

Changes in the Aquatic Plant Community
of
Cedar Lake 1988-2000
and
Sensitive Area Designations

St Croix County, Wisconsin

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EXECUTIVE SUMMARY

Cedar Lake is a eutrophic lake with poor water quality. The lake supports a below average quality plant community with good species diversity. The most abundant plant growth occurs in the 1.5-5ft depth zone of Cedar Lake.

In Cedar Lake, 41% of the littoral zone supports some type of aquatic vegetation; the largest portion of the lake, which is deeper than 20ft, supports no vegetation.

The Cedar Lake aquatic plant community has undergone some dramatic changes. There has been a shift from a community dominated by **small pondweed - slender naiad - wild celery** to a community dominated by **slender naiad - coontail**. This results in a community with less structural diversity and less diversity of habitat.

The 1988 and 1991 aquatic plant community were not significantly different; from 1991 to 2000, each aquatic plant study recorded a plant community that was significantly different from the plant community in the previous study (only 55-58% similar). The 2000 aquatic plant community was more similar to the 1988 plant community (70%) than to the previous community in 1997. This suggests that the plant community is likely shifting back to a community more similar to the 1988 plant community.

Water quality in Cedar Lake has declined between 1986 and 2001; as nutrients and algae have increased. Declining water quality has likely been one factor in changes in the plant community:

Decreased

- 1) quality of the aquatic plant community (AMCIndex)
- 2) maximum rooting depth
- 3) total density and total occurrence of aquatic plants, especially at greater depths
- 4) occurrence of species that are associated with good water clarity

Increased

- 1) filamentous algae (four-fold)
- 2) increased disturbance tolerance (FQI)
- 3) abundance of plant species known to increase with excess nutrients

Management Recommendations

- 1) Pursue options for the removal or suppression of the carp population that are destroying plant beds and contributing to declining water clarity.
- 2) Increase natural shoreline by creating buffer zones of native vegetation. Disturbed land cover now covers more than half of the Cedar Lake shoreline; cultivated lawn alone covers 45% of the shore.
- 3) Designate and protect sensitive area on the lake that would protect areas on the lake critical for habitat and water quality protection.
- 4) Evaluate reasons for the ineffectiveness of the aeration system after its initial benefit to water clarity.

Changes in the Aquatic Plant Community of Cedar Lake, St. Croix County 1988-2000

I. INTRODUCTION

Studies of the aquatic plants (macrophytes) in Cedar Lake were conducted during July in 1988, 1991, 1994, 1997 and 2000 by Water Resources staff of the Western Central Region - Department of Natural Resources (DNR). Northern Lake Services, Inc. conducted macrophyte studies in August 1977 and July 1984 using a grid system of sampling points (Krueger 1984), so the results can not be directly compared to the Department of Natural Resources studies.

The DNR has collected water quality data on Cedar Lake since 1986.

Long term studies of the diversity, density, and distribution of aquatic macrophytes are ongoing and will 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.

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.

Cedar Lake has been impacted by algae blooms since the 1930's.

Copper sulfate treatments have been conducted in an attempt to reduce algae growth since the 1940's (Sorge and Engel 1989). Records indicate that at least 12,175 pounds of copper sulfate was applied to Cedar Lake (Appendix XVII). This figure is less than what was actually added because the amount of copper applied was not recorded in at least four different years.

Copper treatments for algae were recorded in 1947-1959, 1962, 1983-1986. Chemical treatments for submerged aquatic plants were conducted in 1971 and 1977 (Appendix XVII).

No treatments have occurred since 1988 and are not recommended in the future due to the ineffectiveness of the treatments. Copper sulfate treatments are very temporary.

In 1983, seven algae treatments were conducted during the growing season. 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.

- 1) Copper kills only the algae cells with which it comes in contact as it rapidly precipitates from the water.

- 2) The winds in Cedar Lake concentrate algae from untreated areas into treated areas soon after treatments.
- 3) Algae continue to reproduce as long as nutrient levels remain high and temperatures remain warm.
- 4) In many years, there have been insufficient submerged plant growth in Cedar Lake to compete with the algae for nutrients

The amount of copper sulfate added to Cedar Lake is of concern, since copper is toxic to aquatic insects (the food source of many game fish) and mollusks (the natural water filters in a lake).

In order to determine the source of the nutrients causing the algae blooms, studies of phosphorus inputs to Cedar Lake were conducted in 1986 and 1987. It was determined that a large amount of phosphorus was being recycled (Sorge and Engel 1989) in two ways.

- 1) **The large carp population:** Carp are bottom feeders that take up phosphorus rich organisms and excrete the phosphorus, thus recycling phosphorus within the lake.
- 2) **Release of phosphorus from lake sediments.** Cedar Lake stratifies weakly. During stratification, oxygen is depleted in the lower strata by decomposition organisms. This anoxic condition allows phosphorus in the sediment to be released back into the water. During windy conditions, the stratification breaks down, mixing phosphorus throughout the lake.

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).

Carp impact the water quality in three ways.

- 1) They recycle phosphorus as they feed.
- 2) They uproot and destroy plants that can compete with algae for nutrients. Carp uproot the plants to feed on the insects among the plant roots (McComas 1997). As the plants die they decompose and release more phosphorus.
- 3) Carp stir up the sediments as they feed and spawn.

A study was designed to measure carp damage to aquatic plants in Cedar Lake by caging selected plant beds. Results indicated that carp are responsible for plant damage. The plant beds protected by cages contained 2.9 times more plant material than the unprotected plant beds.

Attempts to remove carp have not been successful at this point.

II. METHODS

Field Methods

The same study design was used for the 1988, 1991, 1994, 1997 and 2000 macrophyte studies and was based primarily 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.

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.

Each species was given a density rating (0-5) based on the number of rake samples at each sampling site on which it was present.
A rating of 1 for each species present on one rake sample;
A rating of 2 for each species present on two rake sample;
A rating of 3 for each species present on three rake sample;
A rating of 4 for each species present on four rake sample;
A rating of 5 indicates that a species was abundant on all rake samples at that sampling site.)

The species recorded include aquatic vascular plants and several types of algae that have morphologies similar to vascular plants, such as muskgrass and nitella. The presence of filamentous algae was recorded. The sediment type at each sampling site was recorded.

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 verified by a second researcher and 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 plants present were collected and saved in a cooler for later preparation of voucher specimens. Nomenclature was according to Gleason and Cronquist (1991).

Data Analysis

The frequency and density data was analyzed separately for each year. The percent frequency of occurrence of each species was calculated (number of sampling sites at which it occurred/total number of sampling sites) (Appendices I-V). Relative frequency was calculated based on the number of occurrences of a species relative to all species occurrences (Appendices I-V).

The mean density was calculated for each species (sum of a species' density ratings/number of sampling sites) (Appendices VI-X). Relative density was calculated based on the density rating of a species relative to all plant densities (Appendices VI-X). A mean density where present was calculated for each species (sum of a species' density ratings/number of sampling sites at which it occurred) (Appendices VI-X). The relative frequency and relative density was summed to obtain a dominance value (Appendices XI-XV).

Simpson's Diversity Index was calculated for each sampling year (Appendices I-V). Each sampling year was compared by a Coefficient of Community Similarity (Table 8).

An Aquatic Macrophyte Community Index (AMCI), developed for Wisconsin lakes, was applied to Cedar Lake. Data in six categories that characterize the aquatic macrophyte community is converted to values 0 - 10 as outlined by Weber et. al. (1995).

Coefficients of Conservatism and Floristic quality (I) were used to evaluate the closeness of an aquatic plant community to an undisturbed condition (Nichols 1998). A Coefficient of Conservatism (C) 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 (\bar{C}) is the mean of the coefficients of conservatism for all species found in a lake. Floristic quality (I), calculated from the coefficients, is a measure of plant community's closeness to an undisturbed condition.

III. RESULTS

PHYSICAL DATA

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

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 levels in Cedar Lake have remained high, in the eutrophic range (Figure 1). Phosphorus levels increased through 1988, dropped in 1990 when the aeration system was installed, stayed at a relatively low level for four years, climbed again to a high in 1995, decreased slightly through 1998 and spiked to a record high in 1999.

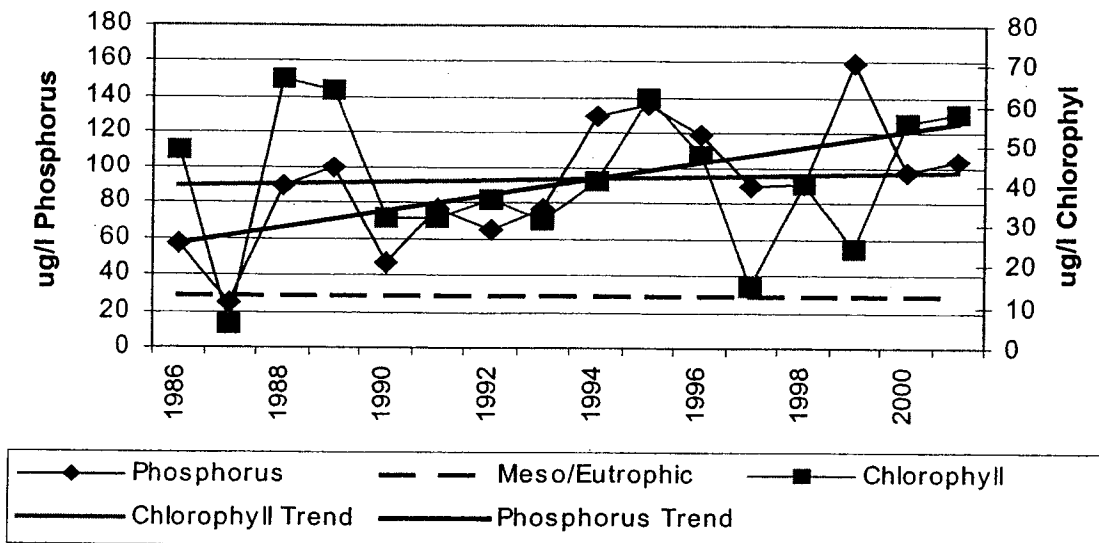


Figure 1. Summer mean phosphorus and chlorophyll in Cedar Lake.

Linear trend analysis indicates that the phosphorus has been increasing since 1986 (Figure 1).

Algae

In Cedar Lake, chlorophyll concentrations (which indicate the amount of algae) have also remained in the eutrophic range. The rise and fall of chlorophyll followed the change in phosphorus levels as the algae used the available phosphorus to reproduce. The exceptions were in 1997, in which the chlorophyll decreased more dramatically than the phosphorus, and in 1999, in which the chlorophyll decreased despite a dramatic increase in phosphorus (Figure 1).

Linear trend analysis indicates that the chlorophyll in Cedar Lake is increasing, although not as steeply as the phosphorus (Figure 1).

Water Clarity

Cedar Lake has poor water clarity. Mean summer water clarity in Cedar Lake, as measured with a Secchi Disc, is in the eutrophic range (Figure 2). The lowest clarity occurred in 1988, which coincided with a peak in phosphorus and algae. The best water clarity occurred in 1997. Linear trend analysis indicates that the summer mean water clarity has increased slightly since 1986 (Figure 2).

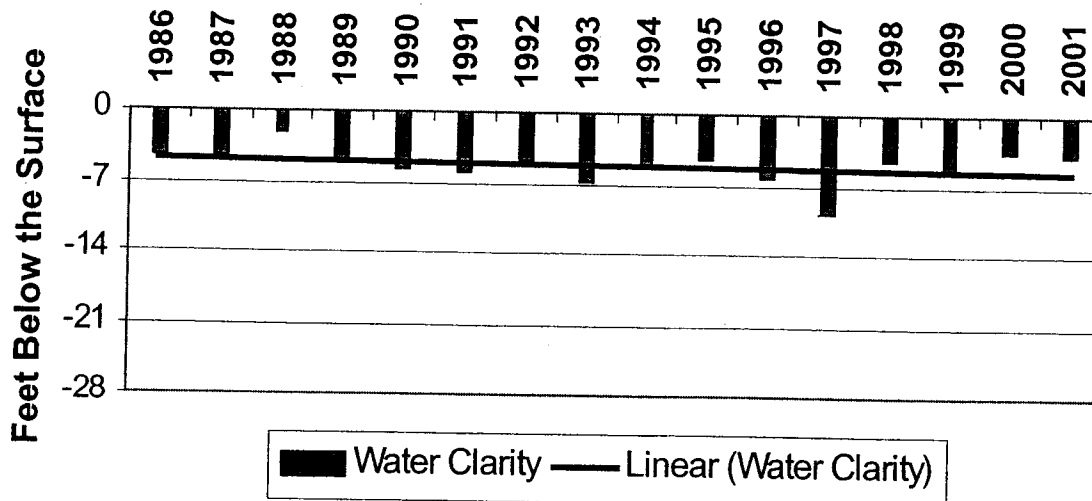


Figure 2. Mean summer water clarity in Cedar Lake, 1986-2001.

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.

Steve Frey's data was also analyzed for yearly trends. His data indicates year-to-year variations, but a gradual worsening of water clarity (Figure 3).

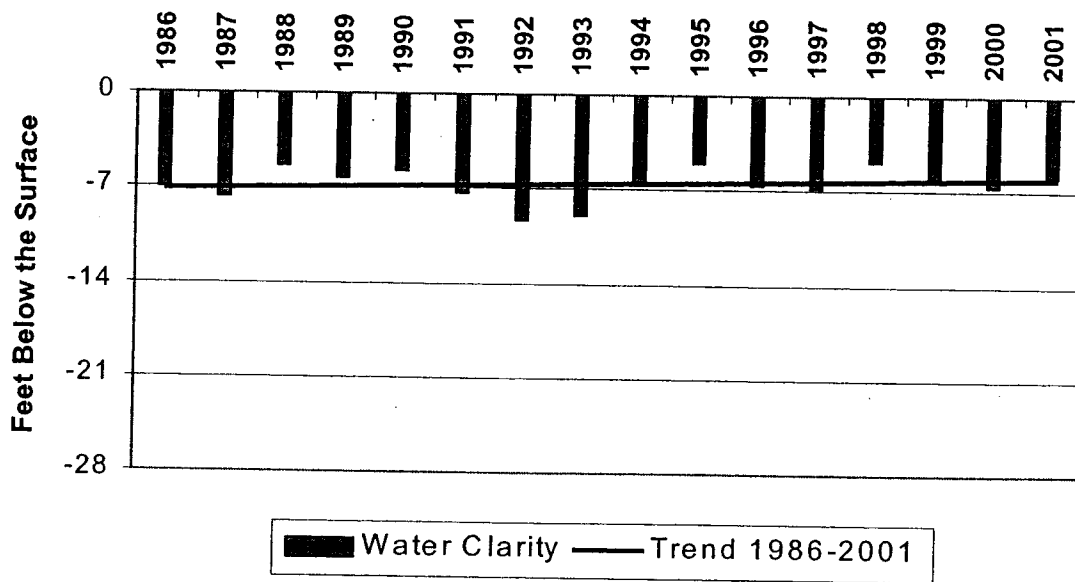


Figure 3. Change in mean water clarity 1986-2001, volunteer monitoring data.

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 4). 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 4).

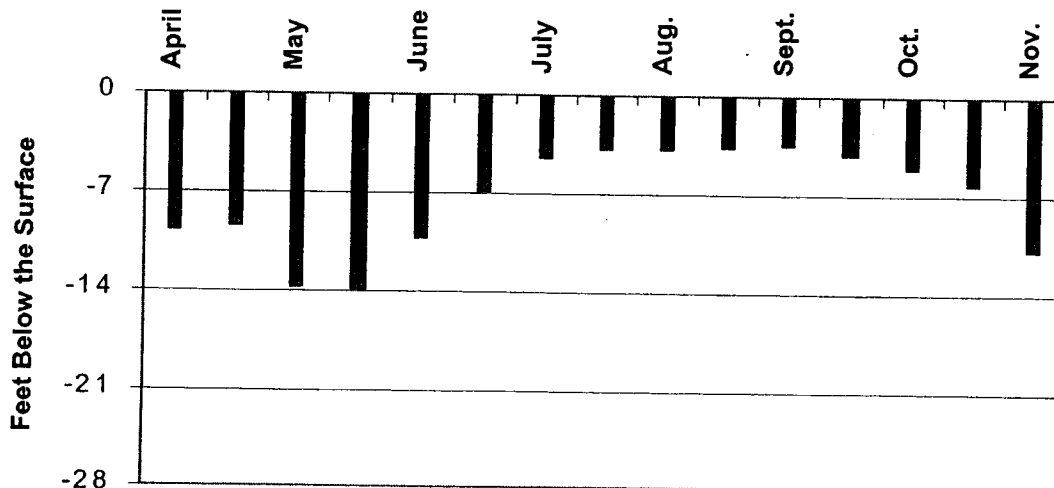


Figure 4. Change in mean water clarity during the season.

In Cedar Lake, the summer mean pH varies between 7.95 and 9.2. The pH varies as photosynthesis of plants and algae remove CO₂ from the water column. This would favor plants adapted to neutral and slightly alkaline water and limit the growth of plants adapted to more acidic waters.

The hardness values have remained fairly constant over the study period, varying between 110 and 135. Water in the range of 61-120 mg CaCO₃/l is considered moderately hard and in the range of 121-180mg CaCO₃/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

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

The most prevalent sediment type in Cedar Lake is sand. Rock type sediments are also common (Table 1), especially in the 0-5 ft depth zone. 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). Silt commonly occurs in the 5-10 ft depth zone, but overall is not a prevalent sediment in Cedar Lake.

Table 1. Sediment Composition by Depth Zone in Cedar Lake.

		0-1.5'	1.5-5'	5-10'	10-20'	Overall
Hard Sediments	Sand	33%	38%	42%	71%	45%
	Rock	33%	25%	17%	14%	22%
	Sand/rock	21%	21%	8%		13%
Mixed Sediments	Sand/silt	8%	12%	8%	9%	10%
Soft Sediments	Silt		4%	21%	5%	8%
	Muck/Silt	4%		4%		2%

The sediment data that has been recorded during the 1988-2000 plant studies have varied only slightly. Sand was the prevalent sediment in all years (Table 2). The percent of rock sediments recorded was less in 1991, but the sand/rock sediments were greater in 1991. Sediments with rock may have been recorded as sand/rock in that year due to the perception of the amount of sand by the researcher.

Muck and silt sediments recorded have also varied. This could be due to differences in the way different researchers distinguish silt and muck.

Table 2. Sediment Composition by Year, 1988-2000

		1988	1991	1994	1997	2000
Hard Sediments	Sand	43%	40%	39%	36%	45%
	Rock	35%	9%	22%	31%	22%
	Sand/rock	7%	35%	11%	12%	13%
Mixed Sediments	Sand/silt				9%	10%
Soft Sediments	Muck	14%	14%	6%	4%	8%
	Silt		2%	16%	9%	2%

Shoreline Land Use

Land use activities strongly impact the aquatic plant community. Practices on shore can directly impact the plant community through increased 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.

Cultivated lawn was the land cover that occurred at the transects most frequently and had the highest mean coverage in 1997 and 2000 (Table 3). The occurrence and mean coverage of cultivated lawn increased between 1997 and 2000 (41%-45%).

Rip-rap and hard structures also commonly occurred at the shoreline study sites. Rip-rap was found at half the sites (50%-46%) and hard structures at one-third (33%) of the sites (Table 3).

Natural shoreline cover types commonly occurred at the sites, but did not have a high coverage. Only wooded cover had a high coverage (33%), but wooded cover decreased in 2001 (23% mean coverage) (Table 3). The occurrence and mean coverage of wooded shoreline decreased between 1997 and 2000.

Table 3. Shoreline Land Use

		Frequency of Occurrence at Sites		% Mean Coverage	
		1997	2000	1997	2000
Disturbed Shoreline	Cultivated Lawn	62%	71%	41%	45%
	Rip-rap	50%	46%	4%	4%
	Hard Structures	33%	33%	4%	4%
	Pavement		8%		3%
	Eroded Soil		4%		1%
	Total Disturbed			49%	57%
Natural Shoreline	Wooded	54%	46%	33%	23%
	Native Herbaceous	58%	46%	15%	15%
	Shrub	21%	25%	2%	4%
	Total Natural			50%	42%

Some type of disturbed shoreline occurred at 63% of the sites in 1997, increasing to 75% of the sites in 2000. The mean coverage of disturbed shoreline increased from 49% in 1997 to 57% in 2000 (Table 4).

Natural shoreline occurred at 79% of the sites in 1997, decreasing to 75% of the sites in 2000. The mean coverage of natural shoreline decreased from 50% in 1997 to 42% in 2000 (Table 3).

MACROPHYTE DATA

Species Present

A total of 36 different species of aquatic macrophytes has been found over the four study years; 13 are emergents species, 5 are floating leaf species, and 18 are submergent species (Table 4).

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

Table 4. Cedar Lake Aquatic Plant Species

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

FREQUENCY OF OCCURRENCE

Najas flexilis, an annual species, was the most frequently occurring species in 2000. It had been one of the most frequently occurring species in 1988-1991, but declined dramatically in 1994-1997 (Table 5).

Table 5. Macrophyte Frequencies in Cedar Lake, 1988-2000

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

The frequency of *Potamogeton pusillus* has declined. It was the most frequent species in 1988, but has continued to decline every year (Table 5).

Elodea canadensis became the most frequent occurring species in 1994, subsequently declining dramatically in 1997-2000, to frequencies much lower than in 1988.

Ceratophyllum demersum had been the most frequent species in 1997, but has declined in 2000 a frequency comparable to its 1988-1991 frequencies (Table 5).

Filamentous algae has steadily increased.

10% of the sites in 1991

12% of the sites in 1994

24% of the sites in 1997

41% of the sites in 2000

Filamentous algae is more frequent at the shallower depths:

0-1.5 ft - 79%

1.5-5 ft - 54%

5-10 ft - 25%

DENSITY

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 (Table 6).

Table 6. Macrophyte Densities in Cedar Lake

<u>Species</u>	<u>1988</u>	<u>1991</u>	<u>1994</u>	<u>1997</u>	<u>2000</u>
<i>Najas flexilis</i>	1.22	1.18	0.14	0.05	0.39
<i>Ceratophyllum demersum</i>	0.38	0.40	1.24	0.48	0.28
<i>Elodea canadensis</i>	0.37	0.19	1.66	0.11	0.12

Elodea canadensis and *Ceratophyllum demersum*, the most frequently occurring species in 1994 and 1997, were also the species with the highest mean density in 1994-97 (Table 6).

DOMINANCE

Combining relative frequency and relative density to calculate a Dominance Value measures the dominance of each species within the plant community.

Based on the Dominance Values, the plant community has changed from year-to-year (Figure 5).

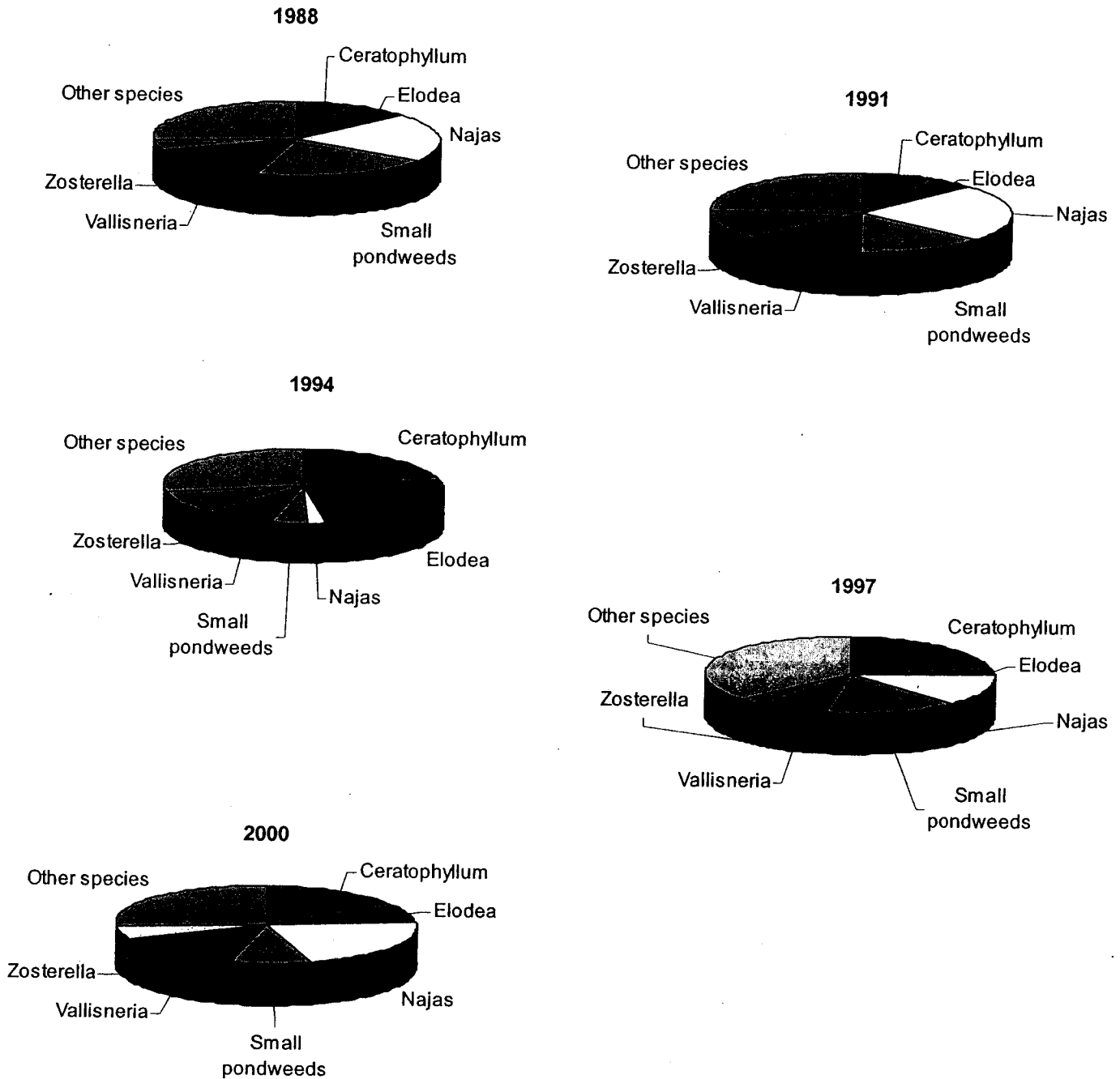


Figure 5. Change in macrophyte dominance in Cedar Lake.

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; a *Ceratophyllum demersum* dominated community in 1997; and a *Najas flexilis* - *Ceratophyllum demersum* dominated community in 2000.

The dominance of *Ceratophyllum demersum* and *Elodea canadensis* increased to a high in 1997 and 1994, then declined. The dominance of *V. americana* has been fairly constant except for a slight decline in 1994-97. The dominance of *Najas flexilis* and *P. pusillus* in the community has varied from year-to-year. The combined dominance of the other species in the community has been fairly constant except for an increase in 1997.

DISTRIBUTION

Vegetation was found in all depth zones. 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 (Figure 6).

The highest percent of vegetated sites over the whole littoral zone was in 1991-94 and the lowest percent of vegetated sites occurred in 1997-2000 (Figure 6).

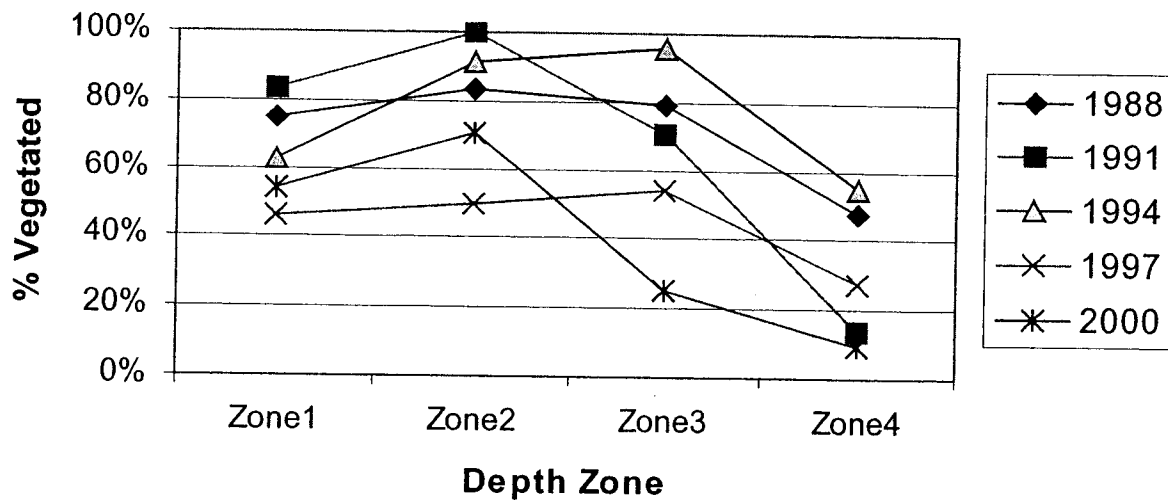


Figure 6. Percentage of littoral zone that is vegetated.

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 7, 8). Total occurrence and density of plant growth was higher during 1988-1994 and noticeably lower in 1997-2000 (Figures 7, 8).

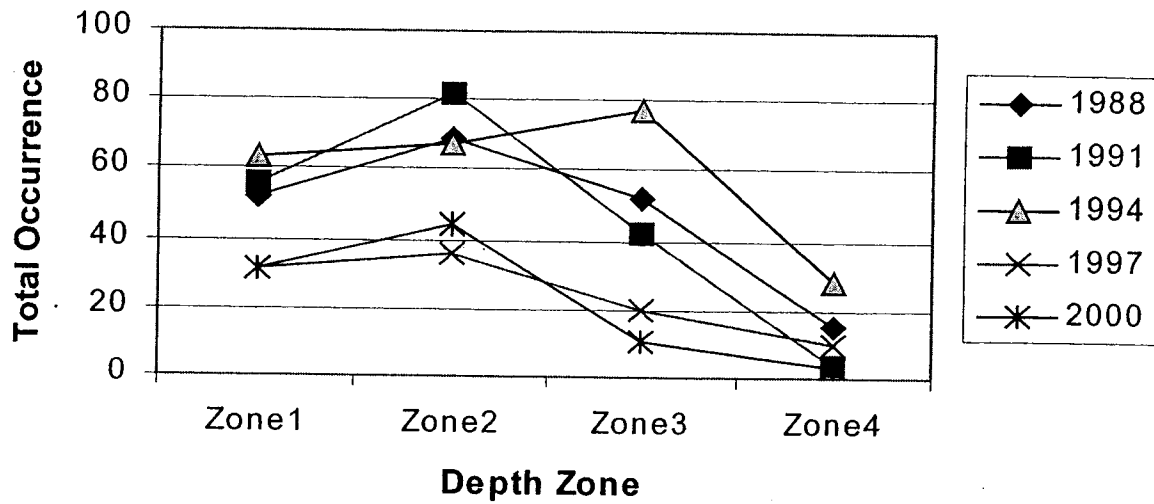


Figure 7. Total macrophyte occurrence by depth zone, 1988-2000.

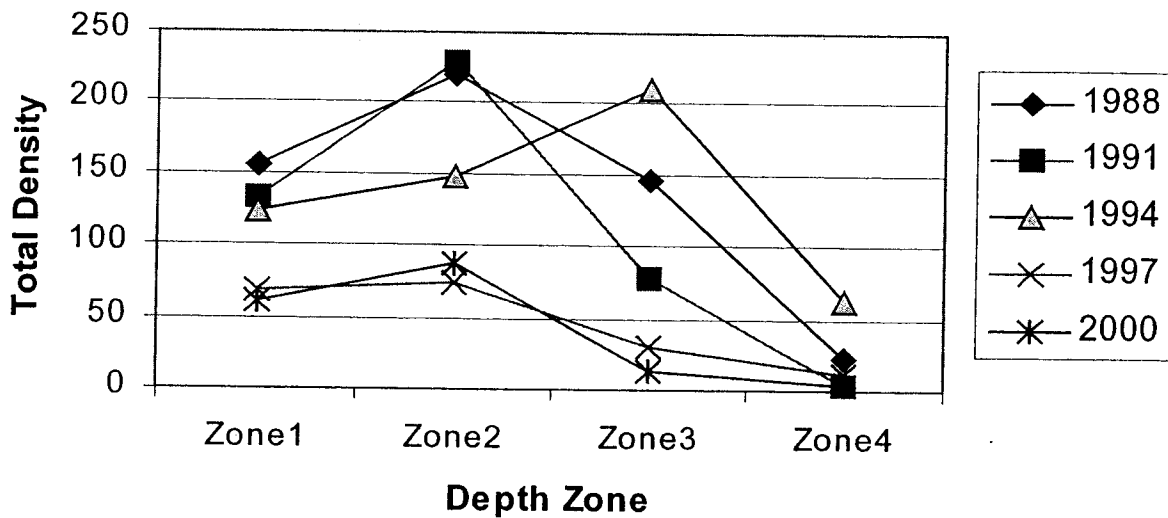


Figure 8. Total macrophyte density by depth zone, 1988-2000.

The most species per site has been found in the 1.5-5 ft. depth zone in all studies of the aquatic plants in Cedar Lake, except in 1994, 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 1997-2000 (Figure 9).

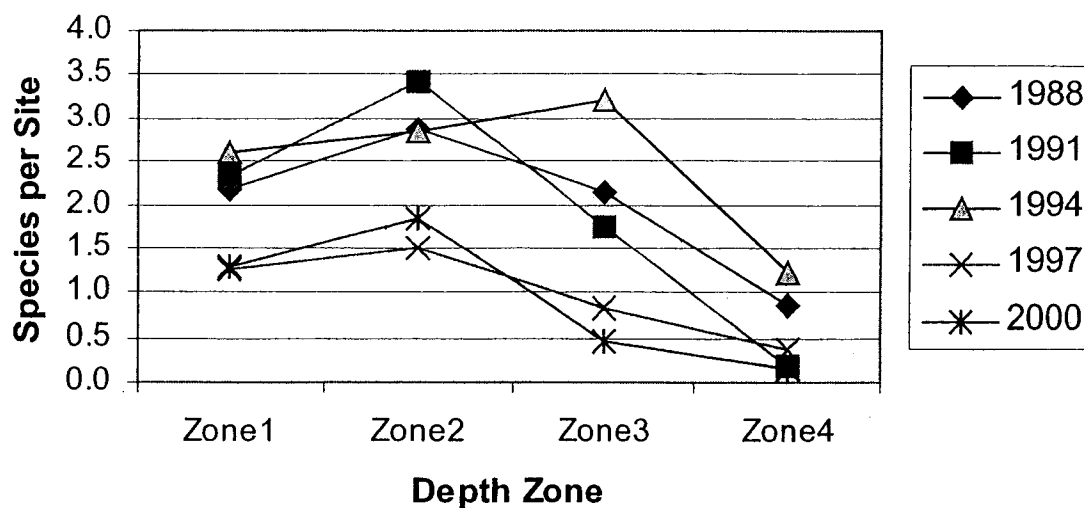


Figure 9. Species per site, by depth zone in Cedar Lake.

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 10, 11). Its frequency and density declined dramatically in 1994 and increased slightly in 2000.

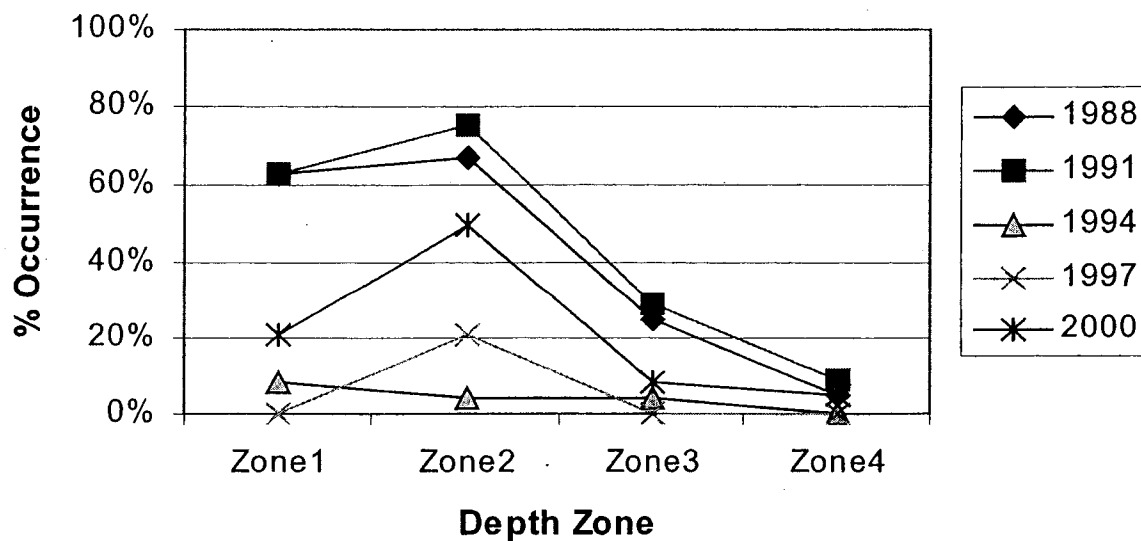


Figure 10. Frequency of *Najas flexilis* by depth zone.

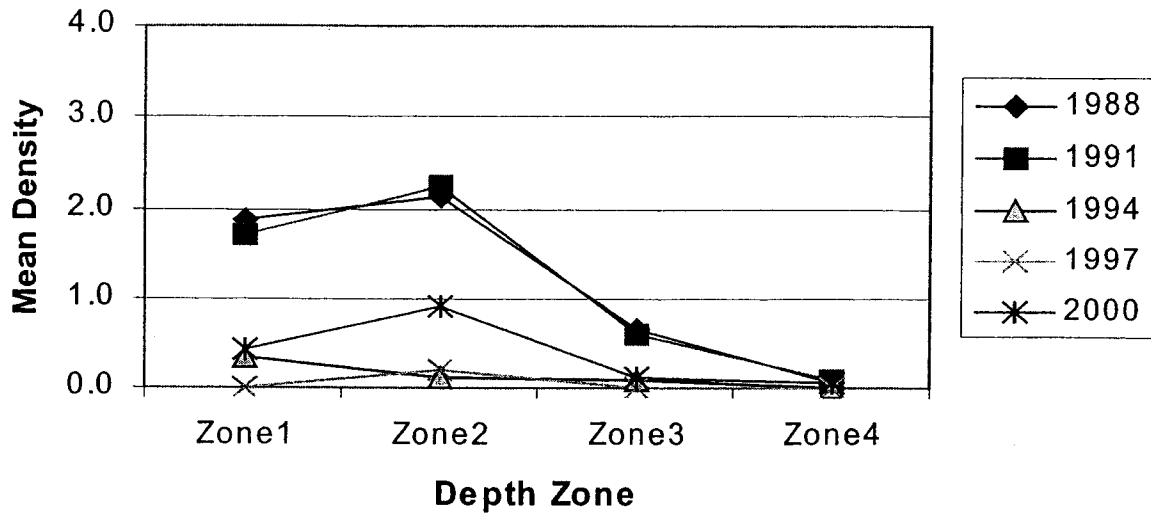


Figure 11. Density of *Najas flexilis* by depth zone.

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 and 2000 (Figure 12, 13).

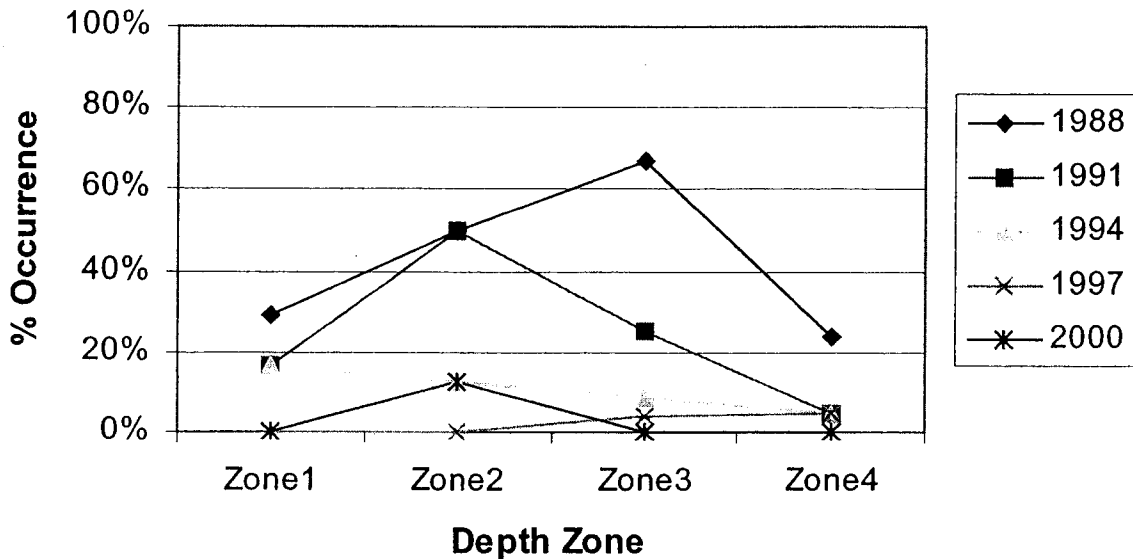


Figure 12. Frequency of *Potamogeton pusillus* by depth zone.

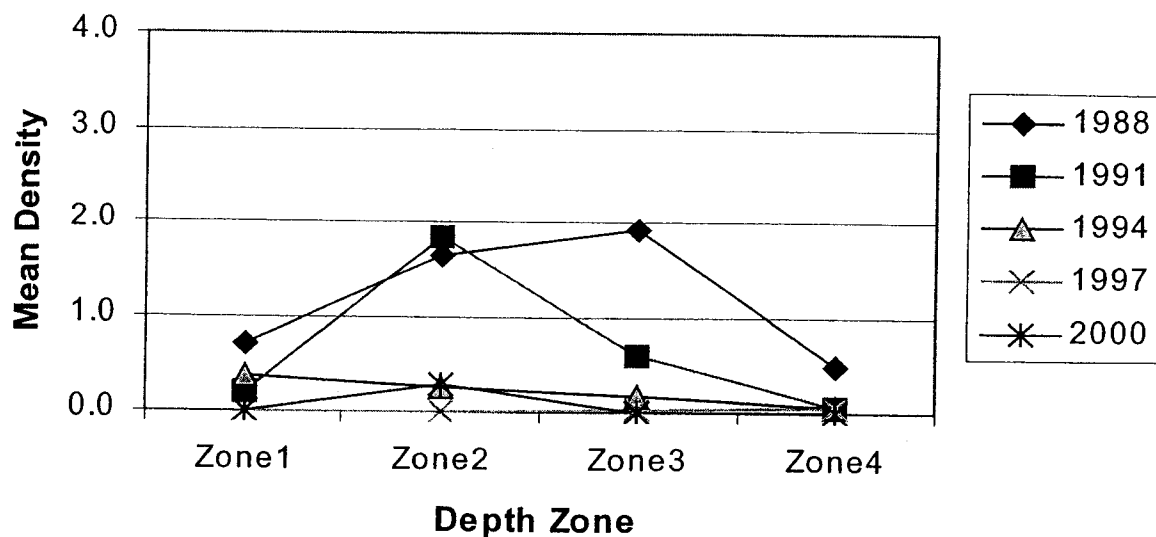


Figure 13. Density of *Potamogeton pusillus* by depth zone.

Ceratophyllum demersum and *Elodea canadensis* were found at moderate frequencies and densities in 1988 and 1991, but both increased in 1994, especially in the 5-10' depth zone, becoming the dominant species in all depth zones in 1994. In 1997, *Ceratophyllum demersum* was still the most frequent species in the 5-20ft depth zone and the most dense species in all depth zones (Figure 14, 15).

C. demersum had its highest frequency and density in 1994, especially in the 5-10' depth zone. In 1997-2000, its frequency and density in the plant community returned to previous levels (Figure 14, 15).

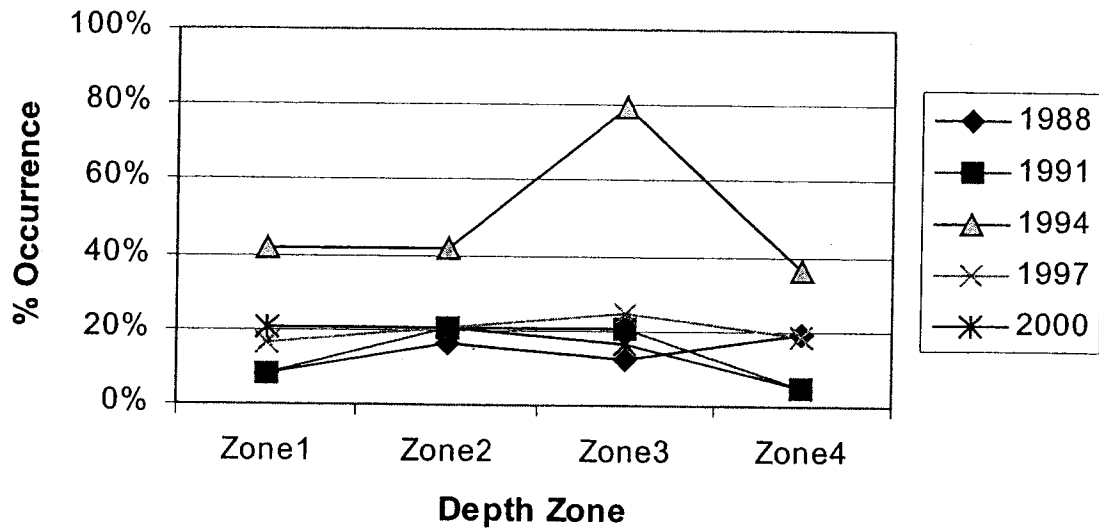


Figure 14. Frequency of *Ceratophyllum demersum* by depth zone.

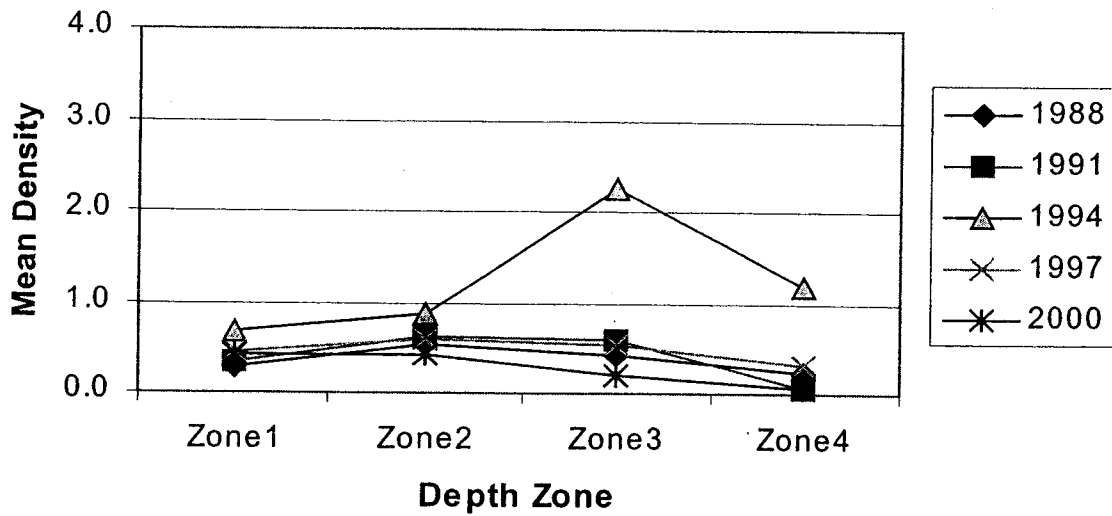


Figure 15. Density of *Ceratophyllum demersum* by depth zone.

Elodea canadensis had its highest frequency and density 1994, especially in the 5-10ft depth zone, and lowest in 1997-2000 (Figure 16, 17).

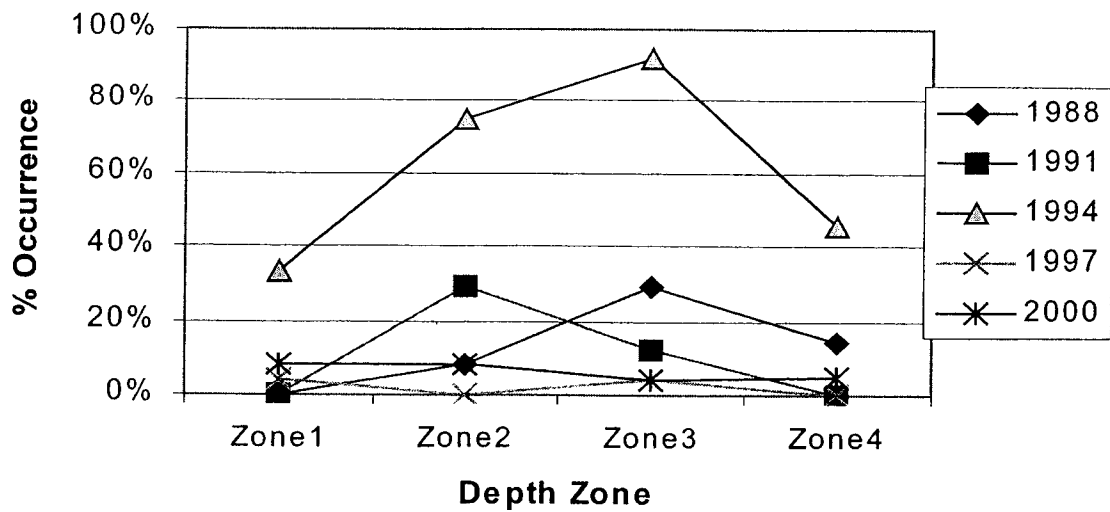


Figure 16. Frequency of *Elodea canadensis* by depth zone.

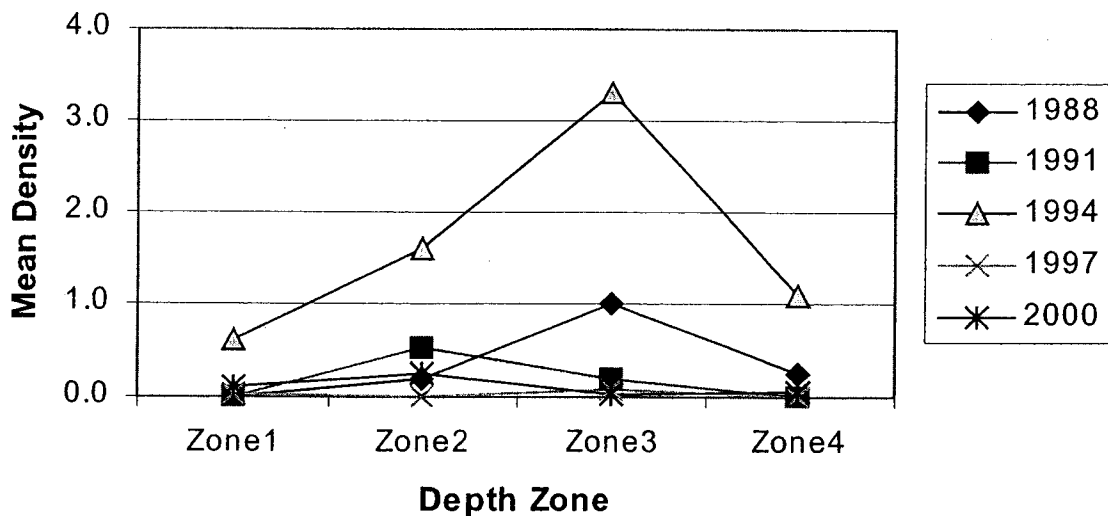


Figure 17. Density of *Elodea canadensis* by depth zone.

Sediment Influence

The availability of the mineral nutrients essential for plant growth is highest in sediments of intermediate density. Silt is an intermediate density sediment that is favorable for plant growth (Barko and Smart 1986).

Sand was the predominant sediment type at the sample sites

in Cedar Lake and one third of these sample sites were vegetated (Table 7). Sand and rock sediments are high density, hard sediments and not as favorable to plant growth (Barko and Smart 1986), but supported vegetation at 67% of the sites.

Silt, which was the least prevalent sediment type at sample sites in Cedar Lake, was vegetated at only 28% of the sites. The lower colonization by vegetation on silt is likely due to the location of silt sediments at depths greater than 5 feet. Light would be the limiting factor at this location.

Mixtures of silt, sand and rock were vegetated at 44% of the sites.

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

Table 7. Macrophyte Occurrence at Sediment Types, 2000.

		% Occurrence	% Vegetated
Hard Sediments	Sand	45%	33%
	Rock	22%	38%
	Sand/Rock	13%	67%
Mixed Sediments	Silt/sand or rock	10%	44%
Soft Sediments	Muck	8%	100%
	Silt	2%	28%

MACROPHYTE COMMUNITY

The Coefficients of Community Similarity indicate the percent similarity between two communities. The 1988 and 1991 aquatic macrophyte communities were 77% similar. This is interpreted as not significantly different.

The coefficients indicate that the aquatic plant community has changed from 1991-2000. There were significant differences between the 1991 and 1994 communities that were only 55% similar.

The 1994, 1997 and 2000 aquatic plant communities were all significantly different from each other, only 58% similar (Table 8).

Table 8. Coefficients of Community Similarity

Coefficient of Similarity		% Similar
1988-91	0.773	77.3%
1991-94	0.546	54.6%
1994-97	0.583	58.3%
1997-00	0.579	57.9%
1988-00	0.699	69.9%

This continual change in the plant community over the twelve years resulted in the 2000 plant community being only 70% similar to the 1988 community (Table 8). Although this coefficient indicates a significant difference between these first plant survey and the most recent, the coefficient indicates a closer similarity than during 1991-2000. This suggests that some of the change that took place is likely a return to the 1988 plant community.

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

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 good plant diversity that has been stable, but was slightly higher in 1997 (Table 9).

Table 9. Changes in the Macrophyte Community

	1988	1991	1994	1997	2000	Change 1988-00	%Change 1988-00
Number of Species	17	22	23	23	17	0	0.0%
Maximum Rooting Depth	12.0	11.5	13.0	13.0	11.0	-1	-8.3%
% of Littoral Zone Vegetated	70%	68%	76%	55%	41%	-0.3	-41.4%
%Sites/Emergents	2%	4%	4%	3%	2%	0.0	0.0%
%Sites/Free-floating	12%	14%	50%	19%	15%	0.0	25.0%
%Sites/Submergents	64%	64%	70%	37%	33%	-0.3	-48.4%
%Sites/Floating-leaf	2%	5%	7%	5%	6%	0.0	200.0%
Simpson's Diversity Index	0.87	0.88	0.87	0.90	0.88	0.01	1.1%
Floristic Quality	20.27	23.03	22.39	23.45	19.40	-0.87	-4.3%

The maximum rooting depth of macrophytes has been fairly stable, slightly less in 2000 (Table 8). Species found at the maximum depths have been *Elodea canadensis*, *Myriophyllum sibiricum*, *Najas flexilis*, *Potamogeton pusillus*, *P. richardsonii*) and *Vallisneria americana*. The maximum rooting depths have been greater than the expected maximum rooting depths based on water clarity. This may be due to the good water clarity early in the year when macrophytes are starting their growth.

The percent occurrence of emergent species has remained fairly stable.

Changes in the aquatic plant community in Cedar Lake include:

The number of species found at the sample sites has increased from 1988-1997, but decreased in 2000.

The percent of littoral zone that is vegetated has decreased, most dramatically in 1997-2000.

The percent occurrence of floating-leaf and free-floating species has increased slightly. The highest percent was in 1994.

The percent occurrence of submergent species declined, most dramatically in 1997-2000.

The Floristic Quality Index, as discussed later in this document, has declined, indicating increased disturbance in the plant community (Table 9).

The predicted maximum depth to which aquatic plants can survive in a lake is calculated from the Secchi disc clarity (Dunst 1982). The actual maximum rooting depth has been greater than the predicted rooting depth. This is likely due to plant growth starting and becoming established early in the year when water clarity is greater, before algae blooms begin.

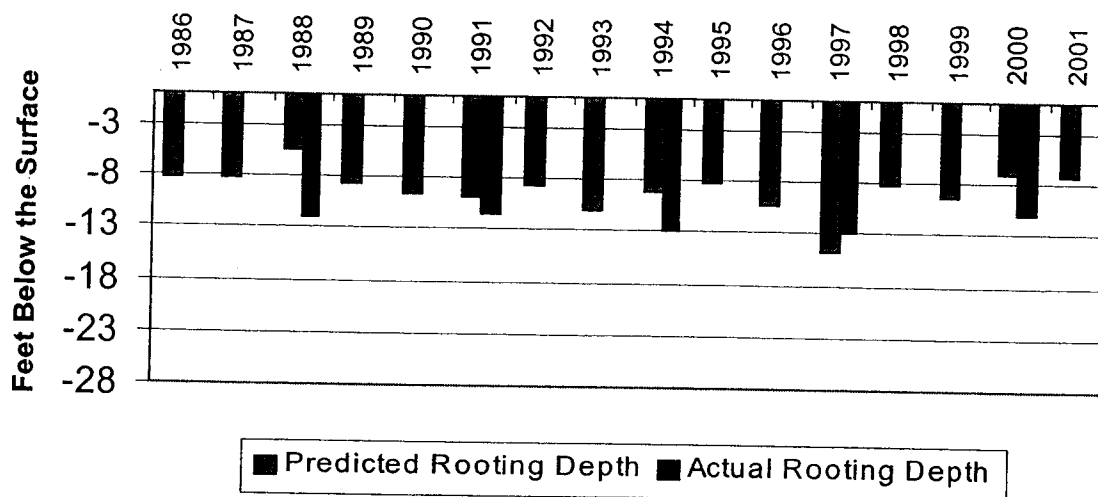


Figure 18. Predicted maximum rooting depth and actual rooting depth in Cedar Lake, 1986-2001.

According to the Aquatic Macrophyte Community Index (AMCI), (Weber et. al. 1995), the aquatic community in Cedar Lake is of average quality. The quality increased in 1991-1997, but declined in 2000 to slightly below average quality (Table 10). The decrease in quality was due to decreases in maximum rooting depth, percent colonization by vegetation in the littoral zone and the number of species.

Table 10. Aquatic Macrophyte Community Index for Cedar Lake.

	1988	1991	1994	1997	2000
Maximum rooting depth	6	6	8	8	6
% Littoral zone vegetated	10	10	10	8	8
Simpson's Diversity Index	9	9	9	10	9
Relative frequency of submersed species	6	10	7	7	7
Relative frequency of sensitive species	0	0	0	0	0
# of taxa (reduced by exotics)	5	7	7	7	5
Total	36	42	41	40	35

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

Two species were not found in 2000 that had been found in all previous surveys at more than a few sites: *Myriophyllum sibiricum*, *Potamogeton richardsonii*. *M. sibiricum* has been declining since its highest frequency and density in 1994; *P. richardsonii* has been declining since 1988.

Potamogeton pusillus has declined 81-94% (Appendix XVI). Other species that have declined by more than 50% in frequency or density are: *Chara*, *Elodea canadensis*, *Najas flexilis*, *Potamogeton crispus*, *P. nodosus*, *P. pectinatus*, *Vallisneria americana*, *Zosterella dubia*.

Spirodela polyrhiza has had the greatest increase in frequency or density. Other species that have increased are: *Lemna minor*, *Nymphaea odorata* (Appendix XVI).

The 1988 - 2000 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 11). Cedar Lake is located in the Northern Central Hardwood Region (NCHR).

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. This is likely the result of being subjected to more disturbance.

Table 11. Mean Coefficient of Conservatism and Floristic Quality of Cedar Lake, Compared to Wisconsin Lakes and Region Lakes.

	(C) Average Coefficient of Conservatism †	(I) 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	4.82	21.37
1997	5.05	23.67
2000	4.76	19.65

* 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)

The Floristic Quality Index (FQI) for Cedar Lake was above the mean for lakes in the North Central Hardwoods Region in 1988-1997, but below the mean in 2000. Compared to all Wisconsin lakes, the FQI for Cedar Lake was below the mean in 1988, above the mean in 1991-97 and below the mean in 2000.

This suggests that the plant community in Cedar Lake has been slightly above average in its closeness to an undisturbed condition for lakes in the state and in the Northern Central Hardwood Region. However, the FQI in 2000 suggest that disturbances on Cedar Lake have increased from 1997 to 2000 and it is now below average in its closeness to an undisturbed condition.

Disturbances can be of many types:

- 1) Direct disturbances to the plant beds result from activities such as boat traffic, plant harvesting, chemical treatments, the placement of docks and other structures.
- 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.

V. DISCUSSION

Based on the water clarity and chlorophyll and phosphorus concentrations, Cedar Lake is a eutrophic lake with poor water clarity. Trend analysis indicates that the chlorophyll and phosphorus have been increasing and the water clarity (according to both DNR and volunteer data) has been decreasing since 1986. The water clarity changes dramatically during the open water season.

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 12,175 pounds of copper sulfate has added more than 3068 pounds of elemental copper to the lake. This is more than 2 $\frac{3}{4}$ pound of pure copper per acre on the sediments of Cedar Lake, but 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 the toxicity of copper to important members of the aquatic food chain. Aquatic insects are sensitive to copper; copper is toxic to mollusks, such as clams and snails.

Cedar Lake has had an aquatic plant community of below average quality and good diversity that has varied from year-to-year in the amount of plant growth.

The eutrophic status, hard water and broad, gently sloped littoral zone would favor abundant plant growth. The poor clarity and predominance of sediments low in organic content (sand and rock) could limit plant growth.

The highest percent of vegetated sites, the greatest number of species per site and the highest total occurrence and density of vegetation was in the 1.5-5ft depth zone in 1988-1991, shifted into the 5-10ft depth zone in 1994 and shifted back to the 1.5-5ft depth zone in 1997-2000. The shift of the plant community, which is the habitat for the lake, into the shallow depth zones shifts the aquatic habitat into the areas of the lake which are more prone to disturbance and wide temperature variations.

Changes

The aquatic plant community in Cedar Lake has undergone changes. Starting in 1991, each succeeding plant study revealed a plant community significantly different from the previous, each only 55-58% similar. The plant community in 2000 was 70% similar to the 1988 plant community. Although this is still significantly different, the 2000 aquatic plant community is more similar to the 1988 than the 1997 and suggests some of the changes are changes back to the 1988 condition.

There have been changes in the structure of the plant community. Based on the Floristic Quality Index, there was an decrease in disturbance in 1991-97 and an increase in disturbance in 2000.

There have been changes in individual aquatic plant species.

The species that has undergone the most noticeable decrease was *Potamogeton pusillus*. It was the dominant species in 1988 and decreased steadily, starting in the deeper zones first, until becoming a rare species in 2000. During the same time period, *Ceratophyllum demersum* increased, most dramatically in the 5-10ft-depth zone.

Najas flexilis decreased during 1994-97 and partially recovered in 2000. *Elodea canadensis* had an opposite pattern, increasing in 1994 and dramatically decreasing in 1997 and 2000.

The decline of all eight species of *Potamogeton* (pondweeds) (Appendix XVI) is disturbing because of their important contributions to fish and waterfowl habitat.

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.

There has been a change in the amount of plant growth. The highest percent of vegetated sites, greatest number of species and highest total occurrence and highest total density of plants was in 1991-94. The lowest percent of vegetated sites, lowest number of species per site, lowest total occurrence of plants and lowest total density of plants was recorded in 1997-2000.

The amount of littoral zone that is vegetated is adequate for habitat, 25-85% of the littoral zone, but the decline of the aquatic vegetation is of concern. Continued loss of aquatic plant habitat could eventually lead to inadequate habitat.

In 1994, the number of species, the diversity index, the percent of vegetated sites and the percentage of sites with submerged vegetation all increased. In 2000, the number of species, the maximum rooting depth, the percent of vegetated sites and the percent of sites with submergent vegetation have all declined.

Filamentous algae has increased in Cedar Lake, from 10% of the sites in 1991 to 41% of the sites in 2000.

The aeration system that was installed in 1990 to reduce the release of nutrients from the sediments, appeared to provide improvements. 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 and 2000.

Reasons

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

- 1) Disturbed shoreline increased from 1997 to 2000 and

- covered more than half the shoreline in 2000.
- 2) Nutrients (phosphorus) are being recycled from the sediments during anoxic conditions and from the carp population (Sorge and Engel 1989)
 - 3) Broad-spectrum herbicides applied in the past non-selectively kill all plant species. Unfortunately, less desirable plant species usually colonize areas recently cleared of plant growth. The reduction in plant growth can result in increased algae growth.
 - 4) The carp are sources of additional disturbance when they stir up sediments and uproot plants (McComas 1997).

COMPARISON WITH 1977 AND 1984 NORTHERN LAKE SERVICE STUDIES

Of the 36 aquatic plant species recorded in the DNR studies, 19 aquatic macrophyte species were recorded in 1977 (Krueger 1984) and 17 were recorded in 1984. Two species occurred in the 1977 and 1984 studies that were not recorded by the DNR:

Potamogeton hillii and *Sagittaria cristata*. *P. hillii* is a special concern species that has only been confirmed by herbarium specimens only in the northeast corner of Wisconsin. *S. cristata* is a rosette-form arrowhead. Arrowheads are difficult to identify to species in vegetative stages.

The noticeable difference between the DNR and Northern Services species lists is the emergent species. The DNR studies recorded 13 emergent species and the Northern Services studies recorded only 3. The grid placement of sample sites may have undersampled the shallow water community.

In both 1977 and 1984, *Najas flexilis* and *Vallisneria americana* were the dominant species. This compares well with the dominance of species in the DNR studies. *Najas flexilis*, *Potamogeton pusillus* and *Vallisneria americana* were the dominant species in 1988 and 1991.

In 1977, the most frequently occurring species was *Vallisneria americana*; *Lemna minor* had the highest mean densities.

In 1984, the most frequently occurring species was *Najas flexilis*; *Lemna minor* and *Spirodela polyrhiza* had the highest mean densities.

VI. CONCLUSIONS

Cedar Lake is a eutrophic lake with poor water quality. The lake supports a below average quality plant community with good species diversity. The most abundant plant growth occurs in the 1.5-5ft depth zone of Cedar Lake.

A healthy aquatic plant community plays a vital role within the lake ecosystem. Healthy macrophyte 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.

- 1) Plants start the food chain that supports many levels of wildlife
- 2) Produce oxygen needed by animals
- 3) Used as food and cover by a variety of wildlife
- 4) Provide food, cover, and spawning sites for fish

Compared to non-vegetated lake bottoms, macrophyte 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 41% of the littoral zone (the area of the lake less than 20ft deep) supports any type of aquatic vegetation; the large area greater than 20ft supports no vegetation.

Changes in the Aquatic Plant Community

The Cedar Lake aquatic plant community has undergone some dramatic changes. There has been a shift from a community dominated by *Potamogeton pusillus* - *Najas flexilis* - *Vallisneria americana* to a community dominated by *Najas flexilis* - *Ceratophyllum demersum*.

From 1991 to 2000, each aquatic plant study recorded a plant community that was significantly different from the plant community in the previous study (only 55-58% similar). The 2000 aquatic plant community was more similar to the 1988 plant community (70%) than to the previous community in 1997. This suggests that the plant community is likely shifting back to a community more similar to the 1988 plant community.

There have been other changes from 1988 to 2000 that suggest a decline in water quality and decline in the quality of the aquatic plant community.

- 1) The increase in nutrients has resulted in increased algae and decreased water clarity that has likely stressed the plant community.
- 2) Filamentous algae has increased four-fold.

- 3) There has been an increase in disturbance tolerance (FQIndex), which suggests an increase in disturbance to the plant community in Cedar Lake.
- 4) Decrease in the quality (AMCIndex) of the Cedar Lake plant community
- 5) Decreased maximum rooting depth
- 6) Decrease in the amount of aquatic vegetation and the colonization of aquatic vegetation and submerged vegetation.

The decrease in colonization of aquatic vegetation, especially submergent vegetation, is a concern if the decrease continued to the point that it provided inadequate habitat. In addition, the shift of the aquatic plant community into shallower water, places the habitat in the area of greatest disturbance.

Increased nutrients and decreased clarity as a major factor causing changes in the plant community is supported by specific changes.

- 1) Of the five species that have increased from 1988 to 2000, four species (*Ceratophyllum demersum*, *Lemna minor*, *Nymphaea odorata*, *Spirodela polyrrhiza*) have been known to grow to overabundance when there is an excess of nutrients or other disturbances in a lake (Nichols and Vennie 1991).
- 2) Of the twelve species that have declined, five are associated with good water clarity: *Najas flexilis*, *Potamogeton richardsonii*, *Scirpus americanus*, *S. validus*, *Chara* sp.
- 3) The dramatic decline of *Potamogeton pusillus* first appeared in the deeper depth zones.
- 4) The maximum rooting depth has decreased.

Management Recommendations

Steps need to be taken to reduce nutrient levels in order to improve the water clarity and the aquatic plant community.

- 1) Pursue options for the removal or suppression of the carp population that are destroying plant beds and contributing to water turbidity.
- 2) Increase natural shoreline by creating buffer zones of unmown native vegetation. Disturbed shoreline now covers more than half of the Cedar Lake shore. Cultivated lawn alone covers 45% of the shore. This is an insufficient amount of natural shoreline to protect the water quality of the lake. In addition, cultivated lawn may be adding nutrients to the lake.
- 3) Designate sensitive area on the lake that would protect areas on the lake that have not yet been disturbed. Initial proposals for sensitive areas based on aquatic plant communities have been mapped (Appendix XVII) and should be delineated during the summer of 2002.
- 4) Evaluate reasons for the ineffectiveness of the aeration system after its initial benefit to water clarity. Many of the declines that have been seen in the Cedar Lake aquatic community showed improvements after the aeration

system was first installed in 1990. After a time period, these conditions returned to conditions similar to or worse than conditions prior to the installation.

- a) After the installation of the aeration system, phosphorus concentrations in the water decreased, planktonic algae growth decreased and water clarity increased.
- b) 1991-97 the disturbance in the plant community decreased
- c) 1991-94 plant growth increased
- d) 1994-97 the number of plant species and the maximum rooting depth of plants increased
- e) 1994 the zone of most abundant plant growth shifted from the 1.5-5 ft depth zone into the 5-10ft depth zone

All of these changes have reverted to the pre-aeration condition.

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

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