condition;
- Use no lawn fertilizers;
- Clean up pet wastes;
- No composting should be done near the water nor should yard wastes & clippings be allowed to enter the lake (Do not compost near the water or allow yard wastes and clippings to enter the lake).

2) Continued involvement in regular water quality monitoring (through the Citizen Lake Monitoring Program) and aquatic invasive species monitoring should occur. This is important for keeping track of changes in the lake and also for evaluating the effect of the management plan activities.

3) Peppermill Lake is heavily used, especially for fishing. The Peppermill Lake District has been very active in the Clean Boats, Clean Waters Program. It is important that this continue. Small-scale grants have recently become

available specifically to help with Clean Boats, Clean Waters activities. The Peppermill Lake District may want to consider applying for this grant.

4) With critical habitat areas designated, a map of these areas should be posted at the public boat ramp with a sign encouraging avoidance of motorboat disturbance to these areas. Education about what these areas mean to the lake would also be a good idea. Landowners on the lake should watch for disturbance of these areas and report any violations. These areas are very important for habitat, the high value aquatic plant community, maintaining the positive water quality, and for preserving endangered and rare species.

5) The Peppermill Lake District should continue working with the Adams County Land & Water Conservation Department and the Wisconsin Department of Natural Resources in the ongoing Eurasian Watermilfoil monitoring project. Hand-pulling efforts should be continued.

6) Pre-and-post treatment monitoring for the presence of aquatic invasives should also continue, if chemical treatment begins again.

7) Lake residents should protect natural shoreline around Peppermill Lake and install/improve buffers practices in the few areas that don't comply with the county shoreland zoning requirements. Due to Adams County Shoreland Zoning, buffers 35 feet landward must be installed by July 1, 2015. Cost-share funds to assist in installing such practices may be available for those who don't wait until the last minutes to preserve their shores.

8) All lake users should protect the aquatic plant community in Peppermill Lake. The standing-water emergent community, floating-leaf community, and submergent plant community are all unique plant communities. Each of these plant communities provides their own benefits for fish and wildlife habitat and water quality protection.

10) An aquatic plant survey should be repeated in 3 to 5 years in order to continue to track any changes in the community and the lake's overall health.

11) The Peppermill Lake District should consider approaching the landowners who own the undeveloped waterfront property on the lake and see if those landowners would be interested in conservation easements. If so, the Peppermill Lake District Lake could apply for a WDNR grant to gain these easements.

LITERATURE CITED

Barko, J and R. Smart. 1986. Sediment-related mechanisms of growth limitation in submersed macrophytes. Ecology 61:1328-1340.

Boyd, C. E. 1974. Utilization of aquatic plants In Aquatic vegetation and its uses and control, D.S. Mitchell ed. Paris, Unesco, pp. 107-114).

Dennison, W., R. Orth, K. Moore, J. Stevenson, V. Carter, S. Kollar, P. Bergstrom and R. Batuik. 1993. Assessing water quality with submersed vegetation. BioScience 43(2):86-94.

Duarte, Carlos M. and J. Kalff. 1096. Littoral slope as a predictor of the maximum biomass of submerged macrophyte communities. Limnol. Oceanogr. 31(5):1072-1080.

Evans, Reesa. The aquatic plant community of Peppermill Lake. 2006. Adams County Land & Water Conservation Department.

Fassett, N.C. 1957. A Manual of Aquatic Plants. University of Wisconsin Press. Madison, WI.

Gleason H. and A. Cronquist. 1991. Manual of Vascular Plants of Northeastern United States and Adjacent Canada (2nd edition). New York Botanical Gardens. NY.

Jaccard, P. 1901. Etude comparative de la distribution florale dens une poitive des Alpes et des Jura (in translation). Bulletin de la Socrete Vaudoise des Sciences Naturalles.

Jessen, R and R. Lound. 1962. An evaluation of a survey technique for submerged aquatic plants. Minnesota Department of Conservation. Game Investigational Report No. 6.

Jester, L.L., M.A. Bozek, D.R. Helsel & S.P. Sheldon. 2000. *Euhrychiopsis lecontei* distribution, abundant and experimental augmentation for Eurasian watermilfoil control in Wisconsin lakes. Journal of Aquatic Plant Management 38:88-97.

Lillie, R. and J. Mason. 1983. Limnological Characteristics of Wisconsin Lakes. Wisconsin Department of Natural Resources Tech Bull #138. Madison, WI.

Newman, R.M., D.W. Ragsdale, A. Milles & C. Oien. 2001. Habitat and the relationship of overwinter to in-lake densities of the milfoil weevil, *Euhrychiopsis lecontei*, Eurasian watermilfoil biological control agent. Journal of Aquatic Plant Management 39:63-67.

Nichols, S., S. Weber, B. Shaw. 2000. A proposed aquatic plant community biotic index for Wisconsin lakes. Environmental Management 26:491-502.

Nichols, S. 1999. Distribution & Habitat Descriptions of Wisconsin Lake Plants. Wisconsin Geological and Natural History Survey, Bulletin 96. Madison, WI.

Nichols, S. 1998. Floristic quality assessment of Wisconsin lake plant communities with example applications. Journal of Lake and Reservoir Management 15(2):133-141.

Nichols, S. and J.G. Vennie. 1991. Attributes of Wisconsin Lake Plants. Wisconsin Geological and Natural history Survey. Information Circular 73.

Shaw, B., C. Mechnich and L. Klessig. 1993. Understanding Lake Data. University of Wisconsin-Extension. Madison, WI.

Thompson, Caroline. 2010. Types of Organic Soil. Livestrong Foundation.