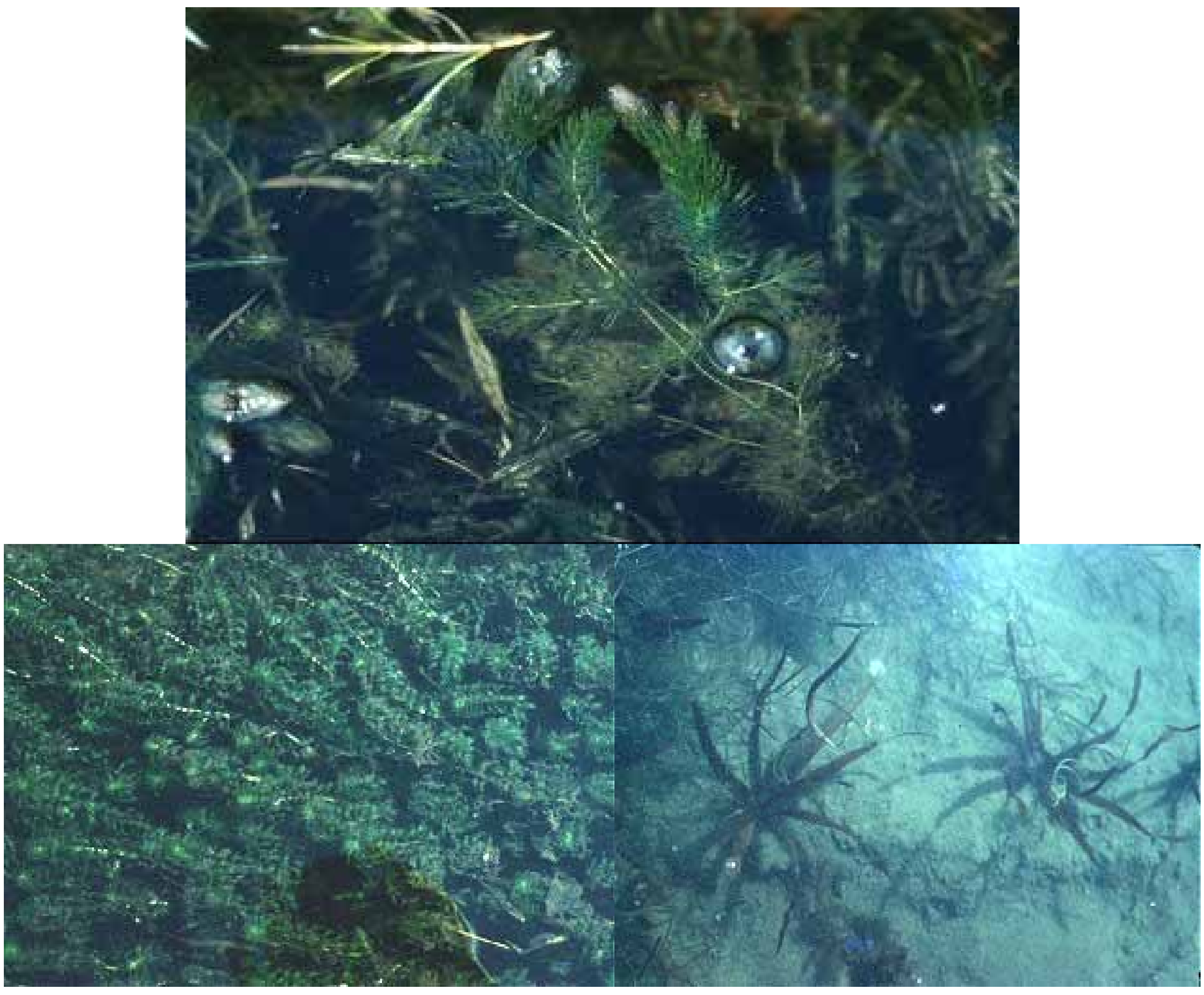
Changes in the Aquatic Plant Community
of
Cedar Lake,
St. Croix County, Wisconsin

1986-2004



Wisconsin Department of Natural Resources
Eau Claire, WI
April 2006

EXECUTIVE SUMMARY

Cedar Lake is a hypereutrophic lake with very poor water quality and poor clarity. Filamentous algae is common in the shallowest zone. Aquatic plant growth is scattered throughout 49% of the littoral zone, to a maximum rooting depth of 7-feet, 23% of the entire lake. The most abundant plant growth occurs in the 1.5-5ft depth zone. The lake supports a low quality aquatic plant community, with fair species diversity, a high tolerance to disturbance and a condition that is farther from an undisturbed lake than the average lake.

Ceratophyllum demersum is the dominant plant species in the community, especially in the deeper depth zones. *Elodea canadensis* and *Vallisneria americana* are subdominant.

The Cedar Lake aquatic plant community has undergone significant change. There has been a shift in community dominance and disturbance measures have increased in the community. There has been decreased maximum rooting depth, increased colonization of free-floating and floating-leaf vegetation, increased frequency and density of turbidity-tolerant/nutrient-favored species, decreased quality of the Cedar Lake plant community, decreased cover of aquatic vegetation, decreased colonization of submergent vegetation, decreased Species Richness and a decline in the 6 native pondweeds in Cedar Lake.

A healthy aquatic plant community plays a vital role within the lake ecosystem. Healthy plant communities improve water quality and provide habitat for fish and wildlife.

Management Recommendations

1) Lake District to maintain carp barriers and promote recreation such as carp spearing to maintain the lowered carp population.
2) Lake residents increase natural shoreline, restoring buffers of native vegetation.
3) Lake District, residents and government agencies follow recommendations for protection of the sensitive areas designated in Cedar Lake (Konkel 2002).
4) Lake residents eliminate all fertilizer use around Cedar Lake and use other lawn and home best management practices such as storm water management.
5) Lake District, residents and agencies protect the remaining wetlands.
6) Lake District and residents cooperate with efforts in to reduce nutrient run-off from the watershed, implementing all possible strategies to reduce nutrient enrichment.
7) Lake District review current water level strategy as higher water levels may be a major factor in the loss and scarcity of valuable emergent vegetation.
8) DNR plan project to restore emergent beds with the help of state, county and local programs.
9) Lake District and residents protect the limited amount of emergent vegetation and maintain the shoreline and aquatic vegetation in an undisturbed condition.
10) DNR establish native emergent vegetation beds such as wild rice.
11) Lake residents leave fallen trees in the water for habitat.

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Changes in the Aquatic Plant Community of Cedar Lake, St. Croix County 1988-2004

I. INTRODUCTION

Studies of the aquatic plants (macrophytes) in Cedar Lake were conducted during July 1988, 1991, 1994, 1997, 2000, and August 2004 by Water Resources staff of the Western Central Region - Department of Natural Resources (DNR). A private consultant conducted aquatic plant studies in August 1977 and July 1984 using different sampling methods, so the results can not be directly compared to the Department of Natural Resources studies.

Long term trend studies of the diversity, density, and distribution of aquatic plants have been ongoing and provide information that is valuable for decisions about fish habitat improvements, designation of sensitive wildlife areas, water quality improvement and aquatic plant management. Trend data can reveal changes occurring in the lake ecosystem.

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 is dependent 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).

Background and History

Cedar Lake is a 1107-acre drainage lake in northern St. Croix and southern Polk Counties. It receives inflow from Horse Creek and has an outlet to the Apple River. The maximum depth of Cedar Lake is 28 feet. The Horse Creek watershed is the watershed of Cedar Lake and covers 34,560 acres. The ratio of watershed to lake area in Cedar Lake is 31:1. Lakes with a watershed:lake ratio greater than 10:1 tend to have water quality problems (Field 1994) because nutrients that run off from a large area concentrate into a relatively smaller body of water.

Cedar Lake has been impacted by algae blooms since the 1930's. Treatments with copper sulfate for algae were started in the 1940's in an attempt to reduce algae growth. By 1983, seven algae treatments were conducted during one growing season and algae blooms were returning after an average of only ten days. In the case of three of the treatments, the bloom returned after only three days. The copper treatments were discontinued in 1988 due to their ineffective and toxicity to aquatic life. Copper does not biodegrade and is toxic to aquatic insects, zooplankton and mollusks.

Copper treatments are ineffective because they kill only the algae cells which contact the copper as it rapidly precipitates from the water. The winds will move algae from untreated areas into treated areas soon after treatments. Algae will continue to reproduce as long as nutrient levels remain high and temperatures remain warm.

In July of 1990, an aeration system was installed to prevent stratification and thus reduce the recycling of phosphorus within the lake. Nutrient monitoring indicated that there was a reduction in the release of phosphorus from the bottom sediments in 1991, after the aeration system was installed (Garrison 1992). Long-term trend monitoring indicates that the lake is still maintaining high concentrations of phosphorus.

The Horse Creek Watershed was selected as a priority watershed and studies were conducted to determine external nutrient sources and solutions. Agricultural fields were found to be the most significant source of external nutrient loading to the watershed (Table 1) (Polk Co LWCD et. al. 2001). Also, 193 wetlands in the ownership of 142 landowners that could have played a role in protecting water quality inputs to Cedar Lake have been drained. Several high quality wetlands remain that need protection (Polk Co LWCD et. al. 2001).

Table 1. Cedar Lake Watershed Land Use, 2001

Land Use Category	Acres	% of Watershed	% of Annual Phosphorus Watershed Load
Forest	7928	26	
Grassland/Shrub Carr	7267	24	
Pasture	6077	20	1%
Row Crops	4120	14	79%
Wetlands	2567	8	
Open Water	2357	8	
Barren	57	0.2	
Total	30373		

(Polk Co LWCD et. al. 2001)

Common carp appeared in the Cedar Lake drainage prior to DNR's firs records in 1940-50. When carp populations reach abundant status in waterways, negative impacts to water quality and plant communities are expected. In 1997, a study designed to measure carp damage to aquatic plants in Cedar Lake used exclosures around selected plant beds. The plant beds protected by cages contained 2.9 times more plant material than the unprotected plant beds (McComas 1997).

More recent attempts to place exclosures on the lake bed at select locations have not resulted in increased plant growth since the areas in which the exclosures were placed were shaded by thick films of planktonic algae.

Numerous attempts to commercially remove carp have failed. During spring 2002, a viral disease, to Spring Viremia of Carp, caused a major die-off of carp. This event, in addition to the construction of a carp barrier at the outlet and the recent popularity of night bow fishing has reduced the carp population to low levels. It is uncertain whether the carp barriers and bow fishing will remain effective long-term control mechanisms.

Currently, Cedar Lake District manipulates water levels in the lake. At ice-out the walter level is raised approximately one foot and lowered again in the late fall.

In 2002, the DNR designated Sensitive Areas on Cedar Lake. This Sensitive Area Study identified the areas on Cedar Lake that are most important for providing habitat for wildlife and fish and preserving water quality. Lake wide and site-by-site recommendations were made for preserving habitat and water quality in Cedar Lake (Konkel 2002).

1) Implement all possible strategies to improve water clarity and restrict nutrient enrichment. This is likely an important factor that is limiting aquatic plant growth.
2) No permitting for bank grading at the sensitive area sites as it would destroy the natural vegetation that protects against erosion and maintains water quality.
3) No permitting of retaining walls whose construction would also destroy natural vegetation.
4) No permitting of dredging at the sites as that would remove the aquatic vegetation and gravel spawning beds.
5) Carefully review the proposed placement of any boat ramps at sensitive sites.
6) Restrict the location and dimensions of recreational floating devices at the sites.
7) Restore the bulrush beds that had been important over water nesting habitat for some birds and prime habitat for a variety of fish.
8) Protect the bulrush beds by preventing snowmobile traffic on the site.
9) Study impact of water levels on the bulrush beds.
10) Protect the limited amount of emergent vegetation that occur at the site for habitat, water quality protection and erosion control.
11) Establish and emergent vegetation for erosion protection and habitat through restoration of bulrush beds and/or establishment of wild rice.

12) Maintain the shoreline and aquatic vegetation in an undisturbed condition for wildlife, fish and aquatic life habitat and as a nutrient buffer for water quality protection.
13) Restore shoreline vegetation at developed sites.
14) Riparian property owners should use lawn and home best management practices. This should include storm water management, buffer zone restoration and elimination of all fertilizer use.
15) Do not remove fallen trees at the shoreline.
16) Do not permit wetland fill on the properties around the lake and in the watershed.
17) Minimize authorization of pea gravel beds, sand blankets or other filling.
18) Pier placement by permit only in sensitive areas and piers constructed of material that allows light penetration.

II. METHODS

Field Methods

A transect study design was used for the 1988, 1991, 1994, 1997, 2000 and 2004 aquatic plant studies and was based on the rake-sampling method developed by Jessen and Lound (1962). Twenty-four equal-distance transect lines were placed perpendicular to the shoreline with the first transect being randomly placed. These transects were mapped to be used in subsequent plant surveys (Appendix XX).

One sampling site was randomly located at each depth zone (0-1.5ft., 1.5-5ft., 5-10 ft., and 10-20ft.) along each transect. Using a long-handled, steel, thatching rake, four rake samples were taken at each sampling site. The four samples were taken at each corner of a 6-foot square quadrat. The aquatic plant species that were present on each rake sample were recorded. The species recorded include aquatic vascular plants and several types of algae that have morphologies similar to vascular plants, such as muskgrass and nitella.

Each species was given a density rating (0-5) based on the number of rake samples on which it was present at a sampling site.

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

The presence of filamentous algae and thick films of planktonic algae was recorded. The sediment type at each sampling site was recorded. Visual inspection and periodic samples were taken between transect lines in order to record the presence of any species that did not occur at the sampling sites. Specimens of all 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 either side of the transect intercept with the shore and 30 feet deep was evaluated. The percentage of each cover type within this 100 ft. X 30 ft. rectangle was recorded.

Data Analysis

Aquatic plant data was analyzed separately for each year and compared. The percent frequency of occurrence of each species was calculated (number of sampling sites at which a species occurred/total number of sampling sites) (Appendices I-VI). Relative frequency was calculated (number of sampling sites at which a species occurred/sum of all species occurrences) (Appendices I-VI). The mean density was calculated for each species (sum of a species' density ratings/number of sampling sites) (Appendices VII-XII). Relative density was calculated (sum of a species' density ratings/sum of all plant densities (Appendices VII-XII). A “mean density where present” was calculated for each species (sum of a species' density ratings/number of sampling sites at which the species occurred) (Appendices VII-XII). The relative frequency and relative density was summed to obtain a dominance value (Appendices XIII-XVIII). Simpson's Diversity Index was calculated for each sampling year ($1-(\sum(\text{Relative Frequency}^2))$ to measure diversity in the plant community (Appendices I-VI). Each sampling year was compared by a Coefficient of Community Similarity (Table 9) to measure change in the aquatic plant community.

An Aquatic Macrophyte Community Index (AMCI), developed for Wisconsin lakes, was applied to Cedar Lake to measure the quality of the plant community. Data in seven categories that characterize the aquatic plant community is converted to values (0–10) and summed as outlined in Nichols et. al. (2000). Average Coefficients of Conservatism and Floristic Quality Index were calculated to evaluate disturbance in the community (Nichols 1998). A Coefficient of Conservatism is an assigned value, 0-10, based on the probability that a species will occur in a relatively undisturbed habitat. The Average Coefficient of Conservatism is the mean of the coefficients of conservatism for all species found in a lake. The Floristic Quality Index is calculated from the Average Coefficient of Conservatism.

III. RESULTS

<u>PHYSICAL DATA</u>

Many physical parameters impact the plant community. Water quality (nutrient levels, algal levels, clarity, water hardness) can influence the aquatic plant community as the plant community can in turn modify these parameters. Lake morphology, sediment composition and land use on shore also impact the plant community.

Water Quality - The trophic state of a lake is an indication of its water quality. Phosphorus concentration, chlorophyll concentration, and water clarity data are collected to determine the trophic state.

Oligotrophic lakes are low in nutrients and support limited plant growth and smaller populations of fish.

Eutrophic lakes are high in nutrients and therefore support a large biomass.

Mesotrophic lakes have intermediate levels of nutrients and biomass.

Nutrients

Phosphorus is a limiting nutrient in many Wisconsin lakes and is measured as an indication of the nutrient concentration in a lake. Increases in phosphorus in a lake can feed algae blooms and, occasionally, excess plant growth.

Throughout the study, phosphorus concentrations in Cedar Lake have remained high, in the eutrophic range (Figure 1). Phosphorus has varied from year-to-year, but overall, has increased 1986-2004.

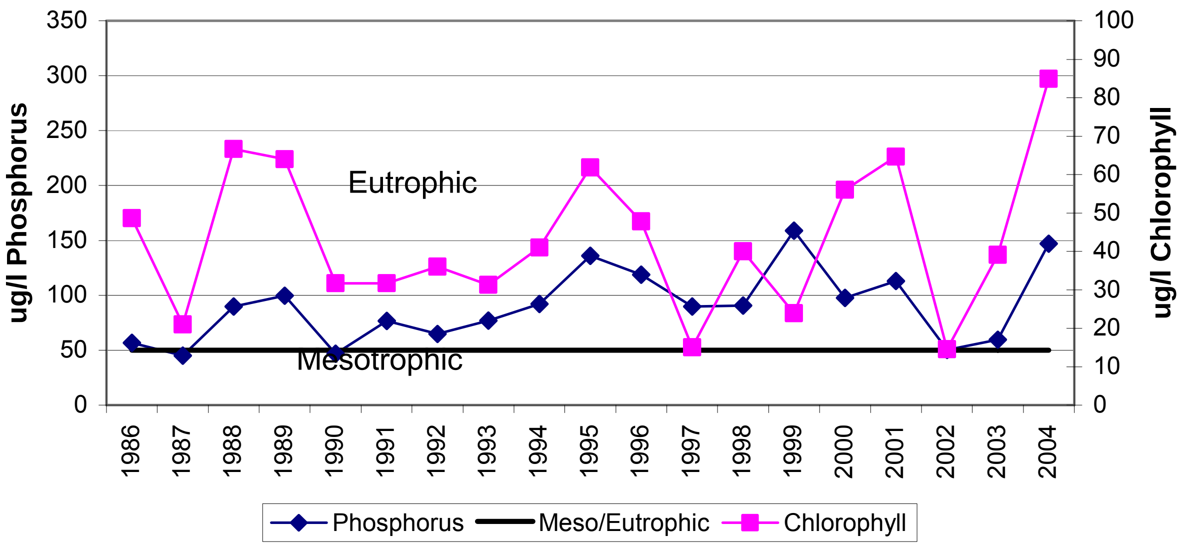

Figure 1. Summer mean phosphorus and chlorophyll in Cedar Lake, 1986-2004.

Algae

In Cedar Lake, chlorophyll concentrations (which indicate the amount of algae) have also remained in the eutrophic range. Changes in chlorophyll concentrations have generally mirrored changes in phosphorus as the algae use available phosphorus to reproduce. Chlorophyll in Cedar Lake has also varied from year-to-year but, overall, has increased since 1986 (Figure 1).

Filamentous algae steadily increased from 1991 to 2000 and then declined in 2004 to 1991-94 levels (Figure 2). The occurrence of filamentous algae is greatest in the 0-1.5ft depth zone (Figure 2).

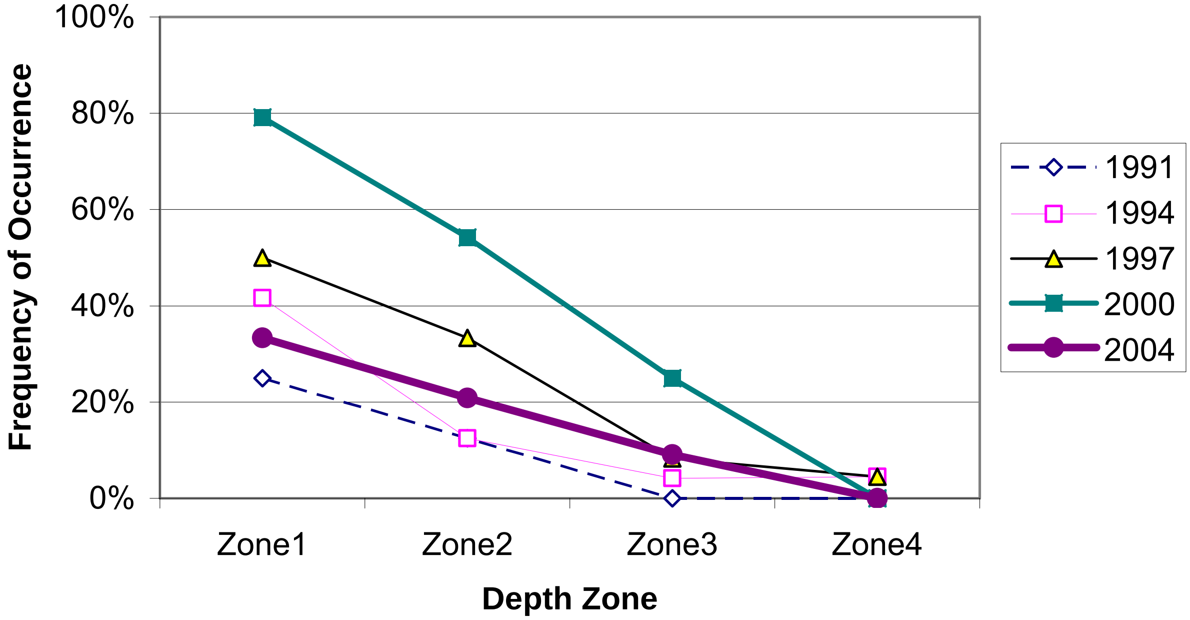

Figure 2. Occurrence of filamentous algae, by depth zone in Cedar Lake, 1991-2004

A thick scum of planktonic algae occurred at 10% of the sites in 2004. This scum of planktonic algae was also greatest in the shallow depth zone.

12% of the sites in the 0-1.5ft depth zone

4% of the sites in the 1.5-5ft depth zone

0% of the sites in the 5-20ft depth zone

Water Clarity

Cedar Lake has poor water clarity. Mean summer water clarity in Cedar Lake, as measured with a Secchi Disc, has varied from year-to-year, but has remained in the eutrophic range (Figure 3). The lowest clarity occurred in 2004, which coincided with a peak in phosphorus and algae. The best water clarity occurred in 1997.

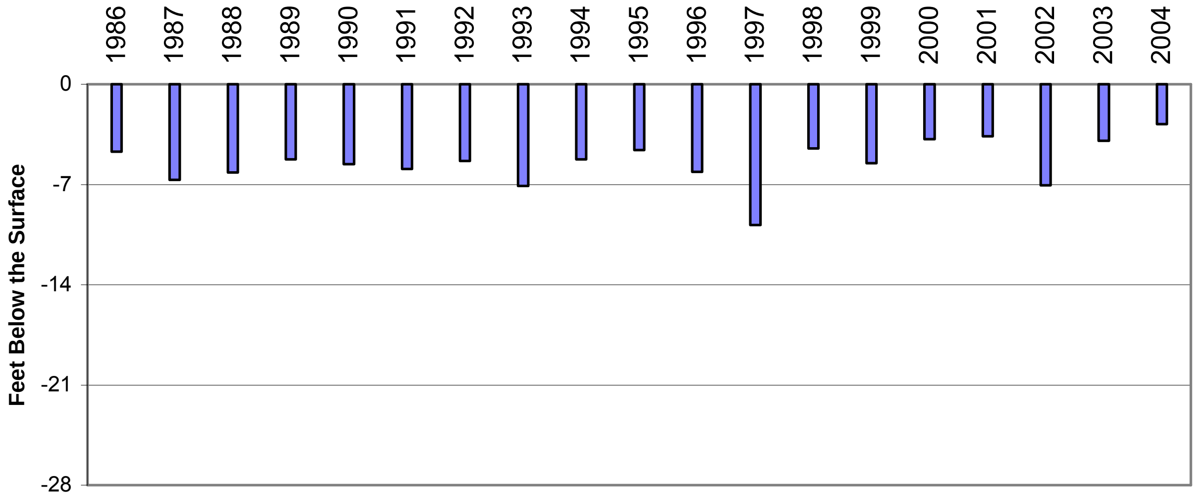

Figure 3. Mean summer water clarity in Cedar Lake, 1986-2004.

The combination of the phosphorus and algae concentrations and water clarity data are combined to determine the trophic state of a lake. Based on these parameters, Cedar Lake is a hypereutrophic lake with very poor water quality (Table 2). In this trophic state, abundant plant growth and/or frequent and severe algal blooms could be expected.

Table 2. Trophic Status

	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
Hypereutrophic	Very Poor	>150	**>30**	**>3**
Cedar Lake – 2004 Summer Mean	Poor/Very Poor	147	84.9	2.8

After Lillie & Mason (1983) & Shaw et. al. (1993)

Steve Frey, a volunteer lake monitor in the Self-Help Volunteer Monitoring Program, has been collecting water clarity data on Cedar Lake since 1986. This data is valuable because it is collected more frequently than the data collected by the DNR and has been collected over a span of many years.

The volunteer monitoring data also showed year-to-year variations in mean summer water clarity. The best clarity was during 1992-93 (Figure 4). Mean summer clarity was lowest in 2004. Water clarity has been decreasing in Cedar Lake as shown by linear regression trend analysis (Figure 4).

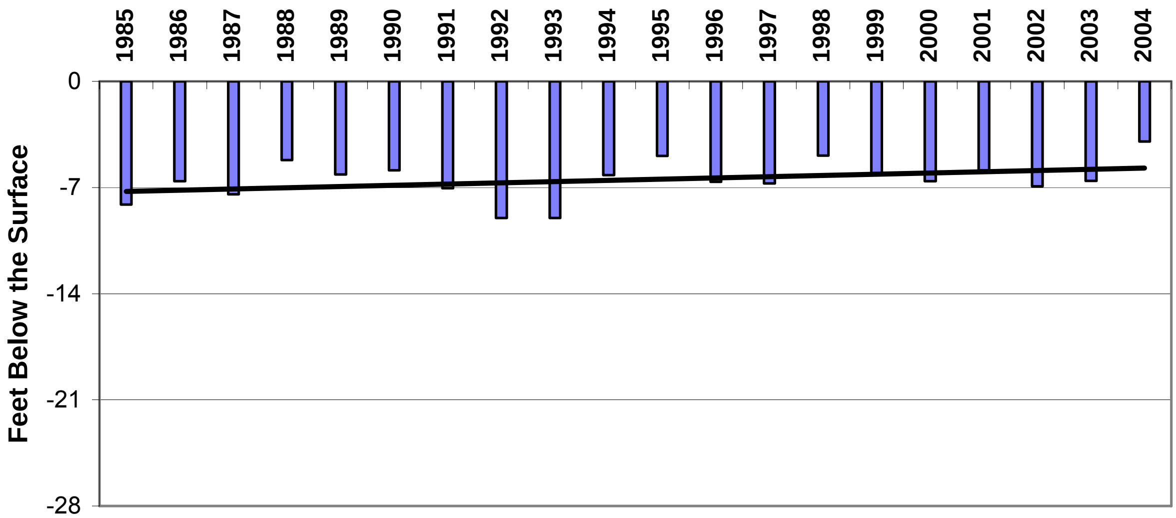

Figure 4. Change in mean water clarity 1986-2004, volunteer monitoring data.

The volunteer data is collected with sufficient frequency to show water quality changes during the growing season. Data collected at the same time of the year is averaged (Figure 5). The seasonal changes are very dramatic on Cedar Lake; the lake has very good water clarity early in the season, before the summer algae blooms. By mid-summer the water clarity has decreased to very poor. As the weather cools and algae decrease, the water clarity again increases to good clarity (Figure 5).

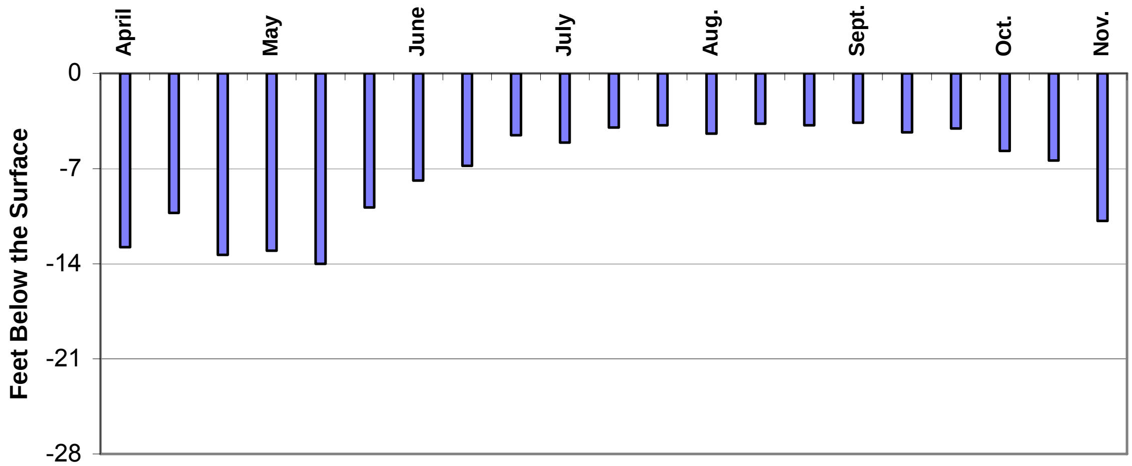

Figure 5. Change in mean water clarity during the season, 1986-2004.

Although the majority of Wisconsin lakes are phosphorus limited, about 10% are nitrogen limited. Nitrogen limited lakes exhibit a nitrogen:phosphorus ratio of 10:1 or less. Lakes are transitional if the ratio is between 10:1 and 15:1 (Shaw et. al 1993). The nitrogen:phosphorus ratio in Cedar Lake has varied between 5.2:1 and 26.8:1. This means that at times, Cedar Lake appears to be nitrogen limited and additions of nitrogen can also worsen algae blooms (Figure 6).

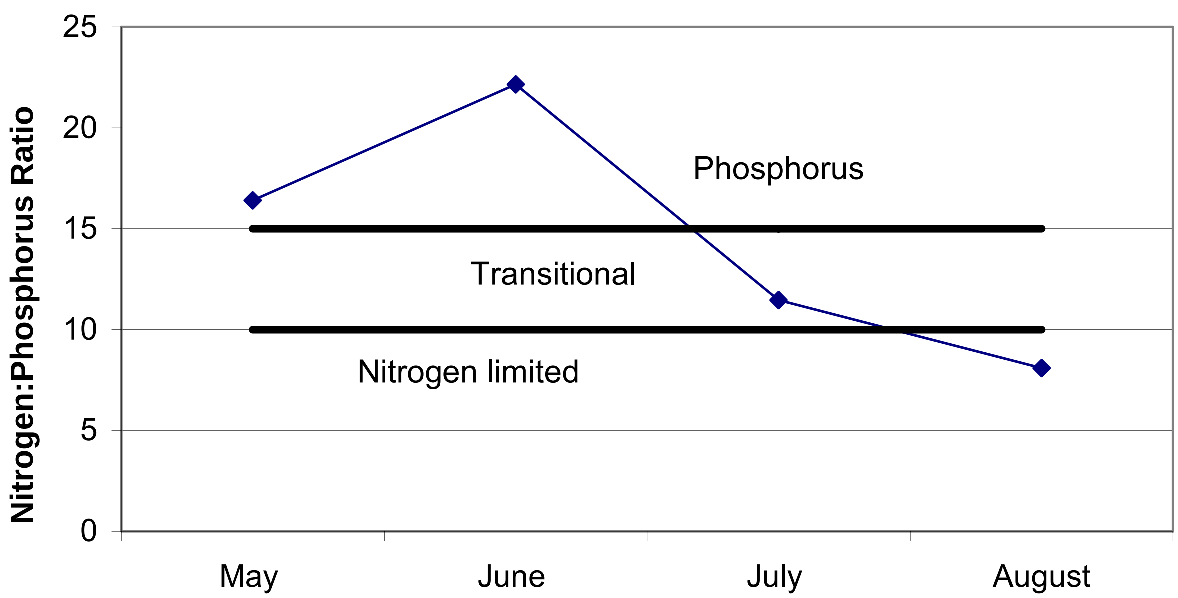

Figure 6. Seasonal change in Nitrogen:Phosphorus Ratio.

Cedar Lake appeared to be transitional between phosphorus limited and nitrogen limited in 1986-1989, 1992, 1998 and 2002. The lake appeared to be nitrogen limited in 1991, 1993-97, 2000-02 and 2004.

Mean phosphorus and nitrogen ratios over the growing season suggest that Cedar Lake starts during the growing season as a phosphorus-limited lake, becomes transitional in July and by August and September, is nitrogen limited.

Hardness

The hardness values have remained fairly constant over the study period, varying between 96 and 135 $CaCO_3$mg/l. Water in the range of 61-120 $CaCO_3$mg/l is considered moderately hard and in the range of 121-180 $CaCO_3$mg/l is considered hard. Hard water lakes tend to have more plant growth.

Lake Morphometry

The morphometry of a lake is important in understanding 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 provide a more stable rooting base and support a broader zone of potential plant growth than steep slopes (Engel 1985).

Cedar Lake's littoral zone is gently sloped along most of the shore, providing a broad zone that is favorable to plant growth.

Sediment Composition

The dominant sediment type in Cedar Lake is sand, especially at depths greater than 1.5 ft. (Table 3) (Figure 6). Rock type sediments are also common, dominating the 0-1.5 ft depth zone.

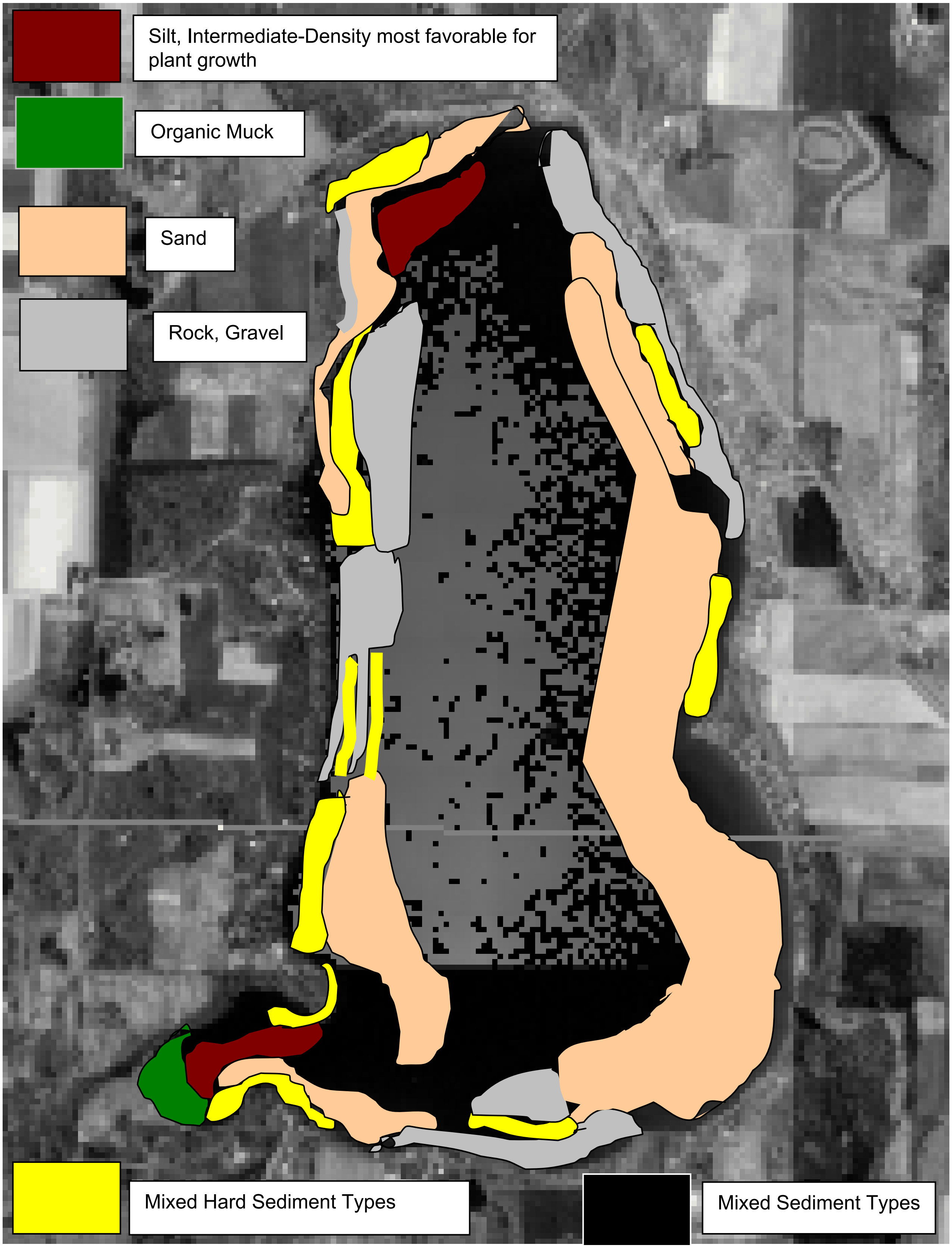

Figure 7. Distribution of sediment types in Cedar Lake, 2004.

Table 3. Sediment Composition by Depth Zone in Cedar Lake, 2004.

		0-1.5'	1.5-5'	5-10'	10-20'	Overall
Hard Sediments	Sand	12%	54%	45%	50%	40%
	Rock	29%	12%	32%	15%	22%
	Sand/rock/ gravel	21%	21%		10%	12%
	Gravel	21%			5%	8%
Mixed Sediments	Sand/silt	8%	8%	18%	10%	11%
	Sand/Muck	4%				1%
	Sand/Peat				5%	1%
Soft Sediments	Silt		4%	4%	5%	3%
	Muck/Silt	4%				1%

Sediment Influence

Some aquatic plants depend on the sediments in which they are rooted for required nutrients. The richness or sterility and texture of the sediment will influence the type and abundance of species that can survive in a location.

Sand was the dominant sediment type at the sample sites in Cedar Lake and less than one half of these sample sites were vegetated (Table 4). Rock and gravel, commonly occurring sediments in Cedar Lake, supported even less vegetation. Sand and rock sediments are high in density and not as favorable to plant growth as sediments of intermediate density (Barko and Smart 1986).

The availability of the mineral nutrients essential for plant growth is highest in sediments of intermediate density, such as silt (Barko and Smart 1986). Sand and rock are high-density sediments and organic muck is a low-density sediment. Silt, which was not common in Cedar Lake, was vegetated at 67% of the sites. The colonization of vegetation on silt sediments in Cedar Lake would likely be higher except the occurrence of silt sediments at depths greater than 5 feet where light would be a limiting factor.

Highly organic muck sediments are low-density sediments. Muck sediments were vegetated at 100% of the sites, but occurred infrequently in Cedar Lake (Figure 7).

Table 4. Aquatic Plant Occurrence at Sediment Types, 2004

		Percent Occurrence of Sediment Type	Percent Vegetated
Hard Sediments	Sand	40%	47%
	Rock	22%	18%
	Sand/rock/gravel	12%	54%
	Gravel	8%	0%
Mixed Sediments	Sand/silt	11%	50%
	Sand/Muck	1%	100%
	Sand/Peat	1%	0%
Soft Sediments	Silt	3%	67%
	Muck/Silt	1%	1%

Shoreline Land Use

Land use activities strongly impact the aquatic plant community. Practices on shore can directly impact the plant community through increased physical disturbance and sedimentation from erosion of high-use areas, increased nutrient levels from lawn fertilizer and agricultural run-off and soil erosion and toxics from farm and urban run-off.

Shoreline cover was recorded at each transect intercept (methods). Occurrence of cover types is defined as the percentage of sites at which that cover type occurred and indicates how often that cover type was found. Coverage is defined as the mean percent cover and indicates the percent of the shoreline covered by a cover type.

In 2004, native herbaceous plant cover had the highest occurrence at the transect sites, but cultivated lawn had the highest mean coverage in 1997 and 2004 (Table 5).

Wooded shoreline also had a high occurrence and mean cover. But, other disturbed shoreline types had high occurrences also: rip-rap and hard structures. Rip-rap was found at half the more than half the sites and hard structures at nearly half the sites in 2004 (Table 5).

Since 1997, the occurrence and mean cover of hard structures has increased, the mean cover of native herbaceous growth has decreased.

Table 5. Shoreline Land Use, Cedar Lake, 1997-2004

		Frequency of Occurrence at Sites		**% Mean Coverage**	
	Cover Type	1997	**2004**	1997	**2004**
Disturbed Shoreline	**Cultivated Lawn**	62%	**62%**	41%	**36%**
	Rip-rap	50%	**58%**	4%	**4%**
	Hard Structures	33%	**46%**	4%	**8%**
	Pavement		**17%**		**6%**
	Eroded Soil		**8%**		**1%**
	Total Disturbed			49%	**55%**
Natural Shoreline	**Wooded**	54%	**58%**	33%	**34%**
	Native Herbaceous	58%	**67%**	15%	**9%**
	Shrub	21%	**12%**	2%	**2%**
	Total Natural			50%	**45%**

Natural shoreline has occurred at 79% of the sites, but the mean coverage of natural shoreline decreased from 50% in 1997 to 45% in 2004 (Table 5).

Some type of disturbed shoreline occurred at 63% of the sites in 1997, increasing to 79% of the sites in 2004. The mean coverage of disturbed shoreline increased from 49% in 1997 to 55% in 2004 (Table 5).

MACROPHYTE DATA

38 different species of aquatic plants have been recorded during the 1977-2004 studies: 13 emergent species; 5 floating-leaf species; 20 submergent species (Table 6).

No endangered or threatened species were found. One non-native species was found: *Potamogeton crispus.*

Table 6. Cedar Lake Aquatic Plant Species, 1977-2004

Scientific Name	Common Name	I. D. Code
Emergent		
1) *Carex aquatilis* Wahlenb.	sedge	caraq
2) *Carex comosa* F. Boott.	bristly sedge	carco
3) *Carex* sp.	sedge	carsp
4) *Cicuta bulbifera* L.	water hemlock	cicbu
5) *Eleocharis palustris* L.	creeping spike-rush	elepa
6) *Impatiens capensis* Meerb.	orange jewelweed	impca
7) *Lycopus americanus* Muhl.	American water horehound	lycam
8) *Sagittaria latifolia* Willd.	common arrowhead	sagla
9) *Scirpus americanus* Pers.	chairmaker's rush	sciam
10) *Scirpus fluviatilis* (Torr.) A. Gray	river bulrush	scifl
11) *Scirpus validus* Vahl.	softstem bulrush	sciva
12) *Sparganium eurycarpum* Engelm.	giant bur-reed	spaeu
13) *Typha latifolia* L.	common cattail	typla
Floating leaf Species		
14) *Lemna minor* L.	lesser duckweed	lemmi
15) *Nuphar variegata* Durand.	yellow pond lily	nupva
16) *Nymphaea odorata* Aiton.	white water lily	nymod
17) *Spirodela polyrhiza* (L.) Schleiden	greater duckweed	spipo
18) *Wolffia columbiana* Karsten.	common watermeal	wolco
Submergent Species		
19) *Ceratophyllum demersum* L.	coontail	cerde
20) *Chara* sp.	muskgrass	chasp
21) *Eleocharis acicularis* (L.) Roemer & Schultes.	needle spikerush	eleac
22) *Elodea canadensis* Michx.	common waterweed	eloca
23) *Myriophyllum sibiricum* Komarov.	common water milfoil	myrsi
24) *Najas flexilis* (Willd.) Rostkov & Schmidt	slender naiad	najfl
25) *Potamogeton amplifolius* Tuckerman.	large-leaf pondweed	potam
26) *Potamogeton crispus* L.	curly pondweed	potcr
27) *Potamogeton foliosus* Raf.	leafy pondweed	potfo
28) *Potamogeton gramineus* L.	variable-leaf pondweed	potgr
29) *Potamogeton illinoensis* Morong.	Illinois pondweed	potil
30) *Potamogeton nodosus* Poiret.	longleaf pondweed	potno
31) *Potamogeton pectinatus* L.	sago pondweed	potpe
32) *Potamogeton pusillus* L.	slender pondweed	potpu
33) *Potamogeton richardsonii* (Ar. Bennett) Rydb.	clasping-leaf pondweed	potri
34) *Potamogeton zosteriformis* Fern.	flatstem pondweed	potzo
35) *Ranunculus longirostris* Godron.	white water crowfoot	ranlo
36) *Vallisneria americana* Michx.	wild celery	valam
37) *Zanichella palustris* L.	horned pondweed	zanpa
38) *Zosterella dubia* (Jacq.) Small.	water stargrass	zosdu

FREQUENCY OF OCCURRENCE

Ceratophyllum demersum was the most frequently occurring species in 2004 and had also been in 1997 (Table 7). *Najas flexilis*, an annual species, had been the most frequently occurring in species in 1991 and 2000. In all the other study years, a different species was the most frequently occurring species in Cedar Lake.

Potamogeton pusillus was the most frequent species in 1988, but has continued to decline since (Table 7). *Elodea canadensis* became the most frequently occurring species in 1994, declined dramatically in 1997-2000 and increased in 2004. All of the prevalent species (Table 7) in Cedar Lake are tolerant of poor water clarity, except for *Najas flexilis* which has declined.

Table 7. Frequencies of the Most Prevalent Aquatic Plant Species in Cedar Lake, 1988-2004

Species	1988	1991	1994	1997	2000	2004
Najas flexilis	41%	**45%**	4%	5%	**21%**	3%
Ceratophyllum demersum	14%	14%	50%	**20%**	16%	**27%**
Vallisneria americana	27%	24%	19%	6%	13%	20%
Zosterella dubia	12%	29%	28%	11%	6%	1%
Elodea canadensis	13%	11%	**62%**	2%	6%	21%
Potamogeton pusillus	**43%**	24%	11%	2%	3%	3%

DENSITY

Density is measured on a scale of 0-4. All aquatic plant densities were low in Cedar Lake (Appendices VII-XII).
Najas flexilis was the species with the highest mean density in 1988-1991, declined in 1994-1997 and again had the highest mean density in 2000 before declining in 2004 (Table 8).

Elodea canadensis and *Ceratophyllum demersum*, the most frequently occurring species in 1994, 1997 and 2004 were also the species with the highest mean density in the same years (Table 8).

Table 8. Densities of Prevalent Aquatic Plant Species in Cedar Lake, 1988-2004.

Species	1988	1991	1994	1997	2000	2004
Najas flexilis	**1.22**	**1.18**	0.14	0.05	**0.39**	0.08
Ceratophyllum demersum	0.38	0.40	1.24	**0.48**	0.28	**0.62**
Elodea canadensis	0.37	0.19	**1.66**	0.11	0.12	0.41

DOMINANCE

Combining the relative frequency and relative density of a species into a Dominance Value measures the dominance of each species within the plant community. Dominance in the Cedar Lake aquatic plant community has changed from year-to-year (Figure 8).

The aquatic plant community has changed from a *Najas flexilis - Potamogeton pusillus - Vallisneria americana* community in 1988-1991; to a *Elodea canadensis - Ceratophyllum demersum* community in 1994; to a *Ceratophyllum demersum* dominated community in 1997; to a *Najas flexilis - Ceratophyllum demersum* dominated community in 2000; finally to a turbidity-tolerant, *Ceratophyllum demersum – Elodea canadensis-Vallisneria americana* dominated community in 2004 (Figure 8).

The dominance of *Ceratophyllum demersum* has increased from 1988. The dominance of *Elodea canadensis* has cycled up and down, but was at a high in 1994. The dominance of *V. americana* declined slightly during 1988-1994, but has been increasing gradually since 1997.

The dominance of *Najas flexilis* and *P. pusillus* in the community has cycled up and down from year-to-year. The combined dominance of the other species in the community has been fairly constant, about 25% of the community, except for an increase in 1997.

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Figure 8. Change in dominance of the most prevalent aquatic plant species in Cedar Lake, 1988-2004.

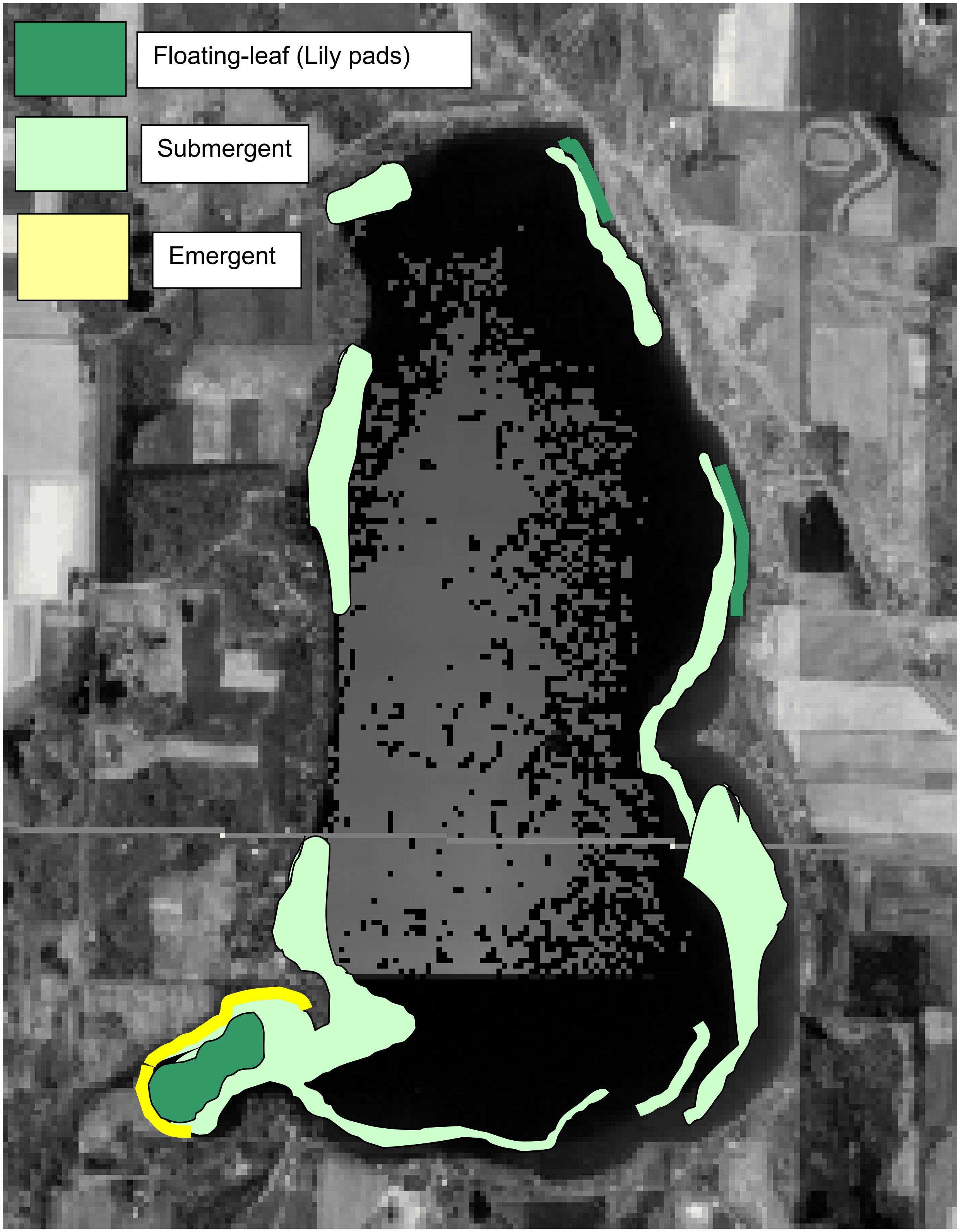

Figure 9. Distribution of aquatic vegetation in Cedar Lake, 2004.

DISTRIBUTION

Aquatic vegetation occurred throughout the littoral zone, at 49% of the sites, in all depth zones (Figure 9), approximately 260 acres of Cedar Lake, 23% of the entire lake.

The highest percentage of vegetated sample sites was in the 1.5-5 ft. depth zone in 1988-91, shifted to the 5-10 ft depth zone in 1994-1997 and returned to the 1.5-5 ft depth zone again in 2000 and 2004 (Figure 10).

The highest percent of vegetated sites over the whole littoral zone was in 1991-94 and the lowest percent of vegetated sites occurred in the last three studies; 1997-2004 (Figure 10).

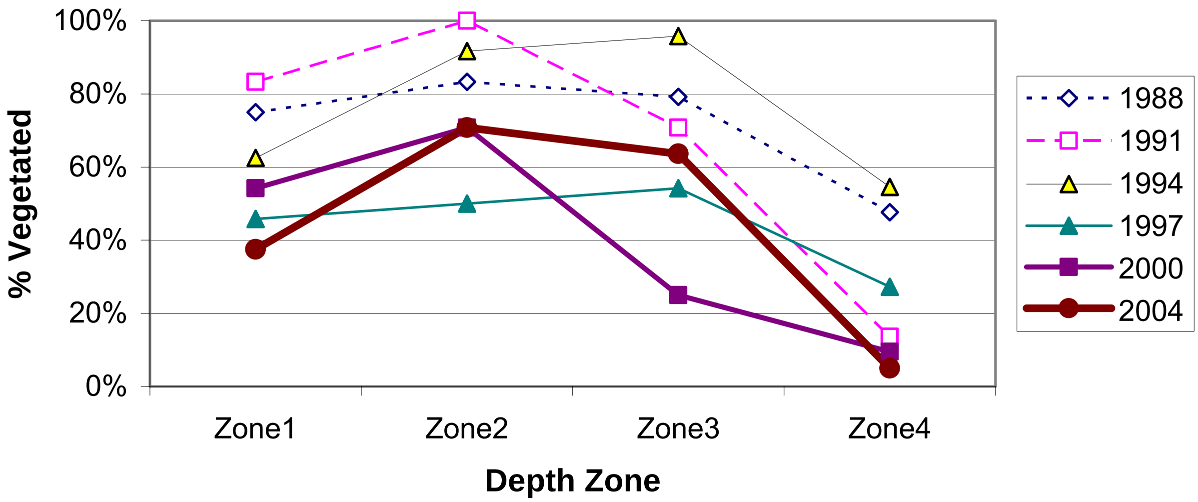

Figure 10. Percentage of littoral zone that is vegetated in Cedar Lake, by depth zone, 1988-2004.

Total occurrence is the sum of all occurrences of all species recorded; total density is the sum of all species densities recorded. The depth zone with the highest total occurrence and density of aquatic plant growth has been in the 1.5-5 ft. depth zone, except in 1994 when the greatest total occurrence and density of aquatic plants shifted to the 5-10 ft. depth zone (Figures 11, 12). Total occurrence and density of plant growth was higher during 1988-1994 and noticeably lower in 1997-2004 (Figures 11, 12).

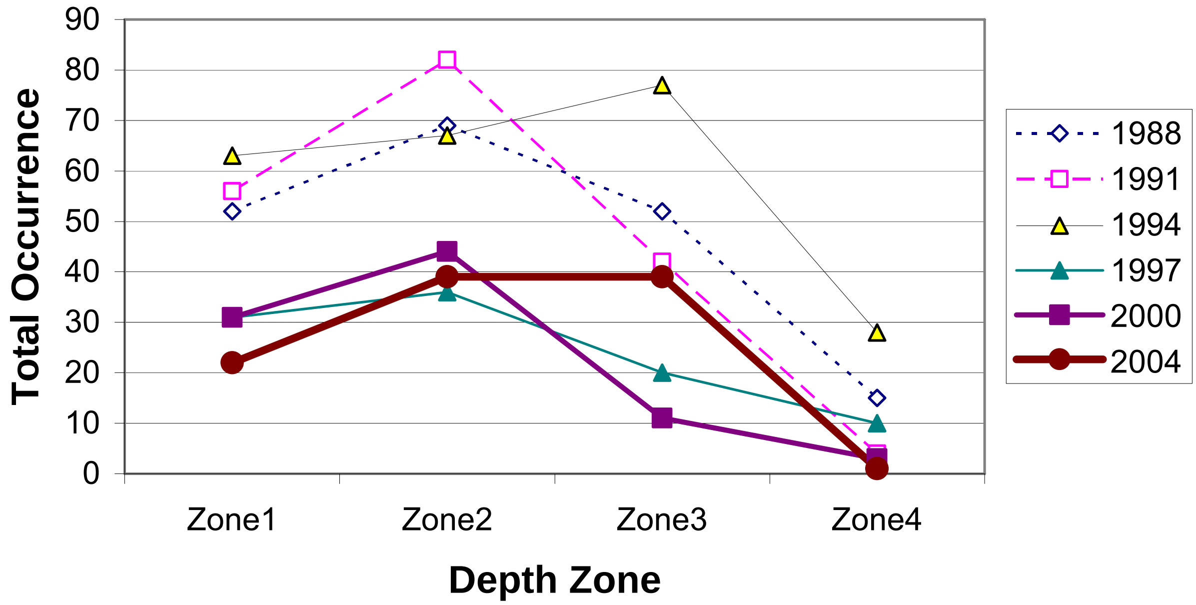

Figure 11. Total occurrence of aquatic plants by depth zone, 1988-2004.

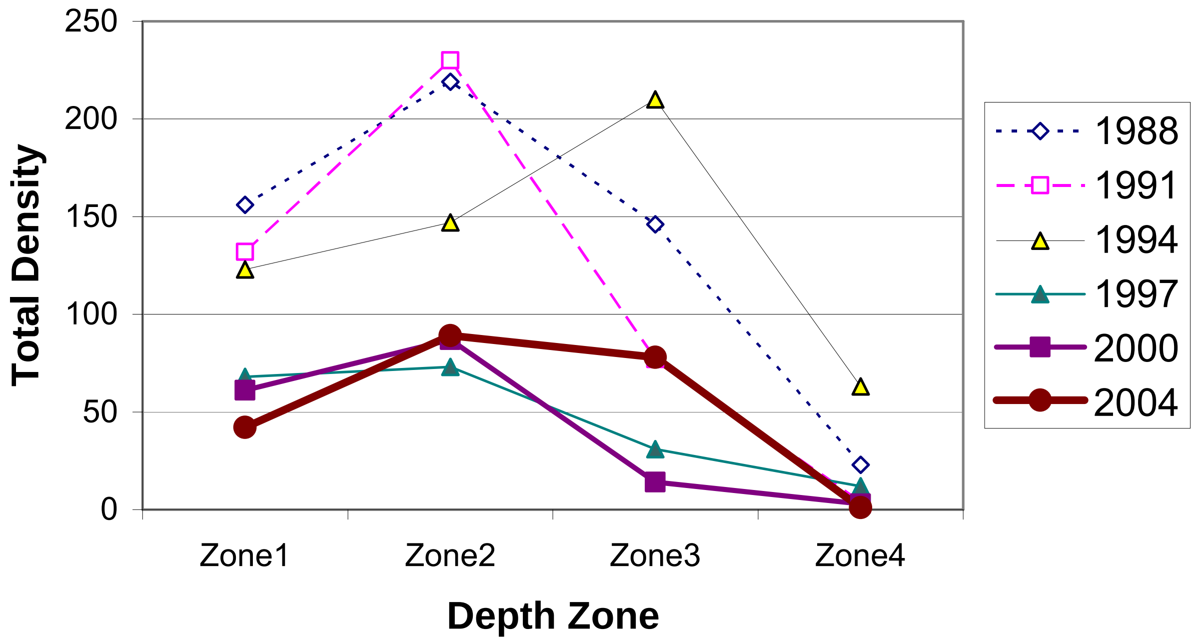

Figure 12. Total density of aquatic plants by depth zone, 1988-2004.

The greatest species richness (species per site) has been found in the 1.5-5 ft. depth zone in all aquatic plant study years in Cedar Lake, except in 1994 and 2004, when the greatest number of species per site shifted to the 5-10 ft depth zone. The number of species per site was noticeably lower in 1997-2004 than in the previous three studies (Figure 13).

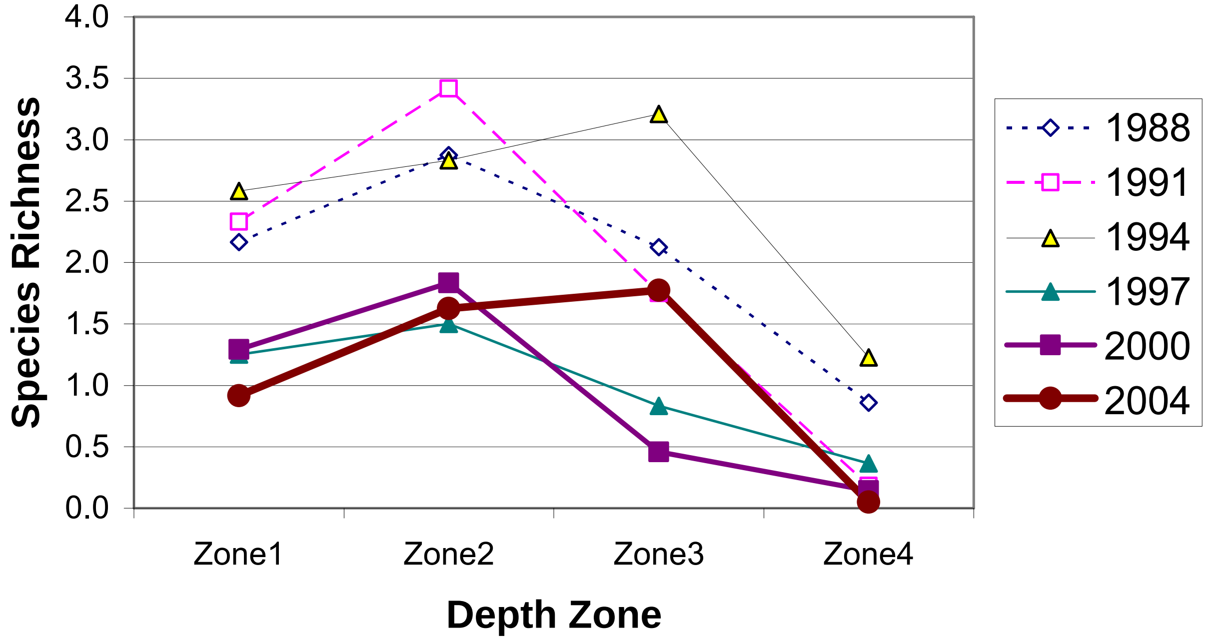

Figure 13. Species richness, by depth zone in Cedar Lake, 1988-2004.

Najas flexilis was the dominant species in the 0-5' depth zone in 1988-1991 and again in 2000. It has occurred at its highest frequency and density in the 1.5-5' zone (Figure 14, 15). Its frequency and density declined dramatically in 1994, increased slightly in 2000 and declined again in 2004.

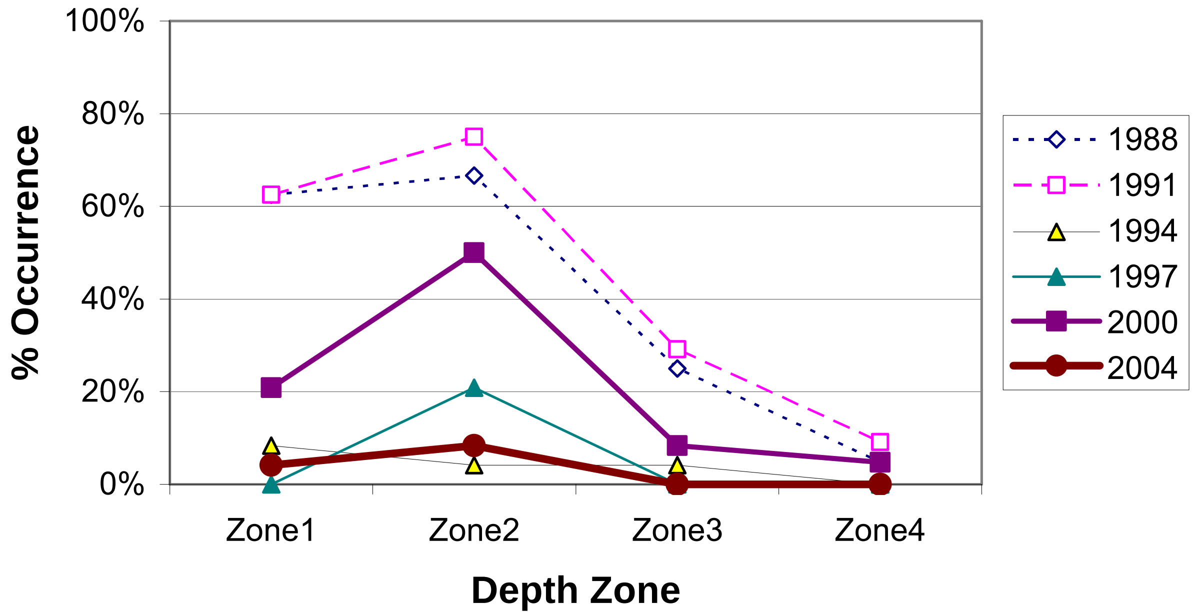

Figure 14. Frequency of *Najas flexilis* by depth zone, 1988-2004.

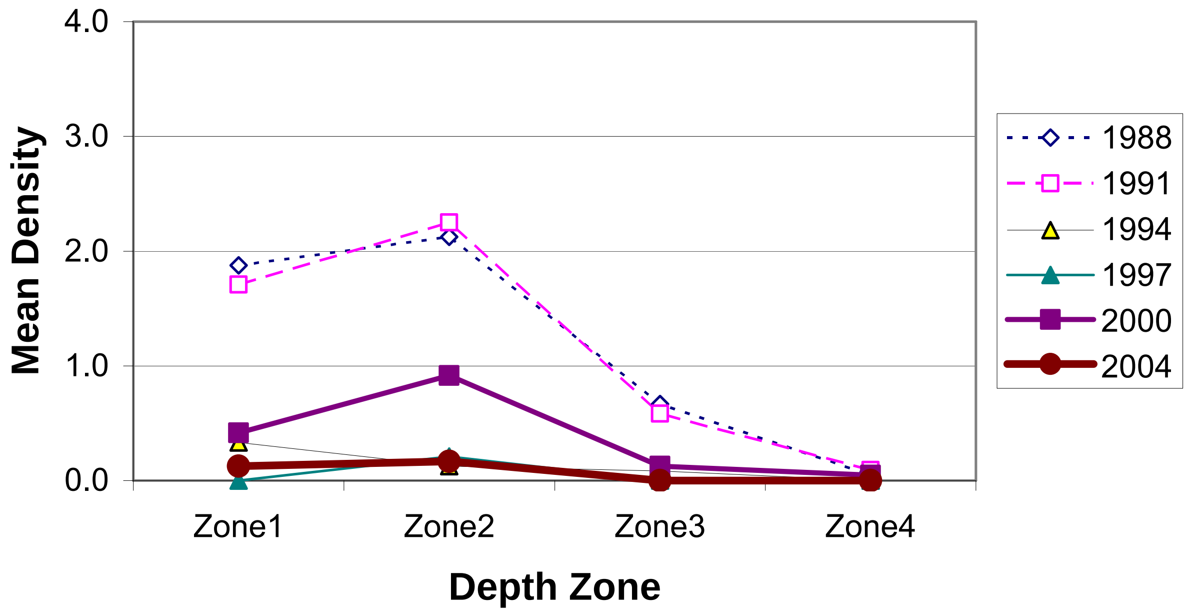

Figure 15. Density of *Najas flexilis* by depth zone, 1988-2004.

Potamogeton pusillus was the dominant species in the 5'-20' zone in 1988 and occurred at its highest frequency and density in 1988. *P. pusillus* started declining in 1991, first in the deeper depth zones and most dramatically in 1994. It was only rarely found in 1997, 2000 and 2004 (Figure 16, 17).

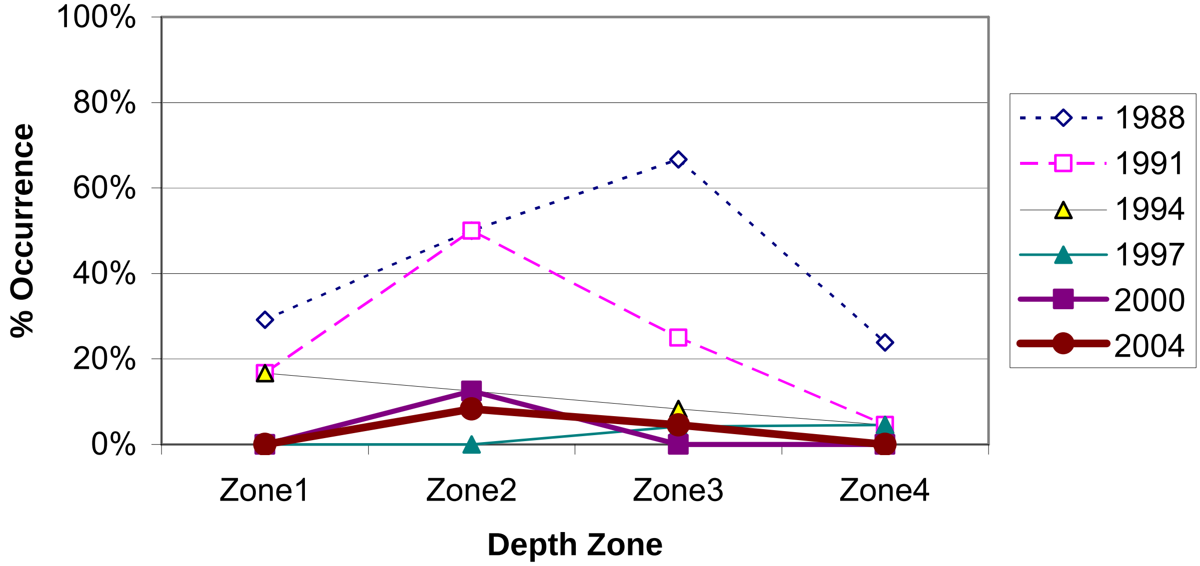

Figure 16. Frequency of *Potamogeton pusillus* by depth zone, 1988-2004.

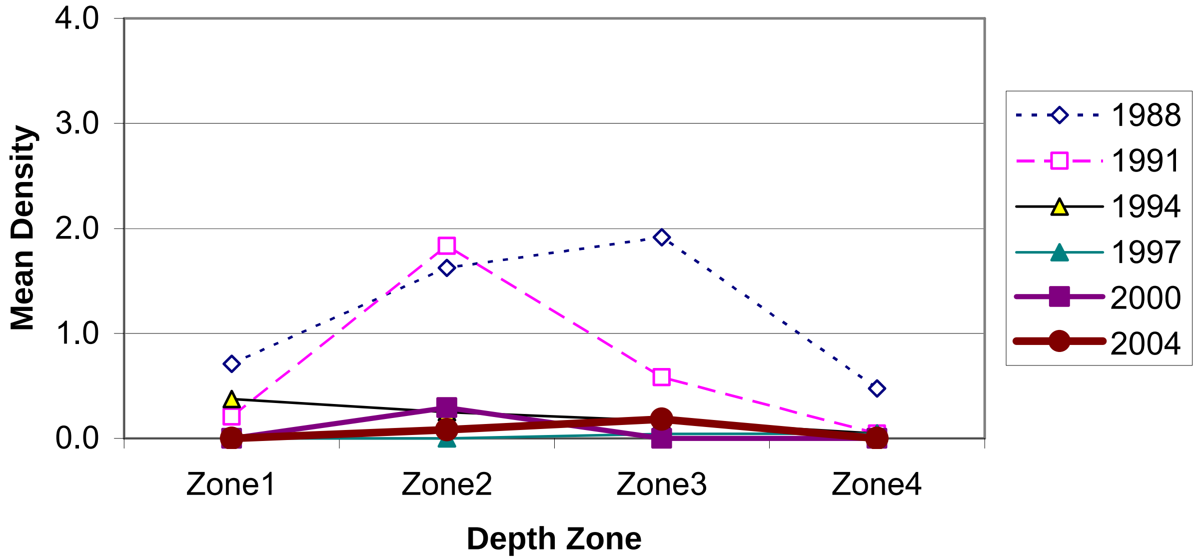

Figure 17. Density of *Potamogeton pusillus* by depth zone, 1988-2004.

Ceratophyllum demersum and *Elodea canadensis* were found at moderate frequencies and densities in 1988 and 1991, but both increased in 1994, especially in the 5-10ft depth zone, becoming the dominant species in all depth zones in 1994. In 1997, *C. demersum* was still the most frequent species in the 5-20ft depth zone and the most dense species in all depth zones (Figure 18, 19).

C. demersum had its highest frequency and density in 1994, especially in the 5-10ft depth zone. In 1997-2000, its frequency and density in the plant community returned to previous levels (Figure 17, 18). In 2004, *C. demersum* increased again and was the dominant species in the 5-10ft depth zone.

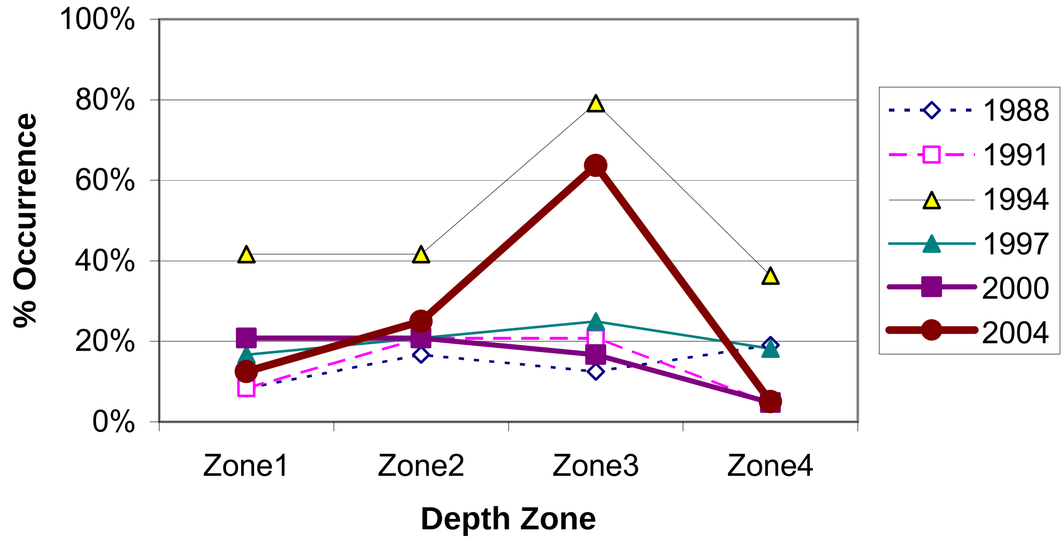

Figure 18. Frequency of *Ceratophyllum demersum* by depth zone, 1988-2004.

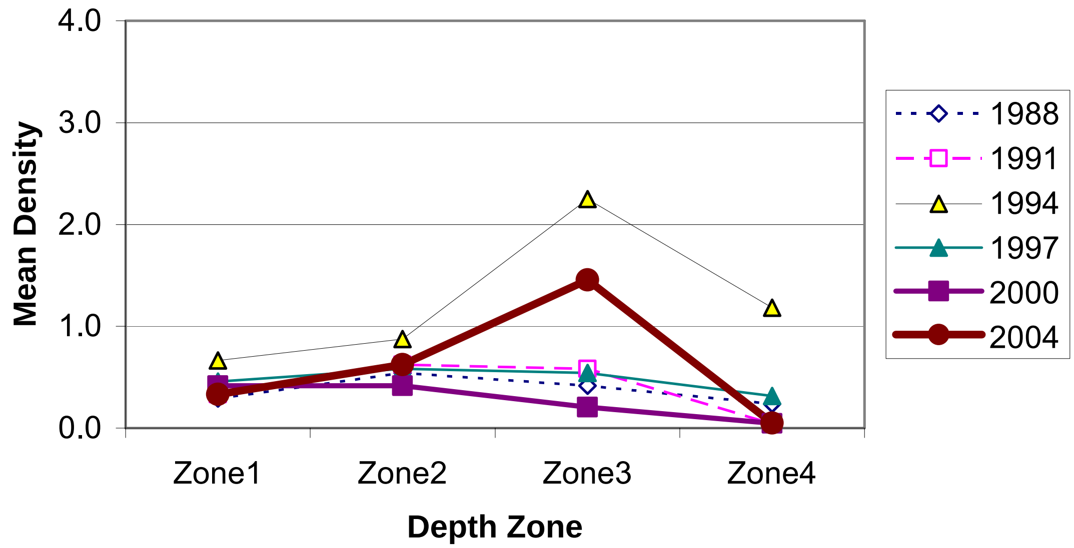

Figure 19. Density of *Ceratophyllum demersum* by depth zone, 1988-2004.

Elodea canadensis had its highest frequency and density 1994, especially in the 5-10ft depth zone, and its lowest in 1997-2000 (Figure 20, 21).

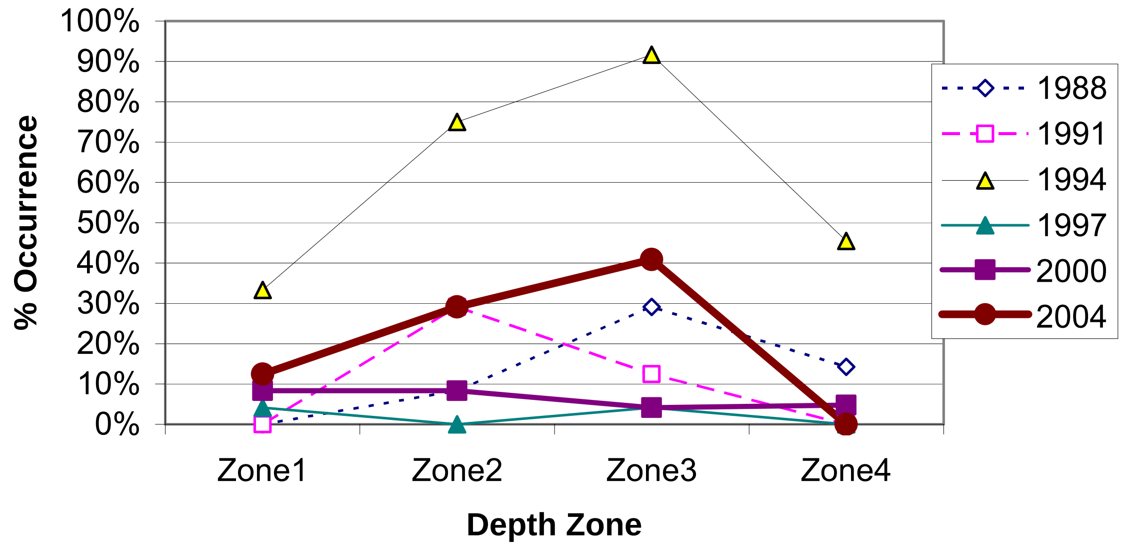

Figure 20. Frequency of *Elodea canadensis* by depth zone, 1988-2004.

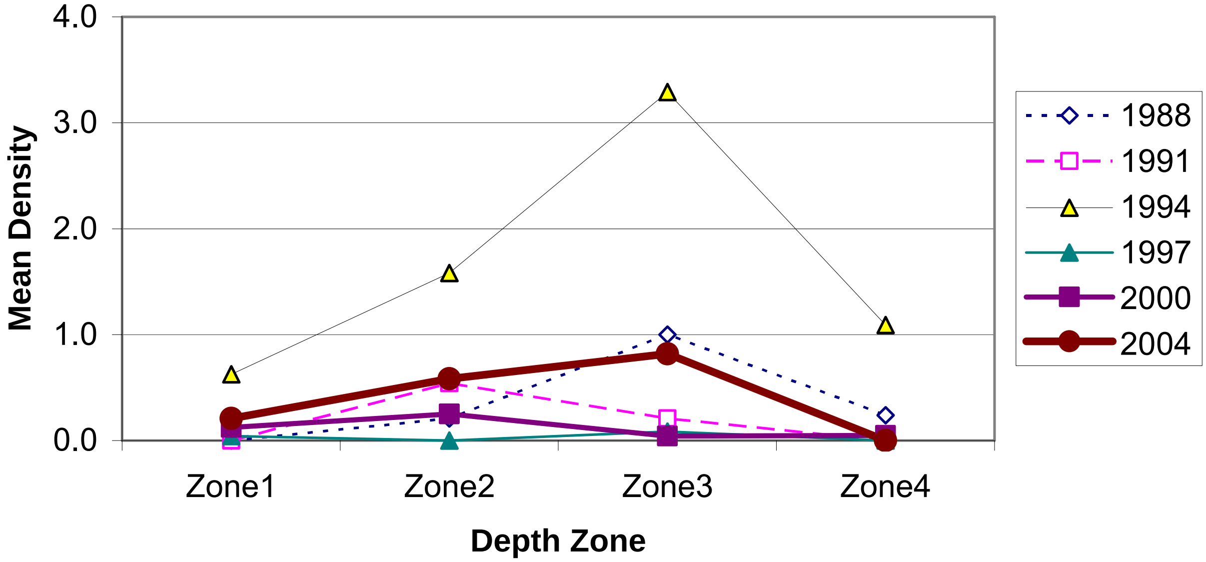

Figure 21. Density of *Elodea canadensis* by depth zone, 1988-2004.

Vallisneria americana became the dominant species in the 0-5ft depth zone in 2004. The frequency and density of *V. americana* has not changed noticeably; there was a gradual decrease from its highest frequency and density in 1988 to its lowest in 1997 and then a gradual increase from 1997 to 2004 (Figure 22, 23). *V. americana* has occurred at its highest frequency and density in the 1.5-5ft depth zone.

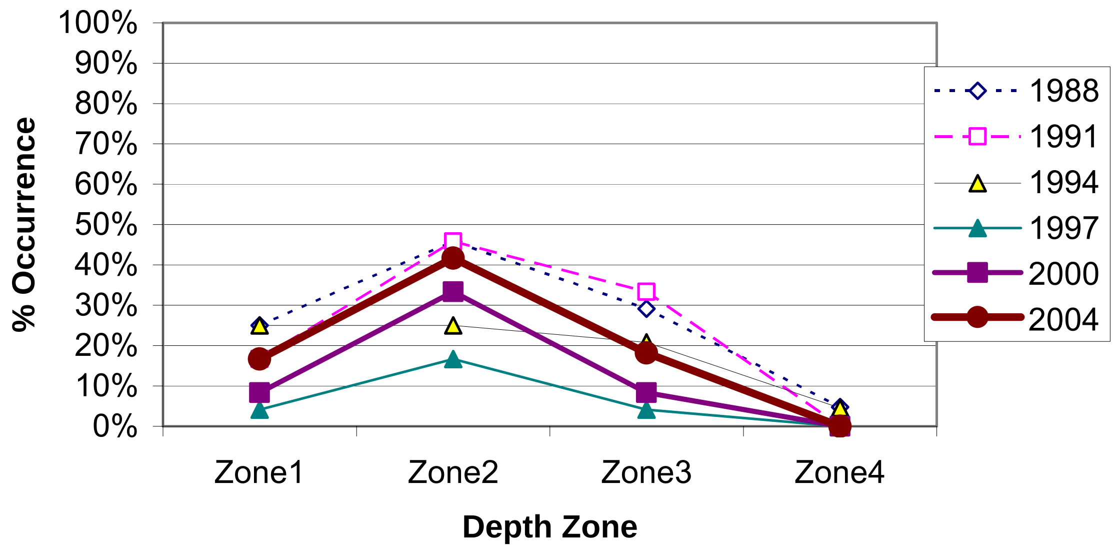

Figure 22. Frequency of *Vallisneria americana* by depth zone, 1988-2004.

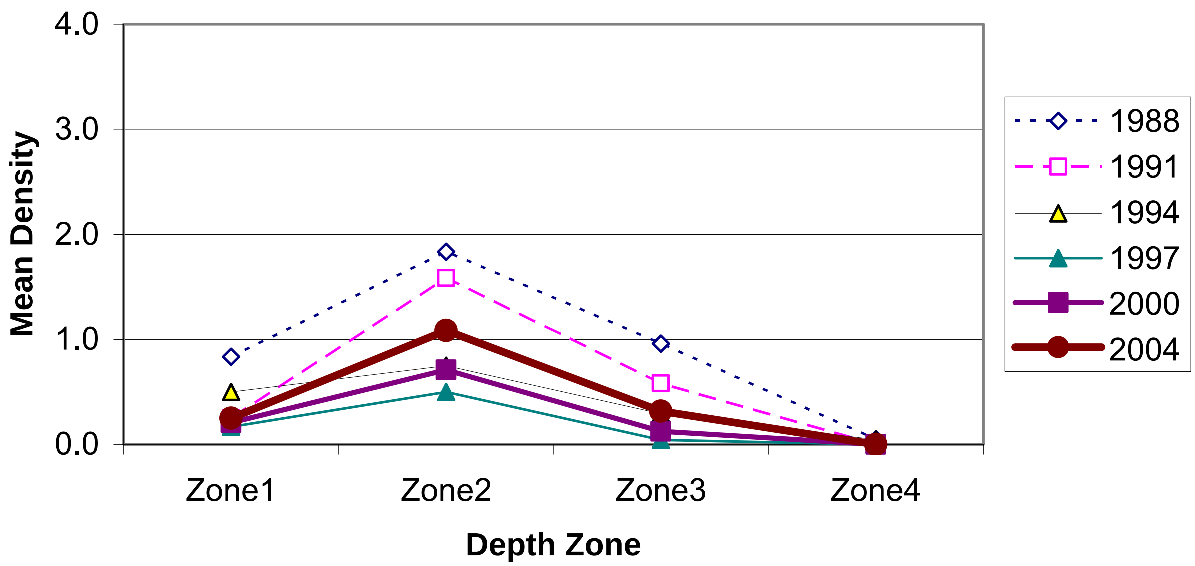

Figure 23. Density of *Vallisneria americana* by depth zone, 1988-2004.

The predicted maximum depth is calculated from the Secchi disc clarity (Dunst 1982).

Predicted Rooting Depth (ft.) = (Secchi Disc (ft.) * 1.22) + 2.73

In most study years, the actual maximum rooting depth has been greater than the predicted rooting depth (Figure 24). This is likely due to plant growth starting and becoming established early in the year when water clarity is generally very good, before algae blooms begin and clarity decreases to very poor.

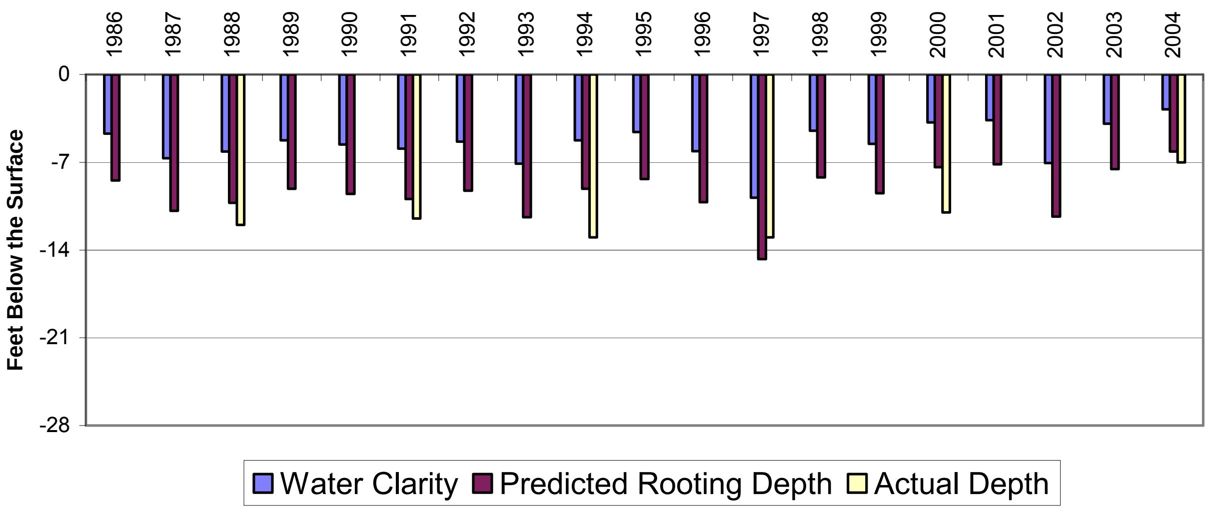

Figure 24. Predicted maximum rooting depth and actual rooting depth in Cedar Lake, 1986-2004.

Species found at the maximum depths have been *Elodea canadensis, Myriophyllum sibiricum, Najas flexilis, Potamogeton pusillus, P. richardsonii* and *Vallisneria americana.*

MACROPHYTE COMMUNITY

The Coefficients of Community Similarity indicate the percent similarity between two communities. The 1988 and 1991 aquatic plant communities in Cedar Lake were 77% similar. This is interpreted as not significantly different. However, the coefficients do indicate that the composition of the aquatic plant community changed significantly from 1991-2004.

There were significant differences between the 1991 and 1994 communities in that they were only 55% similar. The 1994, 1997 and 2000 aquatic plant communities were also all significantly different from each other, only 56-57% similar (Table 9). The 2000 and 2004 plant communities were only 67% similar and therefore also significantly different.

This continual change in the plant community over the sixteen years resulted in the 2004 plant community being only 45% similar to the 1988 community (Table 9).

Table 9. Coefficients of Community Similarity

	Coefficient	% Similar
1988-91	0.774	77%
1991-94	0.546	55%
1994-97	0.561	56%
1997-2000	0.566	57%
2000-2004	0.659	67%
1988-2004	0.446	45%

Different indices can be used to characterize a plant community and determine what changes have occurred in the community.

The number of species found at the sample sites, maximum rooting depth of aquatic plants, the percent of the littoral zone vegetated, percent occurrence of emergent species, percent occurrence of free-floating, submergent vegetation, Floristic Quality (discussed later in this document), Average Coefficient of Conservatism (discussed later in this document) and Species Richness all increased from 1988 to the highest levels in 1994 and declined subsequently (Table 10).

Simpson's Diversity Index is used to measure the diversity of the plant community. A diversity index of 1.0 would mean that each individual in a community was a different species, the most diversity that could be found. Simpson's diversity index indicates that Cedar Lake has had good-to-fair plant diversity and was highest in 1997 (Table 10).

The quality of the aquatic plant community (AMCI, discussed later) increased to its highest in 1991 and has declined since.

The percent occurrence of floating-leaf vegetation has increased.

Table 10. Changes in the Cedar Lake Aquatic Plant Community, 1988-2004.

	1988	1991	1994	1997	2000	2004	Change	%Change
Number of Species	17	22	23	23	17	18	1	5.9%
Maximum Rooting Depth	12.0	11.5	13.0	13.0	11.0	7.0	-5	-41.7%
% of Littoral Zone Vegetated	70%	68%	76%	55%	41%	49%	-0.2	-30.0%
%Sites/Emergents	2%	4%	4%	3%	2%	2%	0.0	0.0%
%Sites/Free-floating	12%	14%	50%	19%	15%	27%	0.2	125.0%
%Sites/Submergents	64%	64%	70%	37%	33%	39%	-0.3	-39.1%
%Sites/Floating-leaf	2%	5%	7%	5%	6%	9%	0.1	350.0%
Simpson's Diversity Index	0.87	0.88	0.87	0.90	0.88	0.86	-0.01	-1.1%
Floristic Quality	20.51	23.24	24.09	23.56	19.65	19.33	-1.18	-5.8%
Average Coefficient of Conservatism	4.83	4.95	5.14	4.91	4.76	4.56	-0.27	-5.6%
AMCI	46	49	45	45	43	38	-8.00	-17.4%
Species Richness	2.04	1.96	2.49	1.0	0.96	1.12	-0.92	-45.1%

Nearly every parameter is decreased as compared to 1988: the maximum rooting depth, the percent of the littoral zone vegetated, the percent cover of submergent species, the diversity of species, Species Richness, Floristic Quality and Average Coefficient of Conservatism are all less than in 1988. Species Richness (the mean number of species at each sample site) has decreased the most).

The percent cover of free-floating species and floating-leaf species are the only parameters that have increased.

The Aquatic Macrophyte Community Index (AMCI) (Nichols et. al. 2000) indicates that the quality of the aquatic plant community in Cedar Lake had been below the mean of lakes in Wisconsin during 1988-2000 and was decreasing. The quality of the plant community had decreased by 2004 to the lowest quartile, the 25% of lakes in the state with the lowest quality plant community (Table 11). When compared to other lakes in the North Central Hardwoods Region of Wisconsin, the quality of the Cedar Lake plant community has been in the lowest quartile in all years except in 1991.

The lack of sensitive species limits the quality of the plant community in Cedar Lake.

Table 11. Aquatic Macrophyte Community Index for Cedar Lake 1988-2004.

	1988	1991	1994	1997	2000	2004
Maximum rooting depth	6	6	7	7	6	3
% Littoral zone vegetated	10	10	10	10	9	9
Simpson's Diversity Index	7	8	7	8	8	7
Relative frequency of submersed species	9	10	6	6	6	5
Relative frequency of sensitive species	0	0	0	0	0	0
# of Taxa	8	9	9	9	8	8
% Exotics	6	6	6	5	6	6
Total	46	49	45	45	43	38

The 1988 - 2004 Average Coefficients of Conservatism for Cedar Lake were within the lowest quartile for all Wisconsin lakes and lakes in the North Central Hardwood Region (NCHR) (Table 12). This suggests that the plant community in Cedar Lake is within the group of lakes in the state and the Northern Central Hardwood Region that are most tolerant to disturbance. The majority of the plant species are not sensitive, more likely to be present in communities with disturbance. This is likely the result of being subjected to high amounts of disturbance.

Table 12. Mean Coefficient of Conservatism and Floristic Quality of Cedar Lake, Compared to Wisconsin Lakes and Region Lakes, 1988-2004.

	Average Coefficient of Conservatism †	Floristic Quality ‡
Wisconsin Lakes	5.5, 6.0, 6.9*	16.9, 22.2, 27.5*
NCHR Lakes	5.2, 5.6, 5.8*	17, 20.9, 24.4*
Cedar Lake, 1988-2000		
1988	4.83	20.51
1991	4.95	23.24
1994	5.14	24.09
1997	4.91	23.58
2000	4.76	19.65
2004	4.56	19.33

* upper limit of lower quartile, mean, lower limit of upper quartile

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

‡- The Floristic Quality ranged from a low of 3.0 (closest to an undisturbed condition) to a high of 44.6 (closest to an undisturbed condition)

Floristic Quality takes into account not only the tolerance or sensitivity of the species in the community, but also the diversity of the community. The Floristic Quality Index (FQI) for Cedar Lake was below the mean for lakes in the North Central Hardwoods Region and the state in 1988. In 1991-1997, the Floristic Quality increased to above the mean for lakes in the state and region, however, the Floristic Quality decreased in 2000-2004 to below the mean again.

This suggests that the plant community in Cedar Lake was farther from an undisturbed condition than the average lake in the state and in the Northern Central Hardwood Region 1988. In 1991-1997, the plant community was closer to an undisturbed condition than the average lake in the state or region. In 2000-2004, disturbance increased in Cedar Lake again and the plant community was again farther from an undisturbed condition than the average lake in the state and region. This also suggests high amounts of disturbance have occurred in Cedar Lake that not only reduced the sensitive species, but also reduced diversity of the species.

Disturbances can be of many types:

1) Physical disturbances to the plant beds result from activities such as boat traffic through plant beds, snow mobile traffic in winter that compacts sediment and crushes emergent vegetation, plant harvesting, chemical treatments, the placement of docks and other structures, water level manipulation.
2) Indirect disturbances can be the result of factors that impact water clarity and thus stress species that are more sensitive: resuspension of sediments, sedimentation from erosion, increased algae growth due to nutrient inputs.

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

The major disturbances in Cedar Lake are likely the poor water clarity, destruction of the plant beds by the carp population and boat and snowmobile traffic, water level manipulations and the high percentage of developed shoreline that will result in increased disturbance from dock placement, boat traffic and run-off.

Aquatic plant communities change because the individual species change; there have been changes in the species in Cedar Lake (Appendix XXI).

Ten species have variously disappeared and appeared in various years that are found at only a couple sites. These changes are likely due to slight shifting of sample sites that do not always capture the uncommon species.

An exception to the loss of species due to shifting transects is the disappearance of the chairmaker's rush, *Scirpus americanus*. A 1910 postcard of Cedar Lake showed large extensive emergent beds in the southeast corner (DNR files). During 1988, 1991 and 1994, *Scirpus americanus* was always found in the southeast corner, but occurred at only one transect since the bed was bisected by one transect. In 1988-1991, *S. americanus* occurred in the 0-1.5ft depth zone. In 1994, the rush bed occurred in deeper water in the 1.5-5ft depth zone where survival may be compromised for an emergent species. The bed was also noticeable smaller and sparser according to the researcher that had seen the bed in the previous survey years (Borman 1994). Density data confirmed this; the density ratings for 1988 and 1991 had been 3 and 4 at the site it occurred. In 1994, its density rating was only 1 at its site of occurrence. In 1997 and 2000, the transect no longer crossed any stems so that the species was not recorded at the transect, but the species occurred as scattered stems in the area becoming progressively sparser and smaller from 1997 to 2000. In 2004, the chairmaker's rush was not found. There was not a single stem in the area that once supported a large dense bed (Konkel 1998). The reasons for the disappearance of this valuable habitat species could be water level manipulations, boat traffic or carp disturbance.

Besides those 10 species, 5 species that had greater coverage at one time have disappeared from the sample sites since 1988. *Myriophyllum sibiricum* is one species that disappeared, declining since its highest frequency and density in 1994. Besides those that disappeared, 9 species have decreased (Appendix XXI). *Najas flexilis* and *Zosterella dubia* have decreased the most, 85-95% declines. Other species that have declined by more than 50% in frequency or density are: *Chara, Potamogeton crispus, P. nodosus, P. pectinatus, P. richardsonii* and the small pondweeds. The five most sensitive species in Cedar Lake (as measured by Coefficient of Conservatism) (Nichols 1998) have all declined or disappeared since 1988.

Four species have increased in frequency and density in Cedar Lake since 1988.

Nymphaea odorata increased the most, increasing more than three-fold in frequency of occurrence (Appendix XXI). All of the species that increased in Cedar Lake are tolerant of high-turbidity and have been known to increase to nuisance levels with nutrient enrichment (Nichols 1999; Nichols and Vennie 1991).

IV. DISCUSSION

Based on the water clarity and chlorophyll and phosphorus concentrations, Cedar Lake is a hypereutrophic lake with poor water clarity and very poor water quality. Chlorophyll (algae) and phosphorus (nutrients) have increased and water clarity has decreased (since 1997 according to DNR and since 1992-93 according to volunteer data). The water clarity varies dramatically during the open water season. Filamentous algae is common in the shallowest zone.

The relatively large watershed is a large source of external nutrient input and anoxic sediments that recycle phosphorus are the largest source of phosphorus. However, DNR water quality data suggests that Cedar Lake is nitrogen-limited at times, meaning nitrogen is also an important factor driving algae growth during some seasons.

Copper use for algae control in Cedar Lake started in the 1940's. Copper treatments were discontinued in the 1980's due to their ineffectiveness. In order to achieve any algae control, large amounts of copper were being applied and multiple treatments (up to 7 times per year) were being conducted. The application of more than 15,575 pounds of copper sulfate has added more than 3925 pounds of elemental copper to the lake. This is more than 3.5 pound of pure copper per acre on the sediments of Cedar Lake, however this copper is likely more concentrated in the littoral zone. Because copper will not biodegrade any further, this usage of copper causes concern due to its toxicity to important members of the aquatic community: aquatic insects (the food source of many game fish) and mollusks (the natural water filters in a lake).

The hypereutrophic status (abundant nutrients), hard water and broad, gently sloped littoral zone in Cedar Lake would favor abundant plant growth. The poor clarity, heavy film of planktonic algae in parts of the littoral zone and dominance of sediments low in organic content (sand and rock) could limit plant growth. The dominance of high-density sand and rock sediments would make Cedar Lake less likely to support abundant vegetation than a similar lake with more favorable silt sediments.

2004 Aquatic Plant Community

Ceratophyllum demersum was the dominant plant species in the 2004 Cedar Lake aquatic plant community, especially in the 5-20ft depth zone. *Elodea canadensis* and *Vallisneria americana* were subdominant, *V. americana* especially in the 1.5-5ft depth zone. Aquatic vegetation occurred throughout the littoral zone to a maximum rooting depth of 7-feet, 49% of the littoral zone is vegetated, 23% of the entire lake.

The 1.5-5ft depth zone supports the greatest amount of plant growth; the highest percent of vegetated sites, the greatest total occurrence of plants and the greatest total density of plants. Species Richness is highest in the 5-10ft depth zone. The aquatic plant community in Cedar Lake in 2004 is characterized by low quality (AMCI Index), fair species diversity, a high tolerance to disturbance and a condition likely determined by above average levels of disturbance (Floristic Quality Index). The major disturbances are likely poor water clarity, destruction from the carp population and the high percentage of developed shoreline.

Changes

The aquatic plant community in Cedar Lake has undergone significant change. Starting in 1991, each succeeding plant study revealed a plant community significantly different from the previous, each only 55-58% similar to the previous. The continual change in the plant community resulted in the 2004 plant community being only 45% similar to the 1988 plant community, meaning that over the 16 years of the plant study, only 45% of the original plant community has been retained.

The largest changes occurred between 1991 and 1994. In 1994, the plant community has at its greatest amount of growth. This was the year in which the vegetation colonized the greatest percent of the littoral zone, had the greatest species richness and had the highest total occurrence and total density of plant growth. This reversed quickly as 1997-2004 as these measures reached their lowest levels.

Besides changing temporally, the plant growth also changed spatially. The depth zone with the greatest amount of vegetation has shifted from 1.5-5ft depth zone in 1988-1991, to the 5-10ft depth zone in 1994 and back to the 1.5-5ft depth zone in 1997-2004. Since, poor water quality limits plant growth in the deeper zones, this change was likely due to the better water clarity in 1994 and worsening clarity subsequently. The zone of greatest plant growth shifted back to the 1.5-5ft depth zone in 1997-2004 when water clarity declined again.

There have been changes in the dominance of species in Cedar Lake. The aquatic plant community has changed from a

1) *Najas flexilis - Potamogeton pusillus - Vallisneria americana* community in 1988-1991;
2) *Elodea canadensis - Ceratophyllum demersum* community in 1994;
3) *Ceratophyllum demersum* dominated community in 1997;
4) *Najas flexilis - Ceratophyllum demersum* dominated community in 2000;
5) *Ceratophyllum demersum-Elodea canadensis-Vallisneria americana* dominated community in 2004.

The dominance of *Ceratophyllum demersum* in the Cedar Lake aquatic plant community has increased since 1988, especially in 5-10ft depth zone. *C. demersum* and the other three species that have increased in frequency and density since 1988 are all turbidity tolerant and known to increase with increased nutrient enrichment (Nichols and Vennie 1991).

There have been changes in individual aquatic plant species. The species that have undergone the most noticeable decrease was *Najas flexilis* and *Zosterella dubia. N. flexilis* was the dominant species in 1988 and has fluctuated since. *N. flexilis* is intolerant of turbidity. The 5 most sensitive species that have occurred in Cedar Lake have all declined or disappeared since 1988.

The decline or disappearance of all six species of native *Potamogeton* (pondweeds) (Appendix XXI) is disturbing because of their important contributions to fish and waterfowl habitat.

The disappearance of the chairmaker's rush, *Scirpus americanus* is a loss to fish and wildlife habitat.

1) The rush bed was always found in the southeast corner during 1988, 1991 and 1994.
2) In 1994, the rush bed "moved" from the shallow 0-1.5ft depth zone to the 1.5-5ft depth zone and was noticeable smaller and sparser, its density ratings dropping dramatically from 3 - 4 in 1988 - 1991 to a density rating of 1 in 1994.
3) In 1997 and 2000, the transect no longer crossed any stems so that the species was not recorded at the transect, but occurred as scattered stems in the area.
4) The rush bed becoming progressively sparser and smaller from 1997 to 2000.
5) In 2004, the chairmaker's rush was not found. There was not a single stem in the area that once supported a large dense bed.

The reasons for the disappearance of this valuable habitat species could be water level manipulations, boat and snowmobile traffic or carp disturbance.

In 1994, almost all measures of the aquatic plant community had increased and were at their highest during the 16 years of aquatic plant studies: the number of species, the maximum rooting depth, the percent of vegetated sites, the percent coverage of submerged and emergent vegetation, the Floristic Quality, the Average Coefficient of Conservatism, Species Richness had all increased to their highest. Starting in the 1997 and 2000 plant studies, these same measures have all declined (Table 10). The decrease in Floristic Quality and Average Coefficient of Conservatism since the 1994 study indicates an increase in disturbance.

Many possible factors may be contributing to changes in the aquatic plant community: shoreline development, water level manipulations, nutrient enrichment and declining water clarity, boating impacts and the carp population.

1) Disturbed shoreline increased from 1997 to 2004 and covered more than half the shoreline in 2004. The loss of natural shoreline has been associated with a loss of in-lake aquatic plant habitat (Konkel et. al. 1997). Aquatic plant beds next to developed shorelines were characterized by lower plant density, lower plant species diversity, lower occurrence of sensitive species and higher occurrence of filamentous algae (Konkel et. al. 1997). Placement of docks will shade vegetation and the resulting boat traffic in and out will physcially tear the vegetation. Nutrient enrichment is probable at developed shorelines.
2) Water level manipulations will stress aquatic plant species by alternately exposing them to dry conditions that are not adapted to withstand and inundating them with more water than they are adapted to survive in.
3) Nutrient input from the watershed impacts the clarity of the water.
    a) Nutrient run-off from the row cropland is contributing 79% of the annual

phosphorus input (Polk Co LWCD et. al. 2001).

b) Nutrients (phosphorus) being recycled from the sediments during anoxic conditions. The aeration system that was installed in 1990 to reduce the release of nutrients from the sediments appeared to provide improvement for awhile. Nutrients and algae decreased and water clarity improved for a time after the installation of the aeration system. Many of the changes in measurements of the plant community follow a pattern of change after the aeration installation in 1990 and a return to pre-aeration conditions in 1997 - 2004.
c) Nutrients can be recycled by carp.

4) Boat propellors chop up plants and resusupend sediments that impact water clarity. Boat hulls can scour sediment.
5) Carp can stir up sediments and uproot plants (McComas 1997).

Shoreline Impacts

Disturbed shoreline has increased in occurrence and cover around Cedar lake since 1997 and covered more than half the shore in 2004. Cultivated lawn was the shoreline cover type with the highest mean coverage on Cedar Lake in 2004. Rip-rap and hard structure were abundant around Cedar Lake. The concern with these shoreline cover types is their inability to filter and slow the run-off of water, inability to protect the shoreline as effectively as natural vegetation and in the case of lawn, the high likelihood that they are a source of nutrients and pesticides.

Transects at shoreline with 100% natural cover on Cedar Lake were separated from transects that had some disturbed cover and analyzed (Appendices XXII-XXIV). Many measures of the aquatic plant community differed between natural shoreline sites and disturbed shoreline sites (Table 13).

At the natural shorelines, the plant community had a greater number of species, a higher Species Richness (species per site) and a higher diversity index (Table 13). These measures of greater diversity in the plant community at natural shorelines indicate that the community will support greater diversity in the fish and wildlife community.

The natural shoreline sites had a greater percentage vegetation cover, greater cover of submergent, floating-leaf and emergent vegetation. This means more habitat and the emergent and floating-leaf beds are very important components of quality habitat.

The Floristic Quality was higher at the natural sites, closer to an undisturbed condition. This corroborates that the plant community at natural shoreline is closer to an undisturbed condition than the plant community disturbed shoreline sites (Table 13).

The two species with the highest sensitivity to disturbance were missing or occurred at a lower frequency at the disturbed sites (Table 13). Conversely, the three most tolerant species in Cedar Lake occurred at a higher frequency at the disturbed shorelines (Table

13).

Table 13. Comparison of the Cedar Lake Aquatic Plant Community at Natural and Disturbed Shorelines, 2004

		Natural	Disturbed
Number of Species		16	9
Species Richness	Overall	2.56	0.76
	0-1.5ft zone	2.8	0.4
	1.5-5ft zone	3.4	1.2
	5-10ft zone	3.0	1.4
Simpsons Diversity Index		0.876	0.817
% of Littoral Zone Vegetated		72%	39%
%Sites/submergent vegetation		67%	32%
%Sites/Floating-leaf vegetation		28%	4%
%Sites/emergent vegetation		11%	0%
Floristic Quality		18.25	15.00
Relative Frequency of Most Sensitive Species		6%	2%
Chara spp.		2%	0%
Potamogeton pusillus		4%	2%
Relative Frequency of Most Disturbance Tolerant Species: Most likely occur in disturbed		37%	58%
Ceratophyllum demersum		20%	27%
Elodea canadensis		13%	24%
Potamogeton pectinatus		4%	7%

V. CONCLUSIONS

Cedar Lake is a hypereutrophic lake with very poor water quality and poor clarity. Filamentous algae is common in the shallowest zone. The lake supports a low quality aquatic plant community with fair species diversity. Cedar Lake has a high tolerance to disturbance and has been impacted by above average disturbance as compared to other lakes in the state and region. Aquatic plant growth is scattered throughout 49% of the littoral zone, to a maximum rooting depth of 7-feet, 23% of the entire lake. The most abundant plant growth occurs in the 1.5-5ft depth zone. The poor water clarity and dominance of high-density sand and rock sediments limit the potential for abundant plant growth in Cedar Lake.

Ceratophyllum demersum is the dominant plant species in the community, especially in the deeper depth zones. *Elodea canadensis* and *Vallisneria americana* are subdominant.

Changes in the Aquatic Plant Community

The Cedar Lake aquatic plant community has undergone significant change. The 2004 aquatic plant community only 45% similar to the 1988 plant community.

There has been a shift from a community dominated by *Potamogeton pusillus - Najas flexilis - Vallisneria americana* to a community dominated by *Ceratophyllum demersum – Elodea canadensis – Vallisneria americana*.

The Floristic Quality Index and Average Coefficient of Conservatism indicate that some type of disturbance may be driving the change in the plant community. The five most sensitive species in Cedar Lake have either disappeared or decreased in frequency and occurrence. Changes that are due to increased disturbance such as carp disturbance, water level manipulations and shoreline development:

1) There has been a decrease in the quality (AMCI Index) of the Cedar Lake plant community.
2) The percent cover of aquatic vegetation and the colonization of submergent vegetation has decreased, which has a negative impact on habitat in the lake.
3) Species Richness has decreased, indicating loss of species at the sites, resulting in decreased diversity of habitat.
4) There has been a decline of six (6) native pondweeds in Cedar Lake. Since pondweeds are premier habitat species, this also negatively impacts in-lake habitat.
5) *Scirpus americanus*, chairmaker's rush, has disappeared from Cedar Lake.

There have been other changes between 1988 and 2004 that are likely the result of declining water quality. Increases in nutrients result in increases in algae and decreased water clarity that has stressed the plant community.

1) Decreased maximum rooting depth
2) Increased colonization of free-floating and floating-leaf vegetation that are not impacted by lowered clarity as greatly as submergent vegetation.
3) The four species that have increased during 1988 to 2004 (*Ceratophyllum*

demersum, Elodea canadensis, Lemna minor, Nymphaea odorata) are turbidity tolerant species that have been known to grow to overabundance when there is an excess of nutrients or other disturbances in a lake (Nichols and Vennie 1991).

4) Nearly every measure of aquatic plant community health increased from 1988 to 1994 when water clarity increased and then declined 1997-2004 when the water clarity declined.
5) The dramatic decline of *Potamogeton pusillus* first appeared in the deeper depth zones.
6) The depth zone that supports the most abundant vegetation shifted from the 1.5-5ft depth zone to the 5-10ft depth zone in 1994, when the water clarity was greater. Plant growth shifted back to the 1.5-5ft depth zone when clarity decreased.

A healthy aquatic plant community plays a vital role within the lake ecosystem. Healthy plant communities improve water quality in many ways.

1) Trap nutrients, debris and pollutants entering a water body
2) Absorb and break down pollutants
3) Reduce erosion by stabilizing banks and shorelines, stabilizing bottoms and reducing wave action
4) Remove nutrients that would otherwise be available for algae blooms (Engel 1985).

A balanced, healthy aquatic plant community provides important fishery and wildlife resources (Table 14).

1) Plants start the food chain that supports many levels of wildlife
2) Aquatic plants produce oxygen needed by animals
3) Plant structure is necessary for food and cover for a variety of wildlife
4) Aquatic plants provide food, cover, and spawning sites for fish

Table 14. **Wildlife and Fish Uses of Aquatic Plants in Cedar Lake**

Aquatic Plants	Fish	Water Fowl	Song and Shore Birds	Upland Game Birds	Muskrat	Beaver	Deer
Submergent Plants							
Ceratophyllum demersum	F,I*, C, S	F(Seeds*), I, C			F		
Chara sp.	F*, S	F*, I*					
Eleocharis acicularis	S	F			F		
Elodea canadensis	C, F, I	F(Foliage) I					
Myriophyllum sibiricum	F*, I*, S	F(Seeds, Foliage)	F(Seeds)		F		
Najas flexilis	F, C	F*(Seeds, Foliage)	F(Seeds)				
Potamogeton amplifolius	F, I, S*,C	F*(Seeds)			F*	F	F
Potamogeton crispus	F, C, S	F(Seeds, Tubers)					
Potamogeton foliosus	F, I, S*,C	F*(All)			F*	F	F
Potamogeton gramineus	F, I, S*,C	F*(Seeds, Tubers)			F*	F	F
Potamogeton illinoensis	F, I, S*,C	F*(Seeds)	F		F*	F	F
Potamogeton nodosus	F, I, S*,C	F*(Seeds)			F*	F	F
Potamogeton pectinatus	F, I, S*,C	F*			F*	F	F
Potamogeton pusillus	F, I, S*,C	F*(All)			F*	F	F
Potamogeton richardsonii	F, I, S*,C	F*(All)			F*	F	F
Potamogeton zosteriformis	F, I, S*,C	F*(Seeds)			F*	F	F
Ranunculus longirostris	F	F(Seeds, Foliage)		F			

Aquatic Plants	**Fish**	**Water Fowl**	**Song and Shore Birds**	**Upland Game Birds**	**Muskrat**	**Beaver**	**Deer**
Vallisneria americana	F*, C, I, S	F*, I	F		F		
Zannichellia palustris	F	F (Seeds)	F (Seeds)				
Zosterella dubia	F, C, S	F(Seeds)					
Floating-leaf Plants							
Lemna minor	F	F*, I	F	F	F	F	
Nuphar variegata	F,C, I, S	F, I	F		F*	F	F*
Nymphaea odorata	F,I, S, C	F(Seeds)	F		F	F	F
Spirodela polyrhiza	F	F		F			
Wolffia columbiana		F			F		
Emergent Plants							
Carex comosa	S*	F*(Seeds), C	F*(Seeds)	F*(Seeds)	F	F	F
Eleocharis palustris	I	F, C					
Sagittaria latifolia		F, C	F(Seeds), C	F	F	F	
Scirpus fluviatilis	F, C, S	F(Seeds)	F	F			
Scirpus validus	F, C, I	F (Seeds)*, C	F(Seeds, Tubers), C	F (Seeds)	F	F	F
Sparganium eurycarpum	I	F(Seeds), C	F, C		F		F*
Typha latifolia	I, C, S	F(Entire), C	F(Seeds), C, Nest	Nest	F* (Entire), C*, Lodge	F	

F=Food, I= Shelters Invertbrates, a valuble food source C=Cover, S=Spawning, *=Valuable Resource in this category

Compared to non-vegetated lake bottoms, aquatic plant beds supported larger, more diverse invertebrate populations (Engel 1985). These larger and more diverse invertebrate populations will in turn support larger and more diverse fish populations. In addition, plants themselves can become a major food source for some fish during certain times of the year (Engel 1985).

In Cedar Lake, only 49% of the littoral zone, 23% of the entire lake bed, supports aquatic vegetation. This is less than the ideal for a balanced fishery.

Management Recommendations

1) Lake District cooperate with efforts in the watershed to reduce nutrient levels in order to improve the water clarity and the aquatic plant community.
2) Lake residents eliminate any fertilizers on shoreline properties.
3) Lake District to maintain carp barriers and promote recreation such as carp spearing to maintain the lowered carp population. Carp can destroy plant beds, recycle phosphorus in the lake and contribute to water turbidity.
4) DNR plan an experimental project for restoring emergent vegetation in Cedar Lake and pursue funding for the project.
5) Lake residents increase natural shoreline by restoring buffer zones of native vegetation. Disturbed shoreline now covers more than half or the Cedar Lake shore and cultivated lawn alone covers more than one-third of the shore. This is an insufficient amount of natural shoreline to protect the water quality of the lake and is likely a source of nutrients to the lake. Analysis of the plant community at disturbed shoreline sites vs. natural shoreline sites showed that
    - b) The plant community at disturbed sites was impacted by disturbance (Floristic Quality Indices and occurrence of more sensitive species)
    - c) The plant community at disturbed shoreline provided a less diverse habitat.
    - d) The plant community at disturbed shoreline provided less cover for fish and wildlife, especially cover of the very important floating-leaf and emergent plant communities.
6) Lake District and government agencies should follow recommendations for protection of the sensitive areas designated in Cedar Lake (Konkel 2002) during the summer of 2002. These areas are the most important areas to protect for fish and wildlife habitat and water quality protection. Recommendations include:
    - a) Implement all possible strategies to improve water clarity and restrict nutrient enrichment.
    - b) No permitting for bank grading at the sensitive area sites.
    - c) No permitting of retaining walls.
    - d) No permitting of dredging at the sites.
    - e) Carefully review the proposed placement of any boat ramps at sensitive sites.
    - f) Restrict the location and dimensions of recreational floating devices.
    - g) Restore the bulrush beds that had been important overwater nesting habitat for some birds and prime habitat for a variety of fish.

h) Study impact of water levels on the bulrush beds.
i) Protect the limited amount of emergent vegetation that occur at the site for habitat, water quality protection and erosion control
j) Establish emergent vegetation for erosion protection and habitat through restoration of bulrush beds and/or establishment of wild rice.
k) Maintain the shoreline and aquatic vegetation in an undisturbed condition for wildlife, fish and aquatic life habitat and as a nutrient buffer for water quality protection.
l) Restore shoreline vegetation at developed sites
m) Riparian property owners should use lawn and home best management practices. This should include storm water management, buffer zone restoration and elimination of all fertilizer use.
n) Do not remove fallen trees at the shoreline.
o) Minimize authorization of pea gravel beds, sand blankets or other filling.
p) Pier placement by permit only in sensitive areas and piers constructed of material that allows light penetration.

7) Lake District, residents and agencies protect the remaining wetlands in the watershed and around the shoreline. 193 have been lost already.
8) Lake District review current water level strategy as it may be a major factor in the disappearance of a valuable habitat species. Chairmaker's rush, *Scirpus americanus* was always found in the southeast corner during 1988, 1991 and 1994 but the bed was becoming noticeable smaller and sparser (density ratings dropped dramatically from 3 - 4 in 1988 - 1991 to 1 in 1994). In 1997 and 2000, the rush occurred as scattered stems in the area that the transect no longer crossed, becoming progressively sparser and smaller from 1997 to 2000. In 2004, the chairmaker's rush was not found as even a single stem in the area that once supported a large dense bed. Other emergent vegetation is sparse in Cedar Lake and may have also been compromised by higher water levels.

Protecting and enhancing the aquatic plant community in Cedar Lake is necessary for protecting the health of the entire lake.

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