Executive Summary

Squaw Lake has been a hypereutrophic, 129-acre natural seepage lake with very poor water quality and water clarity. High nutrient levels support the growth of abundant planktonic and filamentous algae. However, since 1986, the concentration of phosphorus (nutrients) and chlorophyll (algae) have decreased.

Lemna minor (duckweed) was the dominant species in 2005, dominating all depth zones and exhibiting a growth form of above average density. *Typha latifolia* (cattail) was sub-dominant. Aquatic plant growth is sparse, colonizing only 4% of the total lake area and 36% of the littoral zone. The 0-1.5 ft. depth zone supported the most abundant plant growth, reflecting the poor clarity. The aquatic plant community is characterized by poor species diversity, low quality, a high tolerance to disturbance and a condition far from an undisturbed condition.

The aquatic plant community has undergone significant change during 1986-2005 as measured by Coefficients of Community Similarity. Overall, there were increases in the number of species, the percentage of vegetated sites, the coverage of emergents, the coverage of free-floating-species, the coverage of submergent, the quality of the plant community, the diversity of species, the community's tolerance to disturbance and its closeness to an undisturbed condition. Species Richness increased the most. However, from one study to the next, these parameters varied up and down.

These changes may be due to the fluctuating water levels in Squaw Lake; plant growth can not immediately adjust to new water levels. This is likely the reason that the actual maximum rooting depth in Squaw Lake has fluctuated above and below the predicted maximum rooting depth. In years with high water levels, the lake supported greater total occurrence of aquatic plants, total density of plants, diversity of species and species richness. The plant community was closer to an undisturbed condition then also. Years of low water levels saw a reverse in all of these parameters.

Management Recommendations

1) Lake District cooperate with nutrient management programs in the watershed.
2) Lake residents discontinue any lawn fertilizer on lakeshore properties.
3) Lake residents maintain septic systems.
4) Lake residents protect and expand natural shorelines that benefit water quality and wildlife habitat. The lower Average Coefficient of Conservatism, lower Floristic Quality Index and higher frequency and density of disturbance tolerant species at disturbed shoreline sites indicate lawn and hard structure has impacted the aquatic plant community. This does impact the habitat through a lower percentage of vegetated sites and lower cover of submergent vegetation at disturbed sites.
    a) Continue monitoring of the shoreline restoration demonstration sites.
    b) Expand the shoreline restoration projects to include more participants.
    c) Reduce the amount of cultivated lawn near the shore and allow buffer zones of native vegetation to develop.
    d) Re-vegetate eroded areas.
    e) Minimize the placement of hard structures and surfaces on the shore.

Changes in the Aquatic Plant Community of Squaw Lake 1986-2005

I. INTRODUCTION

Studies of the aquatic macrophytes (plants) in Squaw Lake were conducted during July in 1986, 1989, 1992, 1995, 1998, 2001 and August 2005 by Water Resources staff of the Western Central Region – Wisconsin Department of Natural Resources (DNR). The surveys are conducted as part of a statewide Long Term Trend Study. Aquatic plant data is collected every three years and water quality data is collected every year on these trend lakes.

Long term studies of the diversity, density, and distribution of aquatic plants are ongoing and will provide information that will be 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

Squaw Lake is a 129-acre seepage lake, located in western St. Croix County. The lake is 0.2 miles wide and 1.2 miles long with a maximum depth of 32 feet and mean depth of 13 feet. The lake has no outlet and an intermittent inlet.

The Squaw Lake watershed encompasses 1,967 acres and is composed of 61% cropland, 27% woodland, wetland and natural areas, 8% pasture and 2% residential development (Hess et. al. 1997). The watershed to lake ratio is 15:1; lakes with watershed area/lake size ratios greater than 10:1 tend to have water quality problems (Field 1994).

History

Squaw Lake has experienced problems with algae blooms for many years. Copper sulfate was applied annually from 1969-1984 (except 1980) to kill the algae. Almost 7000 pounds of copper sulfate were added to the lake during this 15-year period. In 1985, the lake residents decided to discontinue copper sulfate treatments because of the inability of copper to produce any long-lasting improvements in water quality and its toxicity to aquatic invertebrates and zooplankton (an important food source for fish) and mollusks (clams and snails that are natural consumers of algae).

A watershed and lake management study was conducted to determine the sources of phosphorus contributing to the algae growth in Squaw Lake. The two leading sources of phosphorus in Squaw Lake's watershed were the winter-spreading of manure (42%) and cropland run-off (41%) (Hess et. al. 1997). Recycling from the lake sediment was another important source, contributing 11% of the total phosphorus load (Sorge 1991).

Since 1951, the water levels in Squaw Lake have fluctuated as much as 8 feet (Hess et. al. 1997). In 1987, drought caused a 3-4 foot drop in the lake level. As the water receded, smartweed began dominating the shore of newly exposed lake sediment. In 1989-90, rising water levels flooded the smartweed and other newly colonized emergents. In 1998, the water level had dropped again in 2001 and dropped again in 2005.

II. METHODS

Field Methods

The same study design and transects were used for the 1986-2005 aquatic plant studies and was based on the rake-sampling method developed by Jessen and Lound (1962). Twenty-eight equal-distance transect were placed perpendicular to the shoreline with the first transect being randomly placed (Appendix XXII).

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

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

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

The presence of filamentous algae and the sediment type was recorded at each sampling site. 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' x 30' rectangle was assessed.

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 data for each year was analyzed separately and compared. 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-VII). Relative frequency was calculated (number of occurrences of a species/sum of all species occurrences) (Appendices I-VII). The mean density was calculated for each species (sum of a species' density ratings/number of sampling sites) (Appendices VIII-XIV). Relative density was calculated (summed density rating of a species / sum of all plant densities) (Appendices VIII-XIV). A "mean density where present" was calculated for each species (sum of a species' density ratings/number of sampling sites at which it occurred). The relative frequency and relative density were summed to obtain a dominance value (Appendices XV-XXI). Simpson's Diversity Index (1-sum(relative frequencies)^2) was calculated for each sampling year (Appendices I-VII). Each sampling year was compared by a Coefficient of Community Similarity, which measures the percent similarity between two communities.

The Aquatic Macrophyte Community Index (AMCI) was calculated. Seven parameters that characterize the aquatic plant community (Table 12) are measured and the data for each is converted to a value 0 - 10 as outlined by Nichols. (2000).

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

III. RESULTS

PHYSICAL DATA

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

WATER QUALITY

The trophic state of a lake can be determined by combining data that measures nutrient and algae concentrations and water clarity.
Oligotrophic lakes have low nutrients and biomass.
Eutrophic lakes are high in nutrients and biomass, experiencing frequent algal blooms.
Mesotrophic lakes are intermediate in nutrients and biomass.

Nutrients

Phosphorus is the limiting nutrient in many Wisconsin lakes. This means that the addition or reduction of phosphorus is the nutrient that will have the most impact on water quality. Therefore, phosphorus is measured as an indication of the nutrient status of a lake.
2005 Mean summer phosphorus in Squaw Lake was 166 ug/l.
This concentration of phosphorus is in the hypereutrophic range (Table 1).

Table 1. Trophic Status, 2005

	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**
Squaw Lake –2005 DNR and Volunteer Data	Good	166	94.6	2.8 (Volunteer data)

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

The phosphorus concentration in Squaw Lake has fluctuated widely 1986-2005, but have remained within the eutrophic or hypereutrophic range (Figure 1). Trend analysis indicates that phosphorus has declined since 1986.

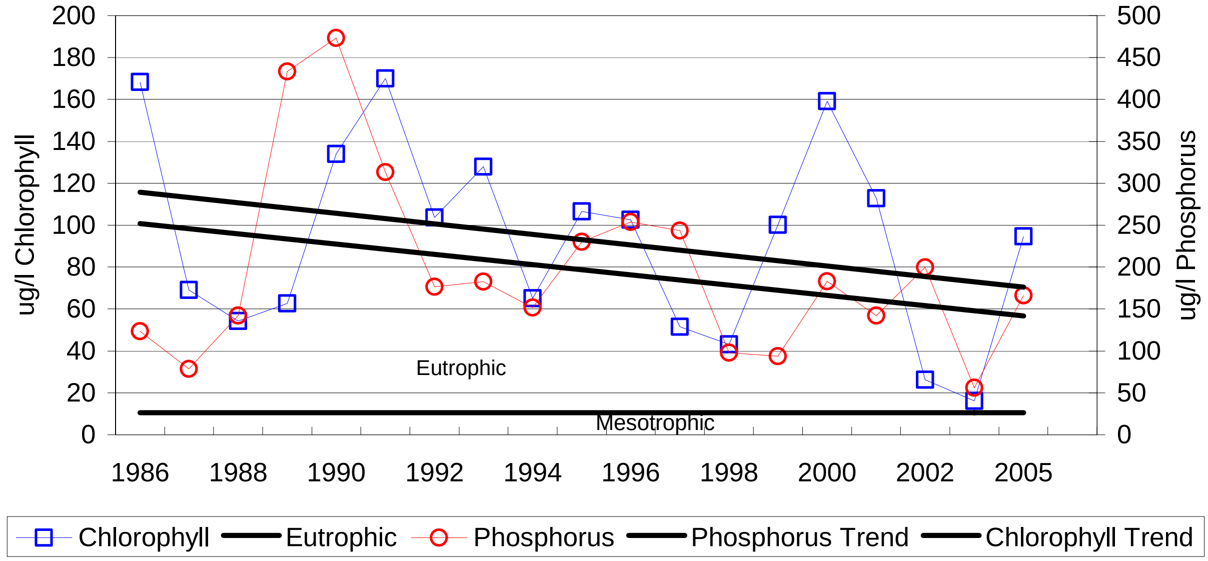


Figure 1. Mean summer phosphorus and chlorophyll concentrations in Squaw Lake, 1986-2005.

Algae

Algae is a natural and necessary part of a lake ecosystem, however, prolonged algae blooms can inhibit the growth of submersed vegetation by reducing water clarity, thus reducing light availability. Since algae cells contain chlorophyll, chlorophyll is measured to determine algae concentrations.

2005 Summer mean chlorophyll a concentration in Squaw Lake was 94.6 ug/l.
This concentration of chlorophyll is in the hypereutrophic range (Table 1).

Chlorophyll a concentrations in Squaw Lake have also fluctuated widely within the hypereutrophic/eutrophic range (Figure 1). The pattern of changes in chlorophyll levels has followed the changing phosphorus levels in most years. Trend analysis indicates that chlorophyll has declined since 1986.

Filamentous algae has been a concern in Squaw Lake, forming dense mats on the sediment. The frequency of occurrence of filamentous algae at sample sites has varied between 1986 and 2005 (Figure 2). The occurrence of filamentous algae was highest in 1992 and lowest in 2001 (Figure 2). Filamentous algae has been abundant in all years.

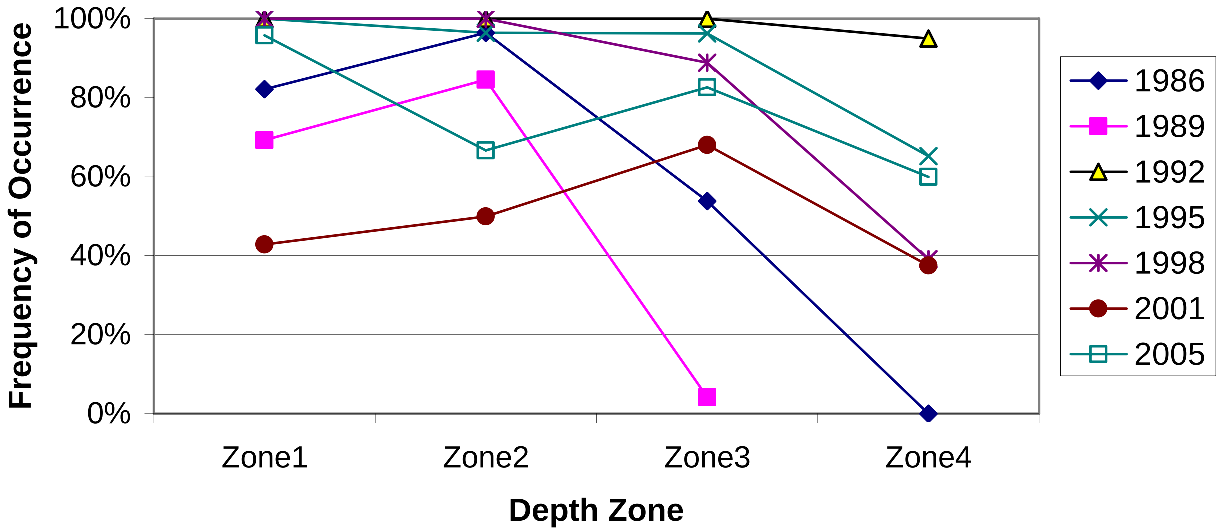


Figure 2. Occurrence of filamentous algae by depth zone, 1986-2005

A heavy scum of planktonic algae occurred at 15% of the sites in 2001 and 1% of the sites in 2005.

Water Clarity

Water clarity is a critical factor for aquatic plant growth. When aquatic plants receive less than 2% of the ambient light, they can not survive; although some aquatic plant species are more tolerant of low light levels than others.

2005 Summer Mean Water clarity in Squaw Lake was 2.8 feet.

The water clarity also indicates that Squaw Lake is hypereutrophic with very poor water clarity (Table 1).

Volunteer lake monitors in the Self-Help Volunteer Lake Monitoring Program have collected water clarity data since 1988.

1988 – Jim Deltmann and Duane Haupt
1989- 1994 - Ernest Nelson
1995-2000 Bill Stute
2001- Ernest Nelson, Bill Stute and Patrick Gronlund
2001-present – Patrick Gronlund

During 2005, Patrick Gronlund started monitoring water chemistry also.

The volunteer data is valuable in that water clarity data is collected more frequently than DNR data (every two weeks to weekly), is collected for a longer time span during the year (ice-out to ice-in), is collected at more locations in the lake and has been collected for many years.

Mean summer water clarity, as measured with a Secchi Disc, has remained in the eutrophic/hypereutrophic range with poor to very poor water clarity during 1986-2005. The best water clarity was in 2003; the poorest water clarity was in 2001(Figure 3).

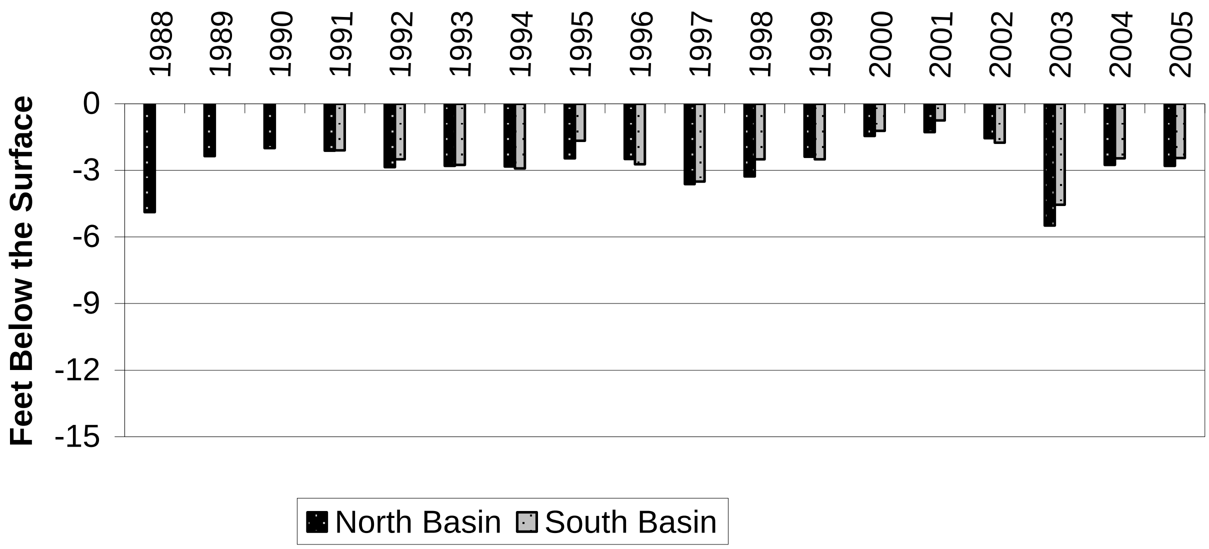


Figure 3. Water clarity in Squaw Lake, 1986-2005.

Volunteer data that was collected at the same time of the year was averaged to show the change in water clarity during the year. After ice-out, the water clarity improves in both basins of Squaw Lake through May and early June. The water clarity starts declining in July and reaches its lowest clarity in mid-August. In September the water clarity starts increasing again and attains the best clarity in October and November as temperatures cool and algae decline (Figure 4).

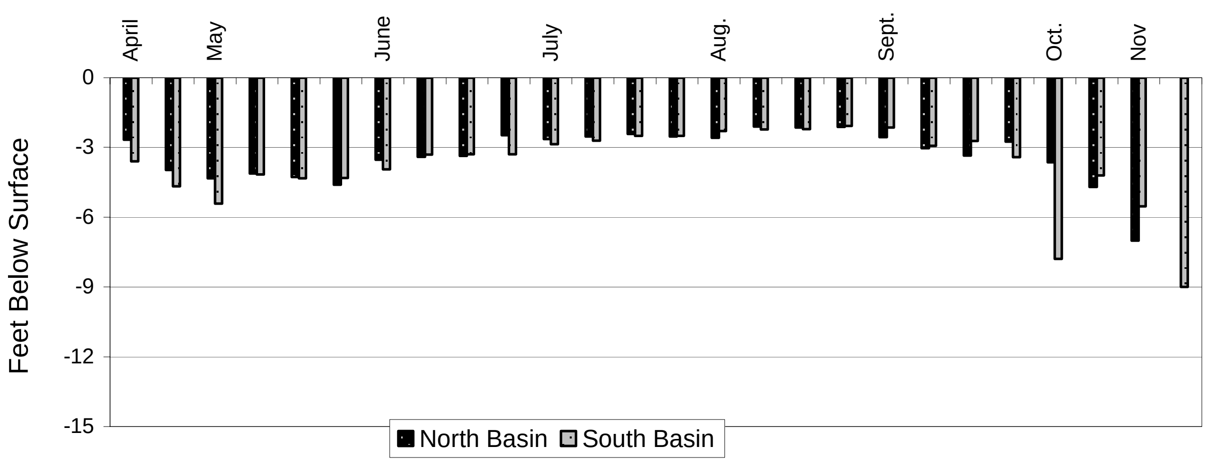


Figure 4. Change in water clarity during the season, 1988-2005 data.

The combination of phosphorus concentration, chlorophyll concentration and water clarity places Squaw Lake as a hypereutrophic lake with very poor water quality.

Hardness

The hardness levels in Squaw Lake, as measured by the amount of calcium carbonate, varied from 16-76 mg/l CaCo3. Hardness levels below 60mg/l CaCO3 are considered soft water. Soft water lakes are more sensitive to the effects of acid rain and support less aquatic plant growth.

LAKE MORPHOMETRY

The morphometry of a lake impacts the distribution of aquatic plants. Duarte and Kalff (1986) found that the slope of the littoral zone accounted for 72% of the observed variability in the growth of submerged vegetation. Gentle slopes support a broader zone of potential plant growth than steep slopes (Engel 1985).

The littoral zone along the east and west side of Squaw Lake is steeper, limiting the area suitable for colonization by aquatic plants. Shallow bays and gradually sloped littoral zones occur at the north and south ends of the lake and could support a broader zone of aquatic plant growth.

SEDIMENT COMPOSITION

Silt was the dominant sediment in Squaw Lake at the sample sites in 2005, especially at depths greater than 1.5ft (Table 2). Silt was found throughout the lake, more commonly at the deeper sites (Figure 5).

Sand and mixtures of rock and gravel were common in the 0-1.5ft depth zone (Table 2).

Table 2. Sediment Composition, 2005

		0-1.5ft Depth	1.5-5ft depth	5-10ft Depth	10-20ft Depth	Overall
Soft Sediments	Silt	4%	46%	77%	87%	49%
	Muck	4%				1%
	Peat					
Mixed Sediments	Sand/silt	17%	12%	9%	7%	12%
	Silt/rock	3%	4%	4%	7%	4%
Hard Sediments	Sand	21%	21%	4%		13%
	Rock/gravel	25%	12%	4%		12%
	Sand/Rock	17%				5%
	Sand/gravel	12%	4%			5%

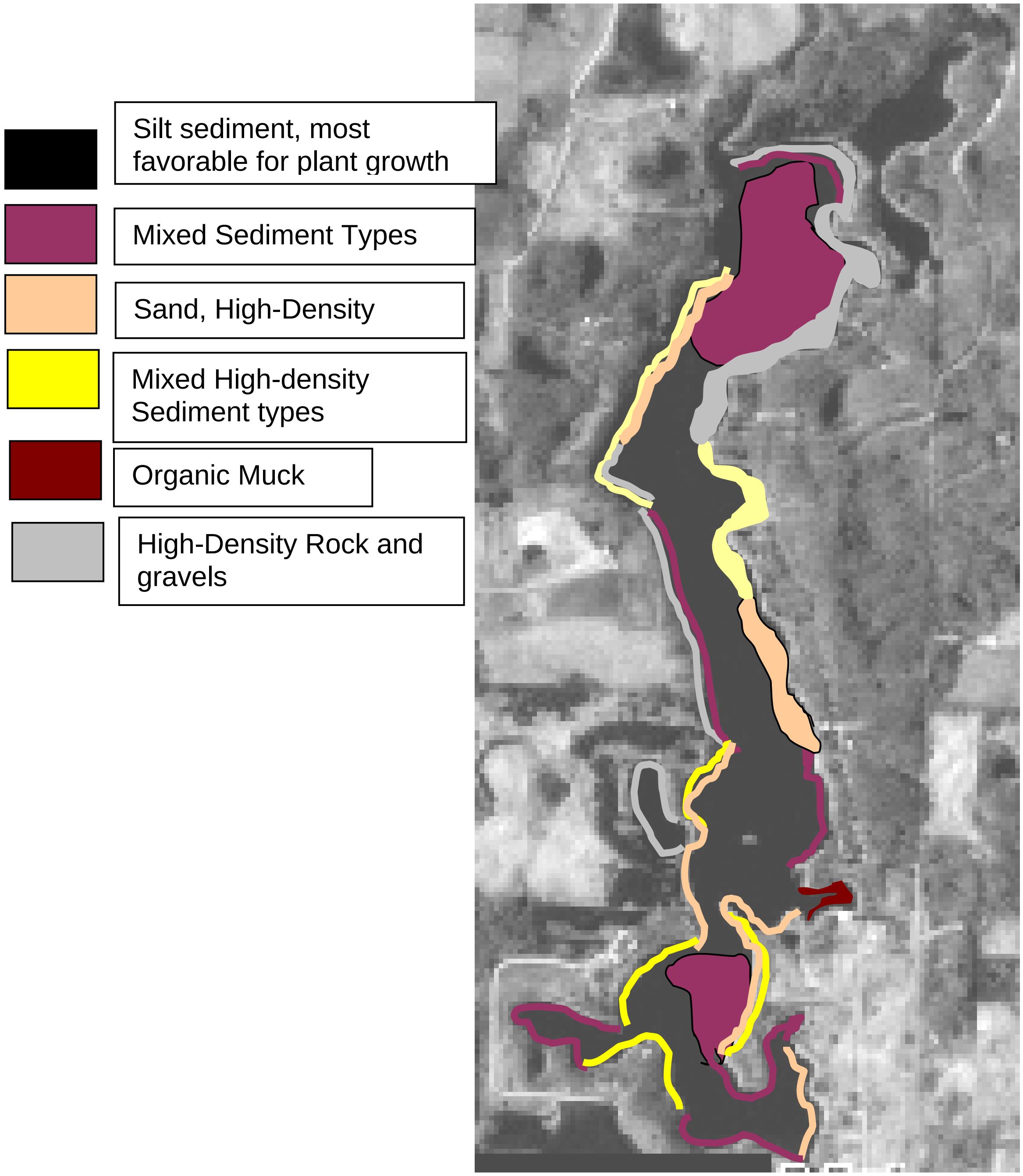


Figure 5. Distribution of Sediment types in Squaw Lake, 2005.

SEDIMENT INFLUENCE

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

The availability of mineral nutrients for plant growth is highest in sediments of intermediate density, such as silt (Barko and Smart 1986). Silt was the dominant sediment in Squaw Lake in 1995-2005; however, only 2% of the sites with silt supported rooted vegetation (Table 3). Silt occurred more frequently in deeper water, beyond the photic zone (Table 2).

Sand and gravel sediments are less favorable to plant growth because they are high-density sediments that can be limiting in nutrient availability (Barko and Smart 1986). However, sand/rock, rock/gravel and sand/gravel sediments supported the most plant growth in Squaw Lake (Table 3). Sites with high-density sediments were common at depths less than 5 feet (Table 2) and the more abundant plant growth on these high density sediments was likely due to greater light availability and not sediment type.

Light availability is appears to be a more important determining factor for plant growth in Squaw Lake than sediment composition.

Table 3. Sediment Influence, 2005

		Occurrence at Sample sites	Percent of sediment type vegetated
Soft Sediments	Silt	49%	2%
	Muck	1%	100%
Mixed Sediments	Sand/silt	12%	40%
	Silt/rock	4%	33%
Hard Sediments	Sand/rock	5%	100%
	Sand	13%	36%
	Rock/gravel	12%	50%
	Sand/gravel	5%	50%

There has been year-to-year variability in the occurrence of sediments at the sample sites in Squaw Lake. This is probably due to the fluctuating water levels in Squaw Lake. Since many sediment types have been more common at certain depths, changes in water levels can alternately expose or inundate different sediment types.

Organic muck was frequently found at the sample sites in some years when water levels were higher, especially in the bays, but did not occur in 1998 (Table 2). Organic muck had been found in the shallow water. Since the water level was down in 1998, the sites previously composed of muck sediments were likely terrestrial in 1998.

Table 4. Sediment Composition, 1986-2005

		1986	1989	1992	1995	1998	2001	2005
Soft Sediments	Silt	10%	26%	28%	73%	38%	40%	49%
	Muck	10%	24%	48%	4%		6%	1%
	Peat					5%		
Mixed Sediments	Sand/silt					9%	12%	12%
	Silt/rock				13	1%	3%	4%
Hard Sediments	Sand/rock	29%	6%	2%	5%	22%	16%	5%
	Sand	7%	22%	6%	1%	15%	9%	13%
	Rock/gravel	11%	18%	2%	5%	3%	9%	12%
	Sand/gravel						3%	5%

WATER LEVEL

Squaw Lake has experienced fluctuating water levels, which stresses the aquatic plant community. The shallow zone becomes a terrestrial environment unsuitable for aquatic vegetation when the water levels drop. When water levels rise, aquatic plants are suddenly placed in water that is too deep for light availability (Nichols 1975).
When the levels drop again, the aquatic plants suffer desiccation.

SHORELINE LAND USE

Land use practices strongly impact the aquatic plant community. Practices on the shore directly impact the plant community through increased sedimentation, increased nutrients from fertilizer run-off and contaminants from farmland and urban run-off.

Native herbaceous growth had the highest occurrence and mean coverage at the sites on Squaw Lake (Table 5). Wooded cover was abundant in occurrence and cover. Shrub growth was commonly occurring (Table 5).

Cultivated lawn was also commonly occurring at the sample sites and hard structures were abundant.

Table 5. Shoreline Land Use, 2005

		Percent Occurred	Mean Coverage
Natural Shoreline	Native Herbaceous	96%	50%
	Wooded	88%	36%
	Shrub	21%	2%
	Bare Sand	17%	1%
			89%
Disturbed Shoreline	Cultivated Lawn	29%	8%
	Hard Structure	38%	3%
			11%

Some type of natural cover occurred at all of the sites and covered 89% of the shore, based on the sample sites. Some type of disturbed shoreline occurred at 46% of the sites and covered 11% of the shoreline (Table 5).

Since 1995, wooded cover has increased and native herbaceous growth and shrub cover has decreased (Table 6). Cultivated lawn has decreased in mean coverage since 1995 (Table 6), but hard structure has increased. Some of the change in shoreline cover may reflect shoreline restoration projects on Squaw Lake.

Table 6. Change in Mean Coverage of Shoreline Land Use, 1995-2005

		1995	2005
Natural Shoreline	Wooded	21%	36%
	Native Herbaceous	61%	50%
	Shrub	6%	2%
Total Natural		89%	89%
Disturbed Shoreline	Cultivated Lawn	11%	8%
	Exposed soil	1%	1%
	Hard Structure		3%
Total disturbed		12%	11%

MACROPHYTE DATA

SPECIES PRESENT

Twenty-five (25) species of aquatic plants were found during the 1986-2005 studies: 17 emergent species, 3 floating leaf species, and 5 submergent species (Table 7).
No endangered, threatened or non-native species were found.
One species of special concern was found in Squaw Lake: *Ceratophyllum echinatum.*
Special Concern Species are species with which there is concern about their lack of abundance or distribution. The main purpose of this designation is to focus attention on these species before they become threatened or endangered.

Table 7. Squaw Lake Aquatic Plant Species, 1986-2005

Scientific Name	Common Name	I. D. Code
Emergent Species		
1) *Alisma triviale* Pursh	northern water plantain	alitr
2) *Bidens* sp.	bur marigold	bidsp
3) *Carex rostrata* Stokes.	sedge	carro
4) *Dulichium arundinaceum* (L.) Britton	three-way sedge	dular
5) *Eleocharis palustris* L.	creeping spikerush	elepa
6) *Glyceria striata* (Lam.) A. Hitchc.	fowl manna grass	glyst
7) *Iris virginica* L. var. *shrevei* (Small) E. Anderson.	iris	irivi
8) *Lysimachia hybrida* Michx.	hybrid loosestrife	lyshy
9) *Phalaris arundinacea* L.	reed canary grass	phaar
10) *Polygonum amphibium* L.	water smartweed	polam
11) *Sagittaria rigida* Pursh.	sessile-fruited arrowhead	sagri
12) *Scirpus fluviatilis* (Torr.) A. Gray.	river bulrush	scifl
13) *Scirpus validus* Vahl.	softstem bulrush	sciva
14) *Sparganium eurycarpum* Engelm.	giant bur-reed	spaeu
15) *Stachys palustris* L.	hedge-nettle	stapa
16) *Typha angustifolia* L.	narrow-leaf cattail	typan
17) *Typha latifolia* L.	common cattail	typla
Floating leaf Species		
18) *Lemna minor* L.	lesser duckweed	lemmi
19) *Nuphar variegata* Durand.	yellow pond lily	nupva
20) *Nymphaea odorata* Aiton.	white water lily	nymod
Submergent Species		
21) *Ceratophyllum echinatum* A. Gray.	spiny coontail	cerec
22) *Eleocharis acicularis* (L.) Roemer & Schultes.	needle spikerush	eleac
23) *Elodea canadensis* Michx.	common waterweed	eloca
24) *Nitella* sp.	nitella	nitsp
25) *Potamogeton pusillus* L.	slender pondweed	potpu

FREQUENCY OF OCCURRENCE

The most frequently occurring species in Squaw Lake has alternated between *Lemna minor* (small duckweed) and *Elodea canadensis* (common waterweed) in various years, with *Lemna minor* being the most frequently occurring species in 2005. *Phalaris* *arundinacea* (reed canary grass) was the most frequently occurring species in 2001 (Table 8). Fluctuating water levels are likely impacting the aquatic plant community that occurs as a thin band around the lake.

Table 8. Frequency of Occurrence of Prevalent Aquatic Plant Species in Squaw Lake 1986-2005

Species	1986	1989	1992	1995	1998	2001	2005
Lemna minor	**14%**	44%	**60%**	**58%**	**22%**	10%	**21%**
Elodea canadensis		**67%**	54%	**58%**	2%	1%	
Phalaris arundinacea	1%	17%	23%	27%		**18%**	8%

DENSITY

The aquatic plant species with the highest mean density has also alternated between *Lemna minor* and *Elodea canadensis, L. minor* having the highest mean density in 2005 in Squaw Lake (Table 9). *Eleocharis acicularis* had the highest mean density in 2001.

Table 9. Densities of Prevalent Plant Species in Squaw Lake 1986-2005

Species	1986	1989	1992	1995	1998	2001	2005
Lemna minor	**0.39**	1.10	**1.57**	**1.66**	**0.35**	0.22	**0.33**
Eleocharis acicularis	0.19				0.01	**0.32**	0.13
Elodea canadensis		**1.90**	1.17	1.57	0.02	0.02	

The "density where present" measures the aggregation or density of growth form of a species. *Lemna minor* (small duckweed) exhibited a growth form of slightly above average density in Squaw Lake during most survey years. In 1989, when *Elodea canadensis* (common waterweed) was the dominant species, it showed a slightly above average growth form; in 1992, two emergent species exhibited a dense growth form, but were not commonly occurring so were aggregated in limited locations; *Potamogeton pusillus* (small pondweed) exhibited a growth form of slightly above average density in 2005, but occurred in only limited areas.

DOMINANCE

The dominance value illustrates how dominant a species is within the plant community (Figure 6). *Lemna minor* (small duckweed) was the dominant species in 1986, was outcompeted by *Elodea canadensis* (common waterweed) for dominant species in 1989, *L. minor* became dominant again in 1992-1998, decreased in 2001 with *Eleocharis acicularis* (needle spikerush) becoming dominant species and *L. minor* was the dominant species again in 2005. *Typha latifolia* (common cattail) was sub-dominant in 2005.

Figure 6. Dominance of the most prevalent aquatic plant species in Squaw Lake, 1986-2005.

DISTRIBUTION

Aquatic plant growth has been sparse in Squaw Lake. In all studies, submerged plants were recorded at widely scattered locations in the lake at varying depths in different years. Colonization of emergent vegetation varies, depending on the lake level and whether the emergents are in the littoral zone or exposed on land. In 2005, the scattered vegetation colonized 36% of the sample sites (littoral zone), approximately 5 acres of Squaw Lake (4% of lake area). Of this, 2-acres were colonized by emergents, 3 acres by submergent (0.5 acre of this was turf-forming species) (Figure 7).

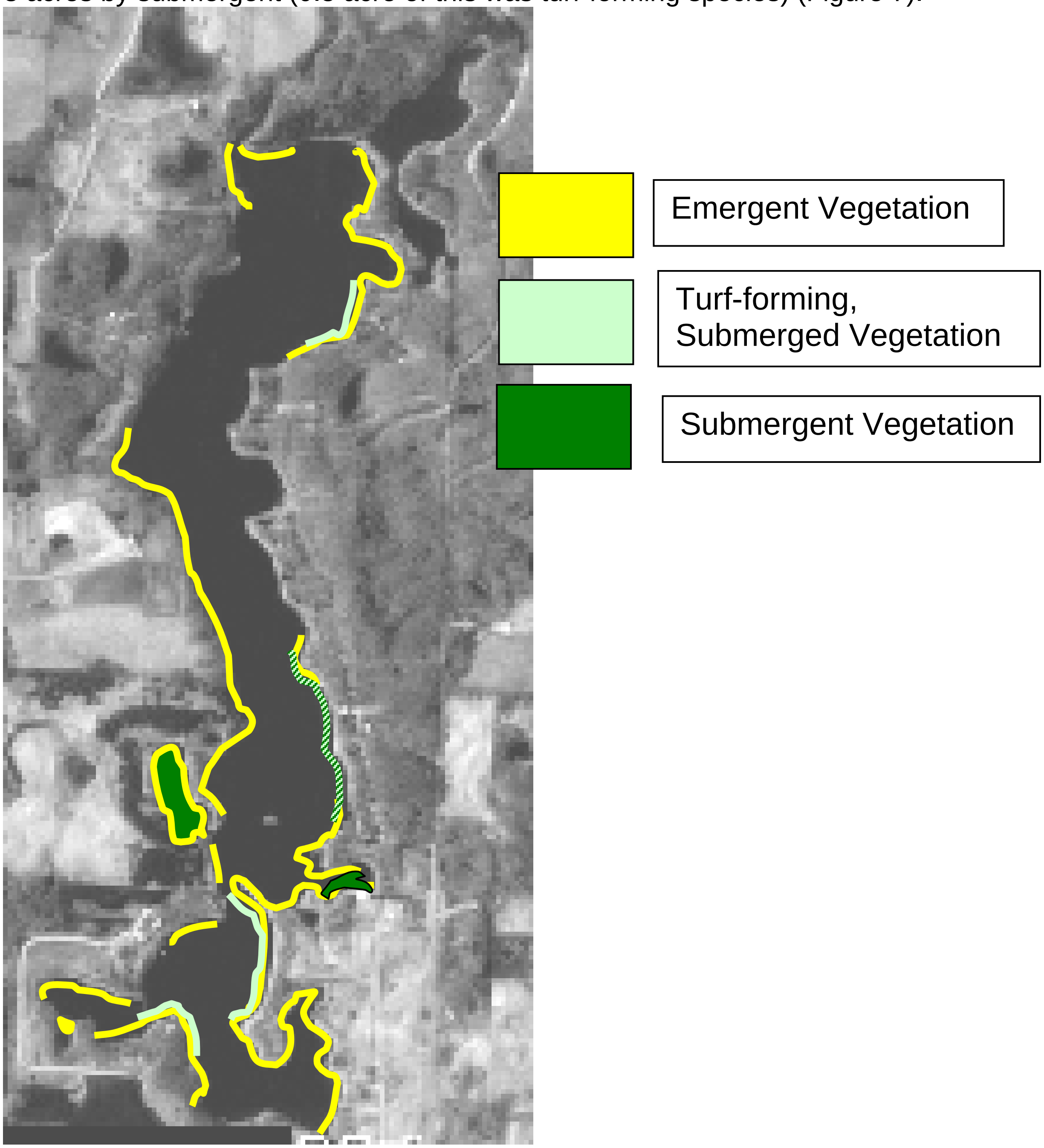


Figure 7. Distribution of aquatic vegetation in Squaw Lake, 2005.

Water clarity data can be used to calculate a predicted maximum rooting depth (Dunst 1982).

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

The actual maximum rooting depth was greater than the predicted rooting depth based on water clarity during the earliest surveys. However, the rooting depth decreased to less than the predicted rooting depth in later surveys (Figure 8). This suggests that water clarity is not the only factor impacting the aquatic plant community.

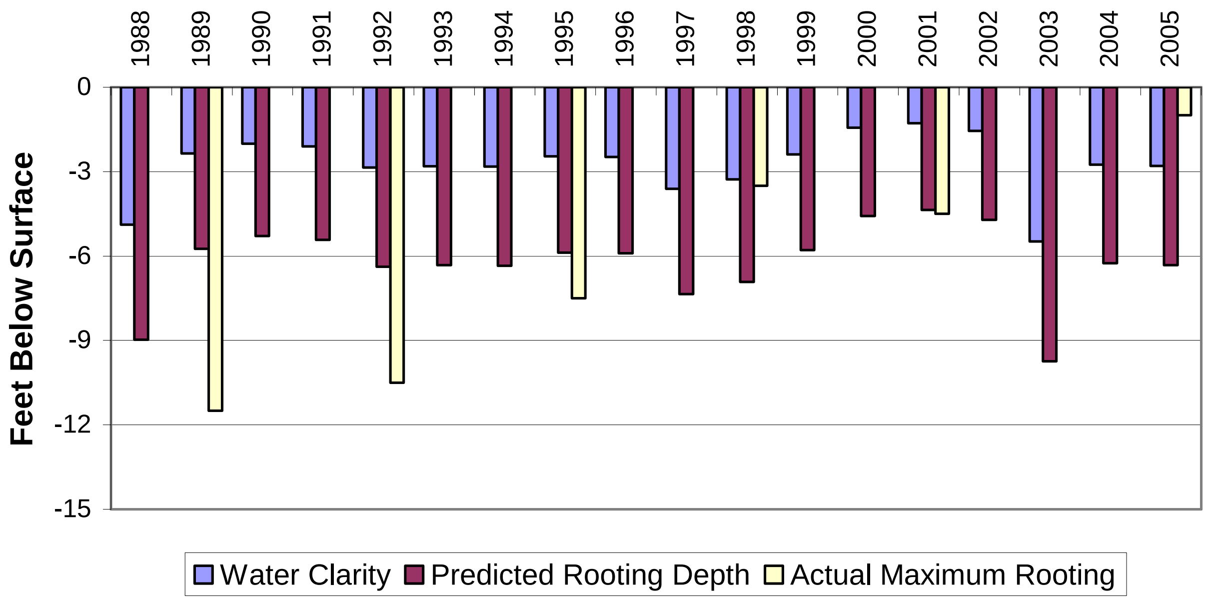


Figure 8. Actual rooting depth as compared to predicted maximum rooting depth in Squaw Lake, 1988-2005.

Eleocharis smallii, Glyceria striata, Phalaris arundinacea, Potamogeton pusillus and *Typha latifolia* occurred at the maximum rooting depth in 2005. *Elodea canadensis* and *Sagittaria rigida* have also been recorded at the maximum rooting depth in previous surveys.

The percentage of sites with rooted vegetation in Squaw Lake increased from the lowest percentage in 1986 to the highest percentage in 1989-95. The shallow depth zone (0-1.5ft) has been the zone with the greatest percent of rooted vegetation in all years (Figure 9).

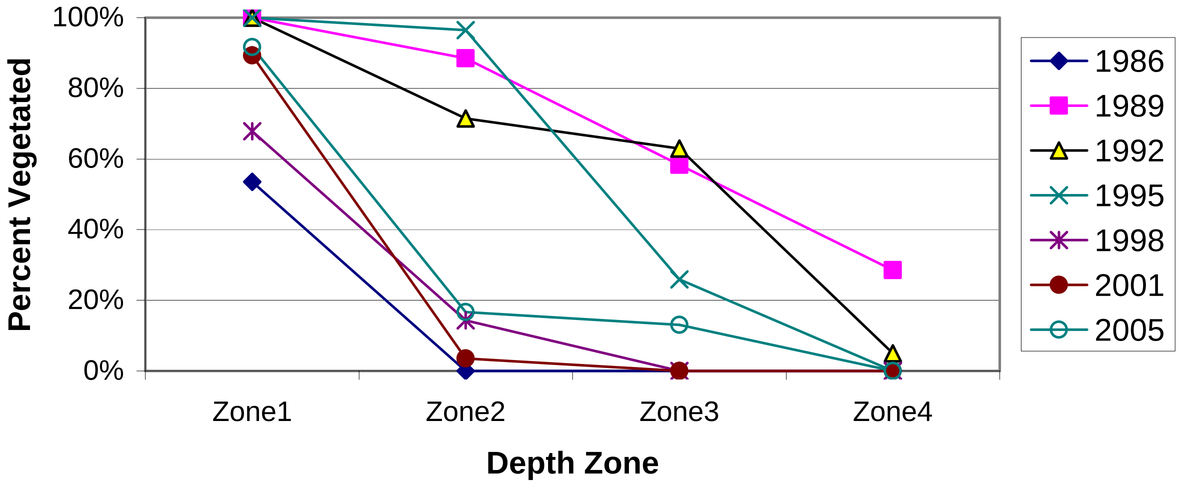


Figure 9. Percentage of sites with rooted vegetation, by depth zone in Squaw Lake, 1986-2005.

The highest total occurrence (Figure 10) and total density (Figure 11) of aquatic plant growth was found in the 0-1.5ft depth zone during all the study years. The occurrence and density of aquatic plants decreased with increasing depth in all years. The total occurrence and total density of plant growth increased steadily from the lowest in 1986 to the highest in 1995, but decreased dramatically in 1998, increasing in the shallow zone in 2001 and decreasing again in 2005 (Figure 10, 11) when the water levels dropped. This follows the pattern of changes in the water level with higher total occurrence and total density of plants in years with higher water levels.

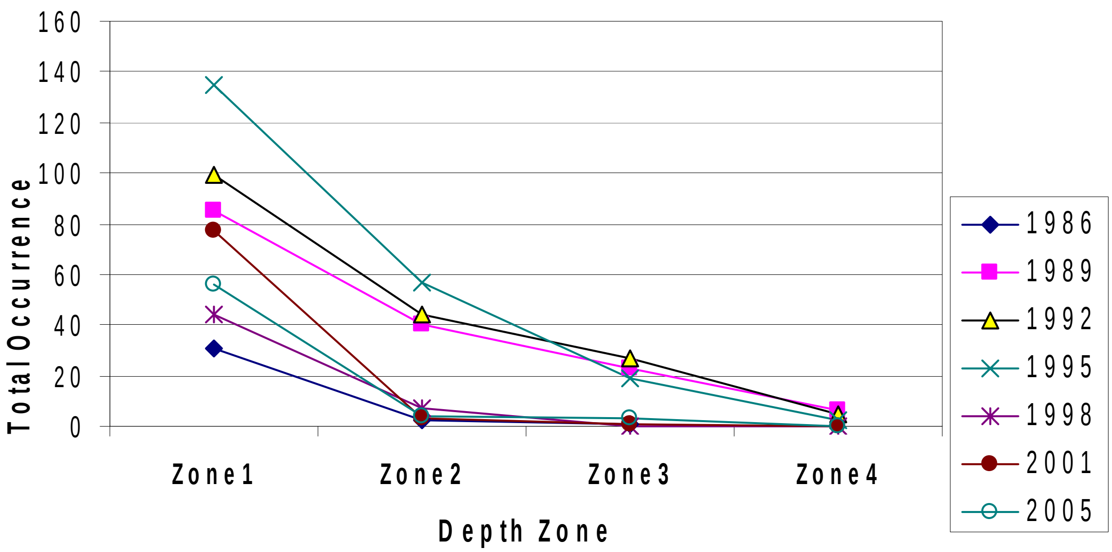


Figure 10. Total occurrence of aquatic plants, by depth zone 1986-2005.

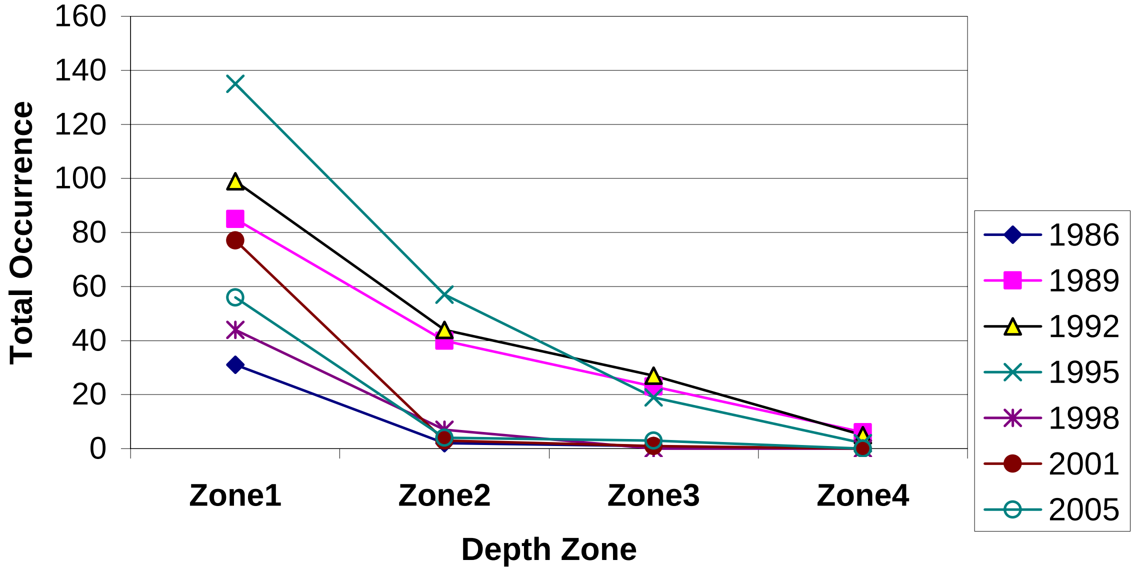


Figure 11. Total density of aquatic plants in Squaw Lake, by depth zone 1986-2005.

The 0-1.5ft depth zone supported the greatest species richness (mean number of species recorded at a site) (Figure 12). Species Richness declined with increasing depth. The greatest overall Species Richness was in 1995 and the poorest Species Richness was in 1986 (Figure 12)

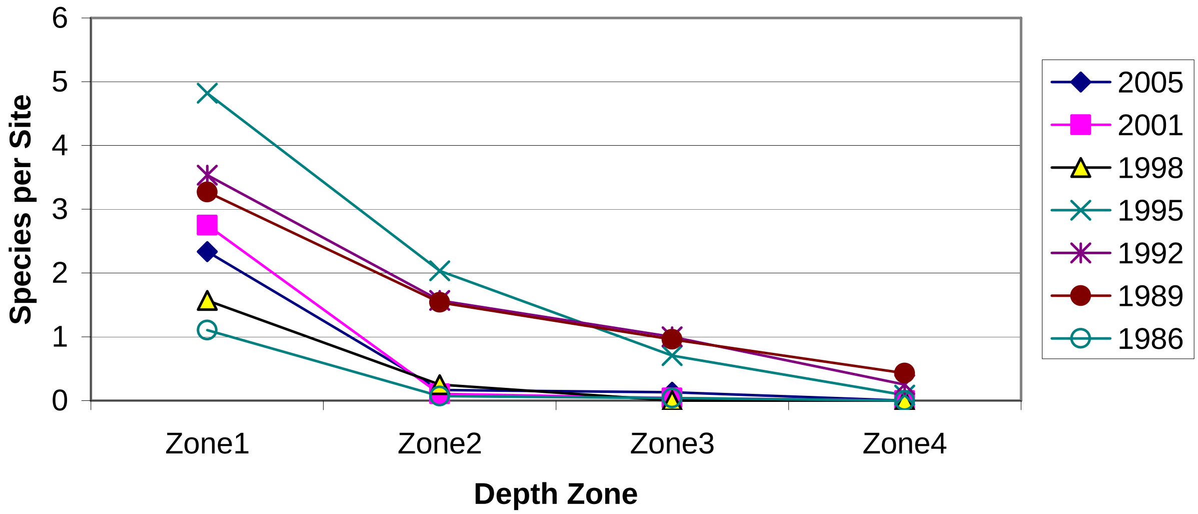


Figure 12. Species Richness in Squaw Lake, by depth zone, 1986-2005.

Lemna minor (small duckweed) was usually the dominant species in all depth zones in Squaw Lake (Appendices I-XIV), many times occurring as the only species in a depth zone. In some years, *L. minor* has shared dominance with one of the emergent species in the shallowest depth zone. A few other exceptions to its dominance were when

1) *Elodea canadensis* (common waterweed) was dominant in the 1.5-20ft depth zone in 1989, in the 1.5-10ft depth zone in 1992 and in the 1.5-5ft depth zone in 1995. These three years were the years that *E. canadensis* exhibited its greatest growth.
2) *Phalaris arundinacea* (reed canary grass) and *Eleocharis acicularis* (needle spikerush) were dominants in the shallowest depth zone in 2001.

Lemna minor (small duckweed) has had its highest frequency and density in the 0-1.5 foot depth zone, declining with increasing depth (Figure 15, 16). The frequency and density of *L. minor* was highest during 1992-1995 and lowest in 2001. (Figure 13, 14).

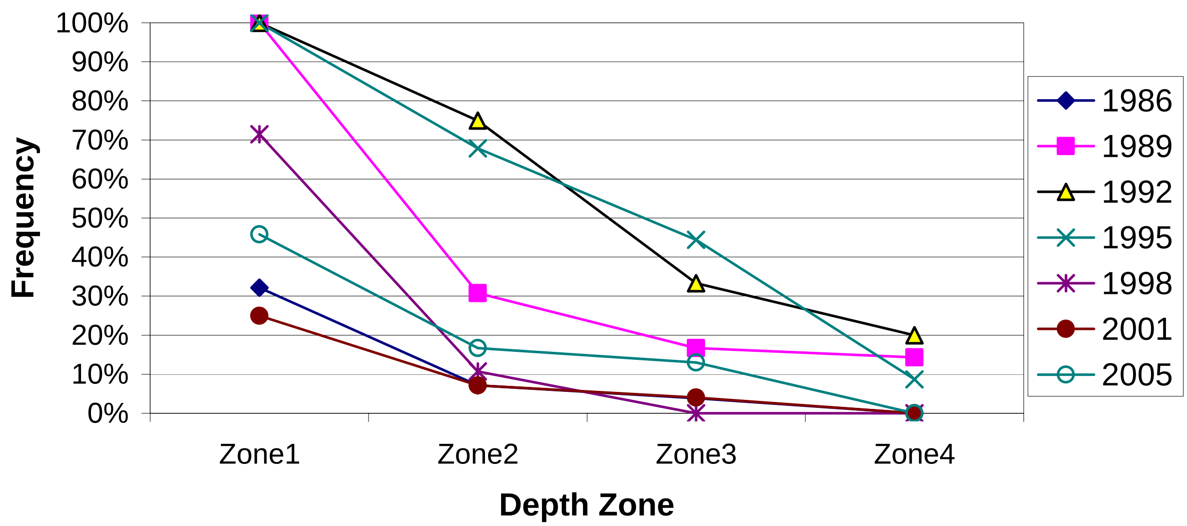


Figure 13. Frequency of *Lemna minor* in Squaw Lake by depth zone, 1986-2005.

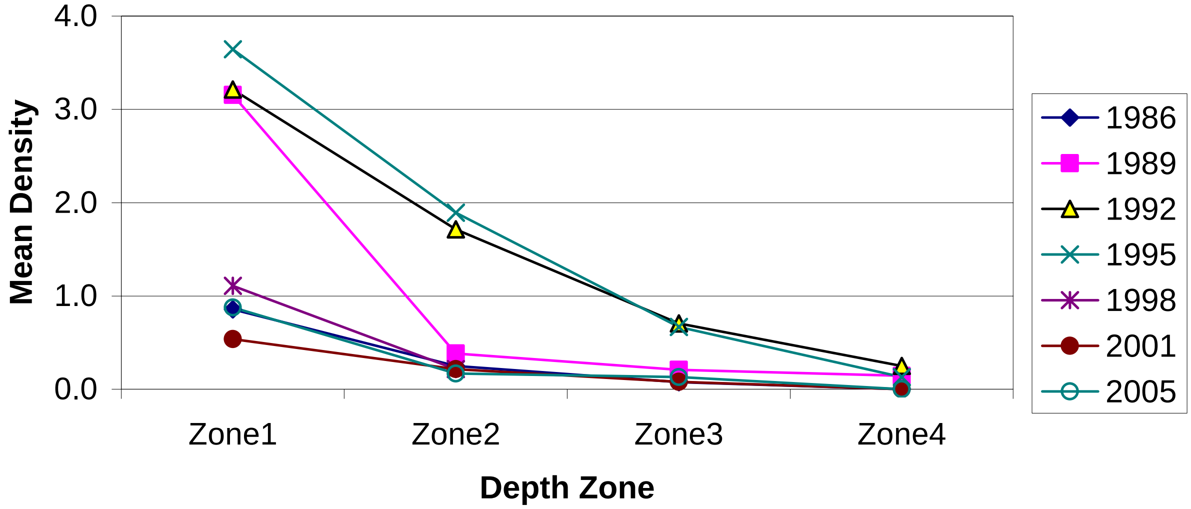


Figure 14. Density of *Lemna minor* in Squaw Lake by depth zone, 1986-2005.

Elodea canadensis (common waterweed) was not found in 1986. During 1989-1995, it was found at its highest frequency and density in the 0-5ft depth zone (Figure 15, 16). *E. canadensis* was dominant in the 1.5-20ft depth zone in 1989, in the 1.5-10ft depth zone in 1992 and in the 1.5-5ft depth zone in 1995. *E. canadensis* decreased to a very low frequency and density in 1998 and 2001 and was not found in 2005 (Figure 15, 16). These three years were the years that *E. canadensis* exhibited its greatest growth.

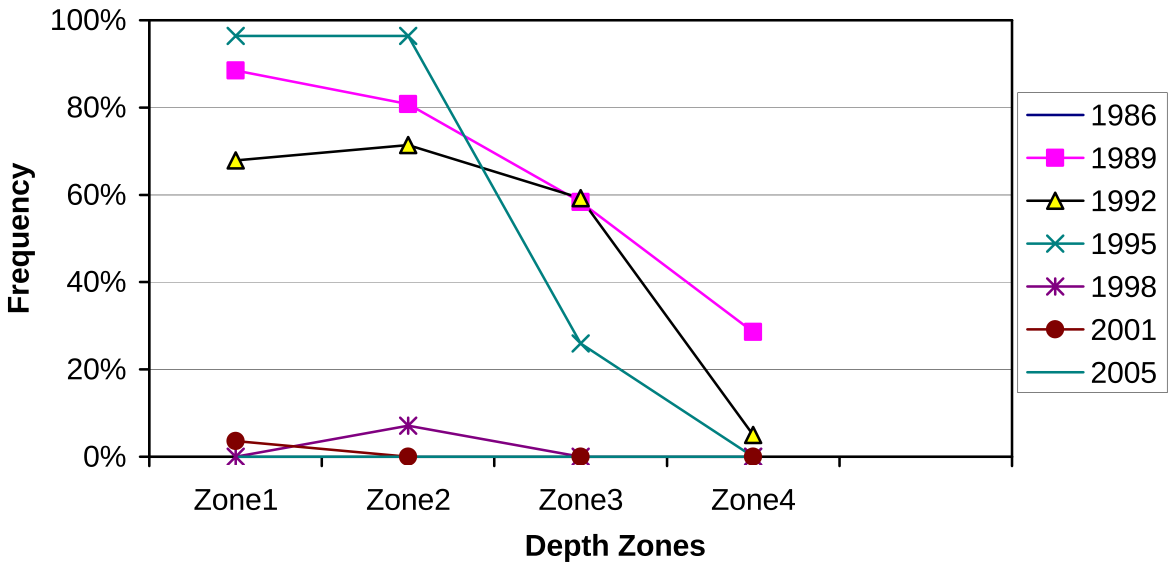


Figure 15. Frequency of *Elodea canadensis* by depth zone in Squaw Lake, 1986-2005.

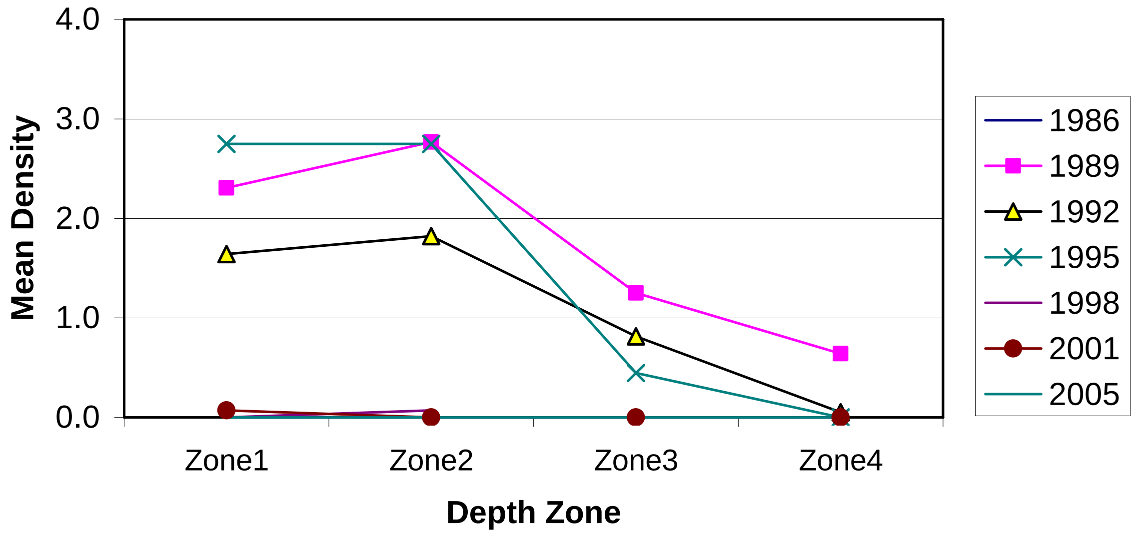


Figure 16. Density of *Elodea canadensis* by depth zone in Squaw Lake 1986-2005.

MACROPHYTE COMMUNITY AND CHANGES IN THE COMMUNITY

Significant changes have occurred in the composition of the aquatic plant community in Squaw Lake. The Coefficients of Community Similarity indicate that the 1986 and 1989 aquatic plant communities in Squaw Lake were significantly different (Table 10). The plant community then appeared to stabilize during 1989-1995 when water levels were higher. Significant change again occurred between each survey from 1995 to 2005 (Table 10). The changes accumulated, resulting in the 2005 community being only 22-49% similar to the community first surveyed in 1986 (Table 10).

Table 10. Coefficients of Community Similarity

Years Compared	**Coefficient**		**% Similar**
	Frequency	**Relative Freq.**	
1986-89	0.2633	0.3881	26-38%
1989-92	0.7953	0.8039	80%
1992-95	0.8332	0.8263	83%
1995-98	0.3788	0.5303	38-53%
1998-2001	0.3197	0.2984	30-32%
2001-2005	0.5043	0.5551	50-56%
1986-2005	0.2247	0.4868	22-49%

*** -** Coefficients less than 0.75 indicates a significant difference between the two communities.

Many parameters can measure what changes have occurred within the aquatic plant

community.
The number of species found in Squaw Lake in 1986 was low, but increased throughout 1989-1995, more than doubling (Table 11). The number of species dropped dramatically in 1998, recovered somewhat in 2001 (Table 11). Species Richness, Simpson's Diversity Index, Floristic Quality Index (discussed later), followed the same general pattern.

The maximum rooting depth of aquatic plants in Squaw Lake increased from its lowest in 1986, to the greatest maximum rooting depth in 1989 and has steadily declined since 1989 (Table 11). The percent of the littoral zone vegetated also increased from its lowest in 1986 to its highest in 1989.

The coverage of the three vegetation types (emergent, submergent and free-floating) has varied up and down. The AMCI Index and Coefficient of Conservatism (discussed later) have varied up and down also (Table 11).

Since 1986, all parameters are increased except the Average Coefficient of Conservatism which has decreased and maximum rooting depths which is the same in 2005 as in 1986. Species Richness has increased the most, 18% (Table 11).

Table 11. Changes in the Squaw Lake Aquatic Plant Community, 1986-2005

	1986	**1989**	**1992**	**1995**	**1998**	**2001**	**2005**	**Change 1986-05**	**%Change 1986-2005**
Number of Species	7	12	16	17	7	12	11	4	57.1%
Species Richness	0.40	1.71	1.70	2.01	0.48	0.84	0.73	0.33	82.5%
Maximum Rooting Depth	1.0	11.5	10.5	7.5	3.5	2.0	1.0	0	0.0%
% of Littoral Zone Vegetated	28.6	81.1	74.8	66.0	29.2	30.9	36.0	7.4	25.9%
%Sites/Emergents	16.7	25.6	25.2	30.2	19.8	23.7	25.6	8.9	53.3%
%Sites/Free-floating	14.3	44.4	61.2	57.5	21.7	10.3	20.9	6.6	46.2%
%Sites/Submergent	0.0	68.9	56.3	57.5	2.8	19.6	10.5	10.5	
%Sites/Floating-leaf								0.0	
AMCI Index	25	44	45	43	23	35	34	9	36.0%
Simpson's Diversity Index	0.73	0.75	0.75	0.80	0.65	0.87	0.85	0.12	16.4%
Average Coefficient of Conservatism	5.14	5.08	5.33	5.00	5.00	4.33	4.45	-0.69	-13.4%
Floristic Quality Index	13.61	17.61	20.66	20.62	13.23	15.01	14.77	1.16	8.5%

Simpson's Diversity Index indicates the aquatic plant community increased from very poor diversity in 1986 to poor diversity in 2005 (Table 11). A diversity index of 1.0 would mean that each plant in the lake was a different species (the most diversity achievable).

According to the Aquatic Macrophyte Community Index (AMCI), the 1986 aquatic community in Squaw Lake was in the lowest quartile of lakes in the state and region, the group of lakes with the lowest quality community (Table 12). The quality increased during 1989-1995, so that the Squaw Lake aquatic plant community was below average for lakes in the state. The quality decreased in 1998-2005 and the plant community was again within the group lakes in the state and region with the lowest quality aquatic plant community (Table 12).

The shallow depth of rooting and the low ratio of submergent vegetation limit the quality of the aquatic plant community in Squaw Lake (Table 12).

Table 12. Aquatic Macrophyte Community Index for Squaw Lake; 1986-2005.

	Values						
	1986	1989	1992	1995	1998	2001	2005
Maximum Rooting Depth	0	6	5	3	0	0	0
% Littoral Zone Vegetated	3	10	10	10	4	4	6
Simpson's Diversity Index	3	3	3	4	2	7	6
Relative Frequency of Submersed Species	1	3	2	1	1	1	1
Relative Frequency of Sensitive Species	5	6	7	7	3	7	6
# of Taxa	3	6	8	8	3	6	5
Exotic Species	10	10	10	10	10	10	10
Total	25	44	45	43	23	35	34

The Average Coefficients of Conservatism for Squaw Lake have remained within the lowest quartile for Wisconsin lakes and lakes in the North Central Hardwood Region, except during 1992. Squaw Lake was below average for lakes in the North Central Hardwood Region 1992 (Table 13). This suggests that the plant community in Squaw Lake was in the group lakes in Wisconsin most tolerant of disturbance. This is likely due to being subjected to disturbance.

Table 13. Floristic Quality and Coefficient of Conservatism of Squaw Lake, Compared to Wisconsin Lakes and Northern Wisconsin Lakes.

	Average Coefficient of Conservatism †	Floristic Quality ‡
Wisconsin Lakes *	5.5, 6.0, 6.9	16.9, 22.2, 27.5
NCHR *	5.2, 5.6, 5.8	17.0, 20.9, 24.4
Squaw Lake, 1986-2005		
1986	5.14	13.61
1989	5.08	17.61
1992	5.33	20.66
1995	5.00	20.62
1998	5.00	13.23
2001	4.33	15.01
2005	4.45	14.77

***** - Values indicate the highest value of the lowest quartile, the mean and the lowest value of the upper quartile. (NCHR) The North Central Hardwoods Region, the region in which Squaw Lake is located

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

The Floristic Quality of the plant community in Squaw Lake was in the lowest quartile of Wisconsin Lakes and lakes in the North Central Hardwood Region in 1986 (Table 13). The Floristic Quality increased to below average in 1989-1995 and then decreased to the lowest quartile again in 1998-2005. This indicates that the plant community in Squaw Lake was in the group of lakes in the state and the region that was furthest from an undisturbed condition, shifted to a lake that was less disturbed but still farther from an undisturbed condition that the average lake in 1989-1995 and shifted back again into the group of lakes farthest from an undisturbed condition.

Disturbances can be of many types:

1) Biological disturbances include the introduction of a non-native or invasive plant species, grazing from an increased population of aquatic herbivores and destruction of plant beds by the fish population.
2) Physical disturbances to the plant beds result from activities such as boat traffic, plant harvesting, chemical treatments, the placement of docks and other structures and fluctuating water levels.
3) 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 and increased algae growth due to nutrient inputs.

The major disturbances in Squaw Lake are likely the fluctuating water levels, shoreline development and very poor water clarity.

Ultimately, plant communities change when species with the community change. Between 1986 and 2005 there were many changes in individual species in Squaw Lake (Appendix XXIII).

Seven species have appeared in only one survey year (six of them in the 1992-1995 time period). These species occurred at very limited number of sites and could have been missed by shifting transects or changes in water level. Two of these species are considered more terrestrial than aquatic.

Seven species have shown a pattern of increasing from 1986 through 1992 and 1995, then declining. Four of these species have disappeared from the community.

Eight species have increased since 1986; *Phalaris arundinacea* (reed canary grass) has increased the most, increasing more than five-fold in frequency and 11-fold in density.

Besides the species that have disappeared from the sample sites, one species has decreased since 1986; *Eleocharis acicularis* (needle spikerush) has decreased 14%.

IV. DISCUSSION

Based on water clarity and concentrations of chlorophyll and phosphorus, Squaw Lake has been a hypereutrophic lake with very poor water quality and clarity during the study period (1986-2005). Squaw Lake experiences severe planktonic and filamentous algal blooms and appears to be nitrogen limited at times. This means that additions of nitrogen or phosphorus can promote algae growth. Since 1986, chlorophyll and phosphorus have declined.

The relatively large watershed with a high percentage of cropland contribute to nutrient enrichment of Squaw Lake. Nutrient run-off from cropland, winterspreading manure and nutrient recycling from the lake sediment were identified as the major nutrient sources to Squaw Lake.

Filamentous algae, especially, has been a concern in Squaw Lake. In some years, the dense mats were observed carpeting the sediment at 46-99% of the sample sites. Occurrence of filamentous algae at the sampling sites has varied, but has remained high.

Plant growth in Squaw Lake would be favored by abundant nutrients in the lake, gradual slopes of the littoral zone on the north and south ends, shallow depths of the bays and the dominance of favorable silt sediments. However, very poor water clarity, soft water, steeply-sloped littoral zone on the east and west shores and fluctuating water levels would limit plant growth.

25 species have occurred in Squaw Lake, more than half of the species (17) have been emergent species. *Lemna minor* (small duckweed) was the dominant species in 2005, dominating all depth zones and exhibiting a growth form of above average density. *Typha latifolia* (cattail) was sub-dominant. The prevalence of species adapted to poor water clarity (emergents, *Elodea canadensis* (common waterweed) and *L. minor*) suggest that water clarity is an important factor determining the structure of the plant community.

Aquatic plants colonized 4% of the total lake area and 36% of the littoral zone in 2005. The most abundant plant growth (highest frequency of vegetated sites, greatest species richness, highest total occurrence of aquatic plants and highest total density of aquatic plants) has been in the 0-1.5 ft. depth zone.

The aquatic plant community is characterized by poor species diversity, low quality, a shallow maximum rooting depth, low ratio of submergent species, a high tolerance to disturbance and a condition far from an undisturbed condition.

Changes in the Aquatic Plant Community

Significant changes have occurred in the Squaw Lake aquatic plant community. The aquatic plant community that was first surveyed in 1986 was only 22-49% similar to the aquatic plant community of 2005. The composition of the aquatic plant community changed significantly between 1986 and 1989; appeared to be in a period of stabilization during 1989-1995 and significant change occurred again between 1995 and 2005.

From 1986 to 2005, there was increases in the number of species, the percentage of vegetated sites, the coverage of emergents, the coverage of free-floating-species, the coverage of submergent, the quality of the plant community, the diversity of species, the community's tolerance to disturbance and its closeness to an undisturbed condition. Species Richness increased the most. *Phalaris arundinacea* (reed canary grass) is the species that has increased the most and *Eleocharis acicularis* (needle spikerush) has decreased the most. However, these parameters varied up and down within this time period.

1986

Vegetation was most sparse throughout the lake in with the fewest number of aquatic plant species, lowest species richness, lowest quality, lowest percentage of vegetated sites, lowest percentage of sites with rooted vegetation, lowest total occurrence of aquatic plants, lowest total density of plants, shallow maximum rooting depth (1 ft) and lowest coverage of emergent and submergent vegetation. The Average Coefficient of Conservatism and Floristic Quality Index placed Squaw Lake among the group of lakes in the state and region most tolerant of disturbance and farthest from and undisturbed condition.

1989-1995

The abundance of aquatic vegetation increased during this time period, with dramatic increases in number of species, the quality of the community, percent coverage of submergent vegetation and maximum rooting depth. In 1995, the aquatic plant community appeared to be at its highest abundance: the greatest total occurrence of plants, highest total density of plant growth, greatest number of species, greatest species richness and greatest cover of emergent vegetation. The plant community in 1989-1995 appeared to be subjected to less disturbance. *Elodea canadensis* (common waterweed) was at its greatest frequency and density during this time.

1998

In 1998, there was a dramatic reversal in the aquatic plant community in Squaw Lake; nearly every measure of the aquatic plant community decreased to the sparse level of plant growth found in 1986. The number of species decreased and species diversity decreased to its lowest. The 1998 aquatic plant community was at its lowest diversity (AMCI) and highest disturbance (FQI).

2001-2005

The aquatic plant community improved somewhat.

These changes may be due to the fluctuating water levels in Squaw Lake; plant growth can not immediately adjust to new water levels. This is likely the reason that the actual maximum rooting depth in Squaw Lake has fluctuated above and below the predicted maximum rooting depth. In years with high water levels, the lake supported greater total occurrence of aquatic plants, total density of plants, diversity of species and species richness. The plant community was closer to an undisturbed condition then also. Years of low water levels saw a reverse in all of these parameters.

Shoreline Impacts

A large portion of the shoreline on Squaw Lake is protected by native vegetation, covering 89% of the shore in 2005. Disturbed shoreline is commonly occurring at the sample sites and covers 11% of the shore. Cultivated lawn and hard structures were disturbed shorelines type that were common to abundant around the lake. Hard structures and cultivated lawn result in increased run-off to the lake that is not filtered as would be with natural shoreline. Cultivated lawn can also deliver fertilizers, pest wastes and other toxic substances to the lake.

Shoreline restoration demonstration sites have been established on riparian properties on Squaw Lake and are contributing to natural shoreline. These sites will provide beauty and wildlife habitat along the Squaw Lake shoreline and, at the same time, help protect water quality in Squaw Lake.

To determine if there was a difference in the aquatic plant community at the sites with lawn, the aquatic plant transect sites off sites with 100% natural shoreline were compared to aquatic plant transect sites off shoreline that contained any amount of lawn or other disturbance (Appendices XXIV-XXVII).

The comparison of various parameters indicate that disturbance on the shore has impacted the aquatic plant community at those sites (Table 14).

Disturbance has impacted the aquatic plant community in Squaw Lake. This is measured by the Average Coefficient of conservatism and Floristic Quality which indicate the natural shoreline sites are less tolerant of disturbance and closer to an undisturbed condition. The species most tolerant of disturbance occurs at a higher frequency and density at disturbed shore sites (Table 14).

The dominant species at both natural and disturbed shore was the same, but the sub-dominant species at natural shoreline was *Eleocharis acicularis* (needle spikerush) and at disturbed shore was *Phalaris arundinacea* (reed canary grass).

Natural shoreline sites provide more habitat through a higher percentage of vegetated sites and a higher colonization of important submerged vegetation.

Table 14. Comparison of the Aquatic Plant Community at Natural Shoreline Sites and Disturbed Shoreline Sites.

Parameter		**Natural Shoreline**	**Disturbed Shoreline**
Average coefficient of Conservatism		4.5	4.3
Floristic quality Index		14.23	13.59
Percent of Vegetated sites		37%	31%
Colonization of Submerged vegetation		15%	8%
Most Tolerant species	Frequency	2%	15%
	Mean Density	0.04	0.21

V. CONCLUSIONS

Squaw Lake has been a hypereutrophic lake with very poor water quality. High nutrient levels support the growth of abundant planktonic and filamentous algae that cause very poor water clarity. However, since 1986, the concentration of phosphorus (nutrients) and chlorophyll (algae) have decreased. Aquatic plant growth in Squaw Lake is limited by the soft water, steep littoral zone in some portions of the lake, fluctuating water levels and very poor water clarity.

Lemna minor (duckweed) was the dominant species in 2005, dominating all depth zones and exhibiting a growth form of above average density. *Typha latifolia* (common cattail) was sub-dominant. Aquatic plant growth is sparse, colonizing only 4% of the total lake area and 36% of the littoral zone.

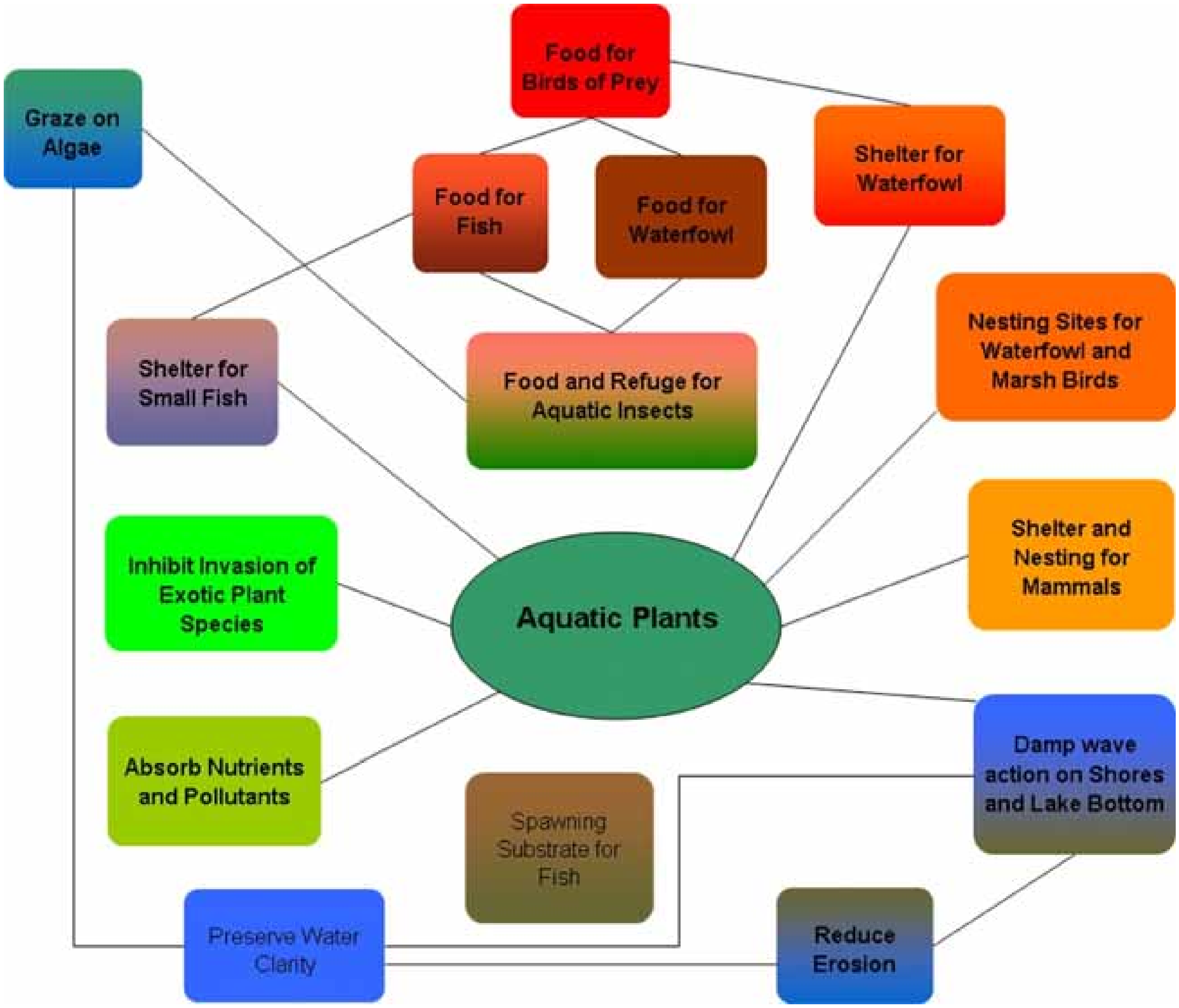
The 0-1.5 ft. depth zone supported the most abundant plant growth, reflecting the poor clarity. The aquatic plant community is characterized by poor species diversity, low quality, a high tolerance to disturbance and a condition far from an undisturbed condition.

The aquatic plant community has undergone significant change during 1986-2005 as measured by Coefficients of Community Similarity. Overall, there were increases in the number of species, the percentage of vegetated sites, the coverage of emergents, the coverage of free-floating-species, the coverage of submergent, the quality of the plant community, the diversity of species, the community's tolerance to disturbance and its closeness to an undisturbed condition. Species Richness increased the most. However, from one study to the next, these parameters varied up and down.

These changes may be due to the fluctuating water levels in Squaw Lake; plant growth can not immediately adjust to new water levels. This is likely the reason that the actual maximum rooting depth in Squaw Lake has fluctuated above and below the predicted maximum rooting depth. In years with high water levels, the lake supported greater total occurrence of aquatic plants, total density of plants, diversity of species and species richness. The plant community was closer to an undisturbed condition then also. Years of low water levels saw a reverse in all of these parameters.

Healthy plant communities improve water quality in many ways:

1) aquatic plants trap nutrients, debris, and pollutants entering a water body;
2) aquatic plants may absorb and break down the pollutants;
3) aquatic plants reduce erosion by stabilizing banks and shorelines, stabilizing bottoms, and reduce wave action that could resuspend sediments;
4) aquatic plants remove nutrients that would otherwise be available for algae blooms (Engel 1985).



The plants present in Squaw Lake provide habitat benefits for fish and wildlife (Table 15). However, only 36% of the sites supported vegetation. This level of vegetation is appropriate for largemouth bass, but not for young fish and panfish that hold an important position in the food chain of a lake. Approximately 4% of the entire lake surface has vegetation. This is less than the desired 20-30% vegetation over an entire lake (Miller et. al. 1989).

Pike, perch, and largemouth bass require vegetation for cover when young. Vegetation is the key to habitat for black crappies, bluegills, and sunfish (Dibble et. al. 1997). Seven to ten times more fish are found in vegetated areas than in open areas (Kilgore et. al. 1993).

Management Recommendations

1) Lake District cooperate with nutrient management programs in the relatively large watershed: responsible placement of manure which has been identified as a major source and conservation practices on cropland which is also identified as a

large nutrient source to Squaw Lake.

2) Lake residents discontinue any lawn fertilizer use that may be occurring on lakeshore properties.
3) Lake residents maintain septic systems to reduce nutrient input.
4) Lake residents protect and expand natural shorelines. Increased natural shoreline is not only beneficial to the water quality, but also to wildlife habitat. The lower Average Coefficient of Conservatism, lower Floristic Quality Index and higher frequency and density of disturbance tolerant species at disturbed shoreline sites indicate lawn and hard structure has impacted the aquatic plant community. A species that protects the lake bottom is less dominant at disturbed sites. This does impact the habitat. Lower percentage of vegetated sites and lower cover of submergent vegetation was found at disturbed sites.
    a) Continue monitoring of the shoreline restoration demonstration sites.
    b) Expand the shoreline restoration projects to include more participants.
    c) Reduce the amount of cultivated lawn near the shore and allow buffer zones of native vegetation to develop.
    d) Re-vegetate eroded areas.
    e) Minimize the placement of hard structures and surfaces along the shoreline.

The goal is to improve water quality in Squaw Lake. Improved water quality may allow aquatic plant species found at low frequencies to expand and flourish. Better clarity could also allow plants to grow in deeper water where they could help to stabilize the sediment and extend the fish habitat. A plant community with higher diversity and better distribution would provide better habitat for fish and wildlife.

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