Southeast Wisconsin's
Pewaukee Lake
Biological Evaluation 2002

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Executive Summary

This study was conducted during late spring through early fall of 2002 to evaluate the status of Pewaukee Lake from a biological perspective. Regular biological assessments can provide a means of monitoring lake quality. Biological monitoring involves sampling organisms that live in the lake and based on the variety and the characteristics of these organisms determining the quality of the lake. If a lake is highly polluted there will usually be little variety and high numbers of individuals that can tolerate pollution, excessive nutrients and low oxygen levels. Lakes that have a wide variety of species including some that are sensitive to pollution and require good levels of oxygen, moderate temperatures, and limited nutrient levels are considered healthy. Healthy lakes are usually aesthetically pleasing and support a wide variety of uses including fishing, boating and swimming. A prior biological evaluation conducted during the summer of 2000 provided a baseline for near term comparison. Earlier studies completed by the Wisconsin DNR and Southeastern Wisconsin Regional Planning Commission (SEWRPC 2003) allow longer term more comprehensive assessment of the lake and its surrounding watershed. Three groups of organisms were sampled for this study; aquatic plants, macroinvertebrates (mainly insect larvae), and zooplankton (water fleas). Water quality data was also collected to provide a context for understanding the community of plants and animals living in the lake.

The results of this study indicate that Pewaukee Lake is moderately healthy with some characteristics of a lake suffering from excessive nutrients. Plant diversity increased slightly since the 2000 survey completed by SEWRPC which continues a trend of increased plant diversity since 1988 (SEWRPC 2003). This would indicate that the current harvesting program is effective in encouraging the recovery of native species of plants in the face of competition from the invader species Eurasion water milfoil. In 2002 and in 2000 collections two types of insect larvae dominated samples taken from the bottom sediments of the lake. These insects, the non-biting midge (Chironomidae) and the phantom midge (*Chaoborus sp.*) both can survive in low oxygen environments. These results indicate that the bottom of Pewaukee Lake suffers from low oxygen concentrations which could be the result of decomposition of excessive plant growth resulting from excess nutrients in the lake. Zooplankton collected in 2002 showed a similar composition of major types to that seen since 1976 indicating a stable environment in the water column of the lake. These organisms feed on algae and are regular prey of small bluegills, minnows, and black crappie. With this position in the middle of the food chain a stable mix of zooplankton types provides some indication that Pewaukee Lake is a healthy system. The two biological monitoring studies (2000 and 2002) and comparisons to prior lake evaluations (SEWRPC 2003) provide a general sense that Pewaukee Lake is very productive yet maintains a healthy community of plants and animals.

Introduction

One of the most successful ways to monitor biological systems is to directly observe the plant and animal communities that live in them. Aquatic plants and animals are useful indicators of water quality, because they are constantly exposed to various stressors. They not only reflect the current conditions of a lake system, but also any changes that may have occurred in the past. The data collected by this type of study is very helpful in managing aquatic resources and ecosystems (EPA 2003a). This can be accomplished through an annual or bi-annual biological monitoring program.

Biological monitoring programs use biocriteria to define the natural condition of a healthy lake community (EPA 2001). Biocriteria include the condition and numbers of types of fish, insects, algae, plants, and other organisms that provide direct and accurate information about the health of a lake (Gurtz 1994, Carlson 1977, Stemberger and Lazorchak 1994, EPA 2003b). The monitoring of these parts of an aquatic environment can ensure that problems will be identified before the whole system is degraded. They also allow assessment and monitoring of the effects of lake and watershed management practices. Assessment and monitoring can be done through biological surveys. These surveys involve the collection of organisms included in the biocriteria. Surveys can provide realistic evidence of the water's quality, because they directly measure the aquatic community's response to pollutants or stressors (Karr and Chu 1999, EPA 2003).

Benthic macroinvertebrates (bottom dwelling insect larvae, aquatic worms, snails, crayfish, etc.) are long-term indicators of water quality because they live in the sediment year round, and are easy to sample (Cairns and Pratt 1993, Saether 1979). Most species have life stages that are sensitive to stressors and pollutants. Macroinvertebrates have been classified according to their sensitivity to pollution. Only a few types of macroinvertebrates have high tolerance for pollution. For example, mayfly larvae are very sensitive to pollution, while oligochaetes (aquatic worms) have a high tolerance for pollution. These tolerance levels result in useful measures for determining water quality (Blocksom et al. 2002). Therefore, a high number of different types of macroinvertebrates indicate low levels of stressors and pollution; while a low number of types often indicate high levels of pollution (Resh and Jackson 1993, Gaufin and Tarzwell 1952).

Zooplankton (water fleas) are also good indicators of water quality adding further credibility to a lake monitoring project. The diversity (number of types) of zooplankton is reduced and relative abundance changes in conditions of chemical stress and excess nutrient loading (Harig and Bain 1998, DeMott and Gulati 1999).

Unlike benthic macroinvertebrates and zooplankton, aquatic macrophyte (plant) populations can be observed from the shoreline. Macrophytes are an integral part of lakes, by providing cover for fish and invertebrates (Cheruvelil et al. 2002, Valley and Bremigan 2002, Schneider 1999, Hatzenbeler et al. 2000, EPA 2001). However, overabundant macrophytes lead to conditions that interfere with recreational activities and the aesthetic appeal of the lake (Hoyer and Canfield 1997). The diversity principle applies here also. There are fewer plant types in higher stress areas, such as lakes with high levels of nutrients. Exotic species of macrophytes have a tendency to out compete native species, meaning that lakes over run by exotic species are often degraded systems (Nichols 1999, Emmons et al. 1999, Holm et al. 1969).

Water chemistry and physical parameter measurements can provide evidence to support biomonitoring results. Samples of lake water can provide information about levels of nutrients (such as nitrogen and phosphorus) as well as evidence of algal growth based on chlorophyll A concentrations (Wetzel 2001). Physical characteristics such as temperature, and dissolved oxygen concentration can help explain results found in the benthic macroinvertebrate, zooplankton, and aquatic macrophyte samples. Total phosphorus concentrations can be used to predict or explain plant and algae growth (Carpenter et al. 1999, Carlson 1977, Kevern et al. 1979). Chlorophyll A concentration indicates the level of algae present in the water (Wetzel 2001). All organisms have specific tolerance ranges for temperature and dissolved oxygen concentration in which they can live. Levels near or outside their tolerance range may result in death of the organism. Measuring these and other physical parameters in various sections of the lake can help explain abundance and distribution of organisms living in the lake.

Pewaukee Lake in Waukesha County, Wisconsin has recently been dealing with dense algae blooms and abundant aquatic plant growth. Previous studies have classified Pewaukee as a eutrophic lake (SEWRPC 1984). The purpose of this study is to determine the current state of Pewaukee Lake and to continue a biannual monitoring program of Pewaukee Lake initiated in 2000 (Schmoldt and Anderson 2000).

Methods

From late spring through early fall of 2002; benthic macroinvertebrates, zooplankton, aquatic plants, and water samples were collected from Pewaukee Lake, Waukesha County, WI. All sampling was done at sites established in 2000 which represent the three main sections of the lake (Figure 1).

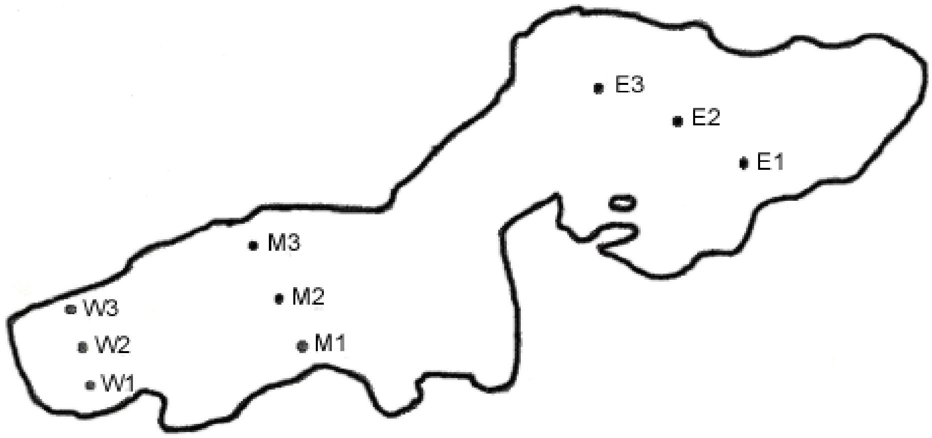

Figure 1: Sampling locations for Pewaukee Lake, WI.

The sampling procedures for benthic macroinvertebrates and zooplankton followed those established by Schmoldt and Anderson (2000). Benthic macroinvertebrate samples were collected at all sites during May – October, 2002. Three grabs with a standard Eckman Dredge (152mm x 152mm) were made at each location. The sediment obtained was emptied into a Standard Mesh SS screen #30 (541µm) bottomed bucket to filter the organisms from the fine sediment. The remaining contents of the bucket were emptied into a plastic bag and placed in a cooler with ice for temporary preservation. The bagged samples were taken to the laboratory where they could be sorted. All of the benthic macroinvertebrates were removed from the sediment with forceps and placed in jars containing 70% isopropyl alcohol. An Olympus zoom dissecting microscope, model LMS-225R, was used to aid in the identification and counting of the benthic macroinvertebrates. Edmondson (1959), Merrit and Cummins (1978), and Pennek (1953) were used for identification purposes. After identification and counting was completed the number of benthic macroinvertebrates per square meter of sediment was calculated.

Zooplankton were sampled from three of the nine stations during May – October, 2002. Samples were collected between 9:00am and 2:00pm, from sites W2, M2, and E2 (Figure 1). A water pump and hose (5cm diameter) assembly was crafted so an intake bucket with lateral intake vents could reach a depth of ten meters. An average pump time was set to be equivalent to five gallons of water. The pump speed could be manually altered in order to limit the stress levels on the zooplankton. At sites W2 and E2, three replicate samples of water were pumped through a 153 um zooplankton net at each depth (surface, mid-depth, and near the bottom). At site M2, three replicate samples were taken from the surface, half the distance to the thermocline, at the thermocline, half the distance to the bottom from the thermocline, and near the bottom. Club soda was added to each sample to relax the zooplankton before preserving in 80% ethyl alcohol. Finally, each sample jar contained 50ml of solution.

Identification and enumeration of zooplankton was performed in the lab using a Sedgwick-Rafter cell and 400x binocular scope. Each sample jar was placed on a stirring plate to ensure a homogenous mixture of zooplankton in the sample. Three separate 1ml sub samples were taken from each homogenous mixture and placed in Sedgwick-Rafter cells for identification and tallying. Edmondson (1959) and Pennak (1953) were used to aid in zooplankton identification. Once completed, an estimate of the number of zooplankton per liter of lake water was calculated.

The water chemistry of Pewaukee Lake was evaluated during June – October 2002. A pipe and bottle were used to sample the water column from the surface to a depth of two meters at sites W2, M2, and E2 (Figure 1). The water samples were taken to the Wisconsin State Laboratory of Hygiene, Madison, WI, to be tested for: Alkalinity, Silica, Nutrients (Nitrate + Nitrite, Total Kjeldahl Nitrogen, Total Phosphorus, and Ammonia-Nitrogen), Dissolved Reactive Phosphorus, Sulfate I. C., Metals (Calcium, Magnesium, Sodium, Potassium, Hardness), and Chlorophyll A. Preservatives were added to the Nutrients and Metals samples. The preserved samples were checked to confirm each had a Ph of 2 or less. All sample bottles were placed in a cooler with ice until they could be tested. Water clarity was measured with a Secchi disc. Temperature, Ph, conductivity and dissolved oxygen were measured with a DataSonde 4 Hydrolab unit. The time, weather, and lake conditions were also recorded.

Aquatic plants were also sampled during June - October at fourteen transects around the lake (Figure 2). The fourteen transects are a subset of transects established by the DNR for Pewaukee Lake plant surveys (SWRPC 1984). The sampling procedure was adapted from Jessen and Lound (1962).

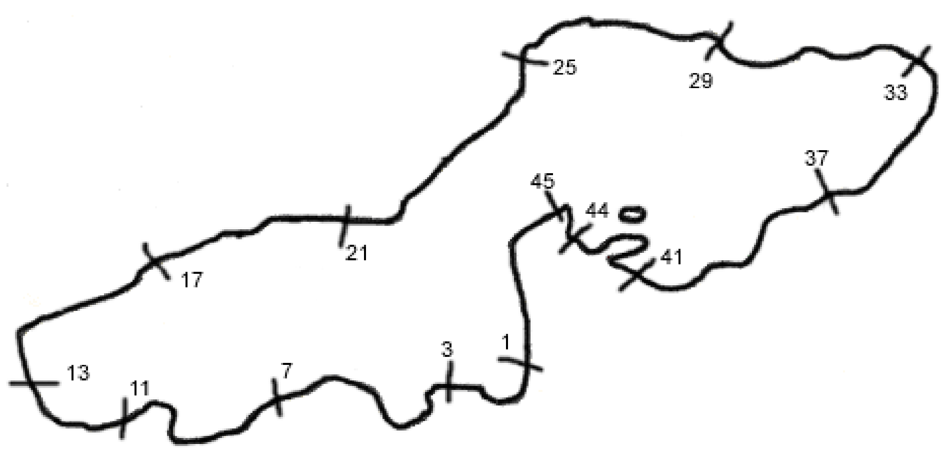

Figure 2: Transect locations for plant sampling on Pewaukee Lake, WI.

Each transect included four samples or rake pulls from the end of the boat at depths of 1.5, 5, 9, and 11 feet. Plants were identified in the field using Borman et al. (1997). A density rating was then calculated for each depth sampled and recorded along with the substrate type.

Results

Macroinvertebrates - From late spring to early fall of 2002, a total of 1,237 benthic macroinvertebrates were collected in Pewaukee Lake. An analysis of the samples revealed 40 different types of organisms. Overall, the most common macroinvertebrate was *Chironomus* a non biting midge. Members of the Chironomid family were found throughout the lake and made up the majority of the organisms identified. The most diverse sample, with 11 different taxa, was taken in May; and the least diverse sample, with 3 taxa, was collected in October (Table 1). Zebra mussels, *Dreissena polymorpha*, a recent invader of Pewaukee Lake, were only found on the west side of the lake (Tables A1 – A6).

Table 1: Average number by taxa of benthic macroinvertebrates per square meter in Pewaukee Lake, WI, based on Eckman dredge samples taken in May to October, 2002.

	May	June	July	August	September	October
Subclass: Hirudinea (Leech)	11.3	17.7	0.0	0.0	0.0	0.0
Order: Ephemeroptera (Mayfly)	51.5	24.2	1.6	4.8	0.0	12.9
Order: Oligochaeta (Annelid)	27.4	22.5	22.5	11.3	3.2	0.0
Family: Dixidae (Fly)	1.6	0.0	0.0	0.0	0.0	0.0
Family: Ceratopogonidae (Biting Midge)	4.8	1.6	0.0	0.0	0.0	0.0
Family: Chaoboridae (Phantom Midge)	46.7	133.7	20.9	11.3	48.3	29.0
Family: Chironomidae (Midge)	296.3	508.9	351.0	99.8	43.5	56.4
Family: Chironomidae pupa	14.5	4.8	3.2	1.6	0.0	0.0
Family: Physidae (Snail)	1.6	0.0	0.0	0.0	0.0	0.0
Family: Haustoriidae (Amphipod)	54.8	6.4	0.0	0.0	0.0	0.0
Order: Hydracarina (Water Mite)	9.7	1.6	3.2	1.6	3.2	0.0
Genus: *Planaria*	9.7	0.0	0.0	1.6	0.0	0.0
Order: Trichoptera (Caddisfly)	3.2	0.0	0.0	0.0	0.0	0.0
Order: Odonata (Dragonfly)	1.6	0.0	0.0	0.0	0.0	0.0
Genus: *Dreissena (polymorpha)* (Zebra Mussel)	4.8	1.6	1.6	0.0	0.0	0.0

Monthly summary comparisons (Figure 3) show that June samples at all sites contained the most macroinvertebrates. The average number of macroinvertebrates increased from May to June and decreased drastically from June to August. Only a slight decrease in the average number was seen from August to October (Figure 3). There were substantial differences between the number of macroinvertebrates per square meter at the south, middle and north sampling sites in the east, middle, and west sections of the lake (Figures 4, 5, and 6) however no consistent pattern was noted that would indicate significant habitat differences between the north and south shores. The differences between the east, middle and west lake sections were also not consistent from month to month and no clear pattern could be found (Figure 7).

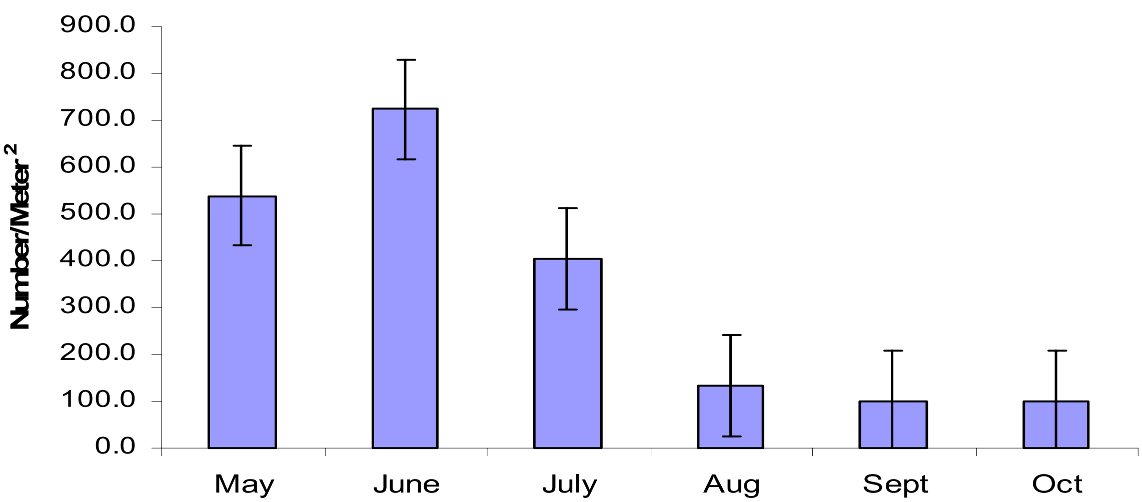

Figure 3: Average number of benthic macroinvertebrates per square meter in Pewaukee Lake, WI, based on Eckman dredge samples taken in May to October, 2002.

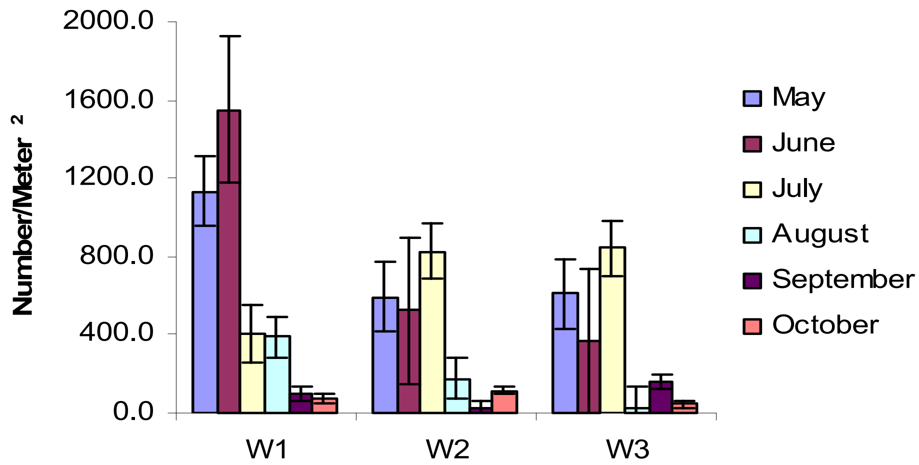

Figure 4: Estimated number of benthic macroinvertebrates per square meter in the west end of Pewaukee Lake, WI, based on Eckman dredge samples taken in May to October of 2002.

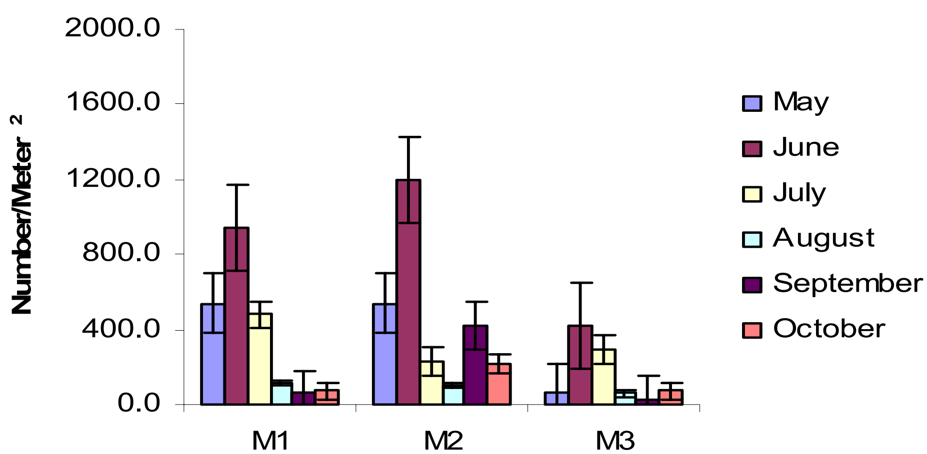

Figure 5: Estimated number of benthic macroinvertebrates per square meter in the middle of Pewaukee Lake, WI, based on Eckman dredge samples taken in May to October of 2002.

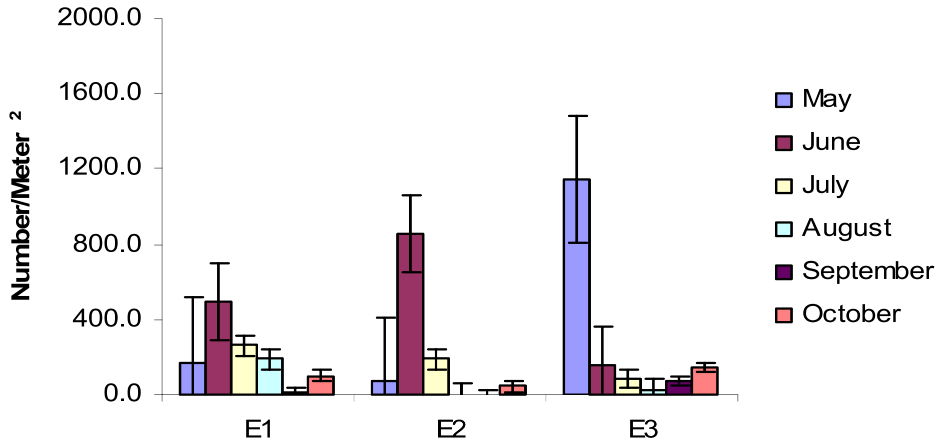

Figure 6: Estimated number of benthic macroinvertebrates per square meter in the east end of Pewaukee Lake, WI, based on Eckman dredge samples taken in May to October of 2002.

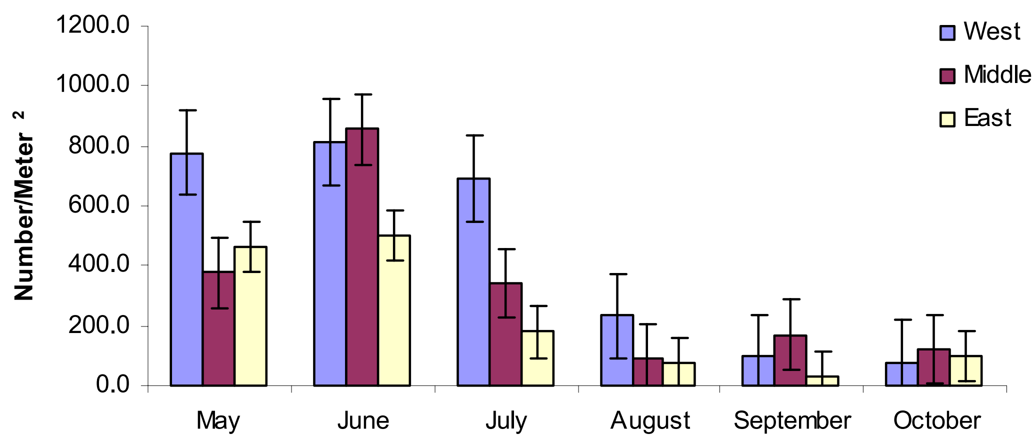

Figure 7: Average number of benthic macroinvertebrates per square meter in the west, middle, and east sections of Pewaukee Lake, WI, based on Eckman dredge samples taken in May to October of 2002.

<u>Zooplankton</u> - A total of 12,191 zooplankton were tallied in late spring to early fall of 2002 in Pewaukee Lake. Fourteen different types were identified (Table 2). The most common zooplankton group was the cladocera. Zooplankton were found throughout the lake, except below the thermocline where dissolved oxygen levels were very low.

Copepods clearly dominated samples in May while cladocerans were more abundant in June and October (Figure 9).

The number of zooplankton decreased from spring to summer, however in fall the numbers increased dramatically (Figure 8). The variety of species decreased each month, with October having the lowest number of species (Table 2). The average number of zooplankton per liter of water in the west section of the lake during October increased with depth however little change with depth was noted during May through September (Figure 10). Plankton density near the bottom was greatly reduced during July through September at the middle lake sampling site (Figure 11). On the east side of the lake zooplankton density was greatest in June and July at the middle depth and near the bottom (Figure 12). On average the west end of the lake had the greatest density of zooplankton during May and October while during June through September greater numbers were noted on the east side of the lake (Figure 13).

Table 2: Estimated average number of zooplankton per liter of water from Pewaukee Lake, WI, in May to October of 2002.

	May	June	July	August	September	October
Copepoda Cyclopoida	18.2	20.6	7.6	4.4	7.6	18.5
Copepoda Calanoida	23.9	13.8	5.2	8.0	8.5	25.8
Copepoda Harpacticoida	0.4	0.0	0.0	0.0	0.0	0.0
Nauplii	13.2	8.8	1.6	0.5	0.2	0.0
Allona costata	0.9	0.1	0.0	0.0	0.2	0.0
Chydorus sphaericus	9.0	7.0	0.3	0.0	0.1	0.4
Eubosmina coregoni	0.1	2.6	0.1	0.0	0.1	0.0
Bosmina longirostris	0.6	36.4	3.3	1.3	5.3	3.6
Ceriodaphnia sp.	0.1	5.5	12.5	3.2	0.2	0.0
Ceriodaphnia reticulata	0.0	0.0	0.0	0.0	0.0	0.0
Diaphanosoma leuchtenbergianum	0.0	1.6	0.4	10.8	0.5	1.0
Daphnia	1.2	2.8	0.1	0.5	1.0	57.6
Leptodora kindtii	0.0	0.0	0.0	0.0	0.3	0.0
Leydigia acanthocercoides	0.0	0.0	0.0	0.0	0.0	0.0
Ostracod *Ostracoda*	0.0	0.0	0.0	0.1	0.3	0.0
Unidentified Copepoda	0.7	0.3	0.0	0.0	0.0	0.0
Unidentified Cladocera	1.0	1.4	0.1	0.1	0.4	0.0
Copepoda Total	56.4	43.5	14.4	12.8	16.3	44.3
Cladocera Total	13.0	57.5	16.8	15.6	8.0	62.5
Total	69.4	101.0	31.2	28.6	24.5	106.8

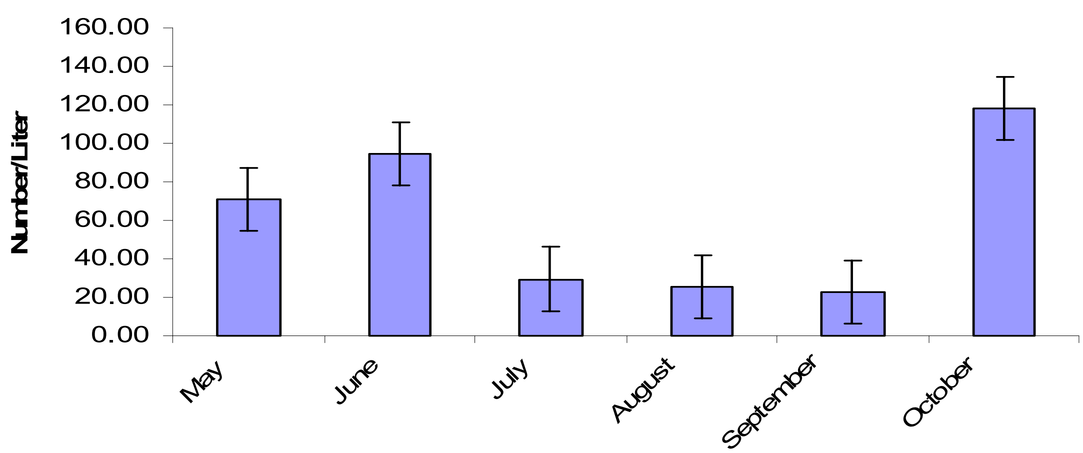

Figure 8: Average number of zooplankton per liter of water in Pewaukee Lake, WI, from May to October of 2002.

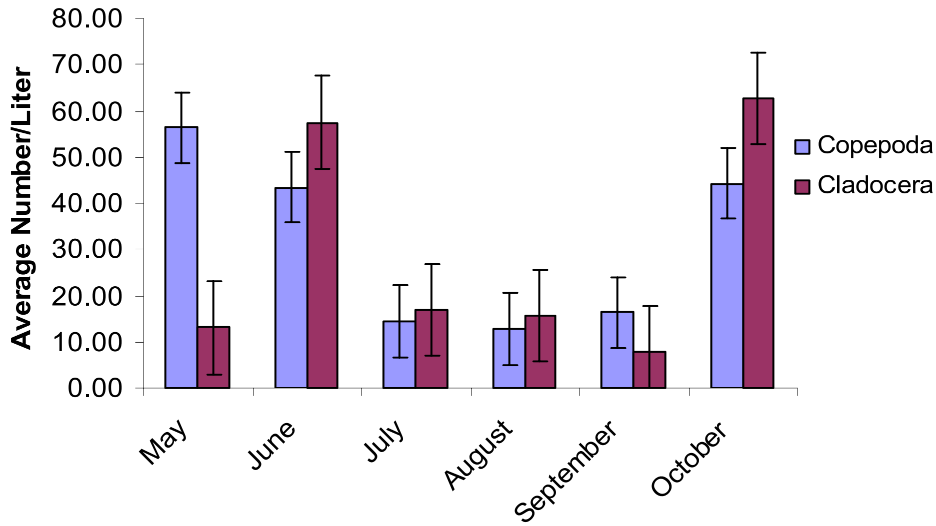

Figure 9: Average number of copepoda and cladocera zooplankton per liter of water in Pewaukee Lake, WI, from May to October of 2002.

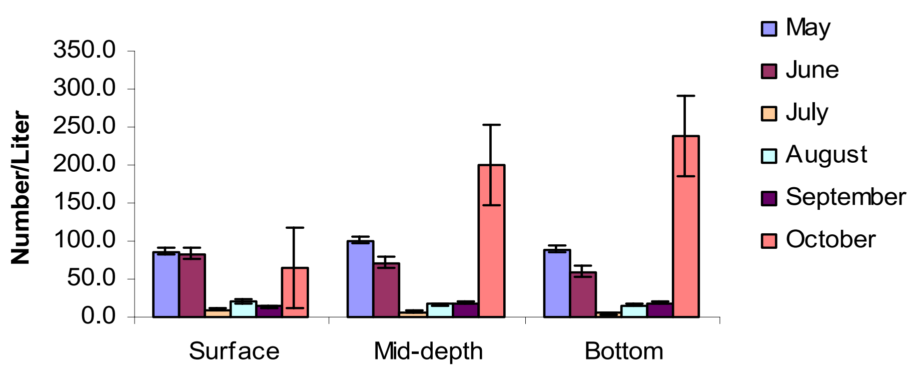

Figure 10: Average number of zooplankton per liter of water in the west end of Pewaukee Lake, WI, from May to October of 2002.

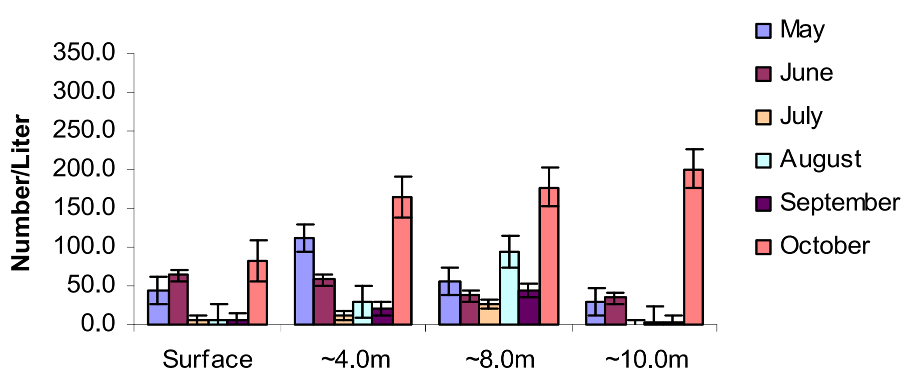

Figure 11: Average number of zooplankton per liter of water in the middle of Pewaukee Lake, WI, from May to October of 2002.

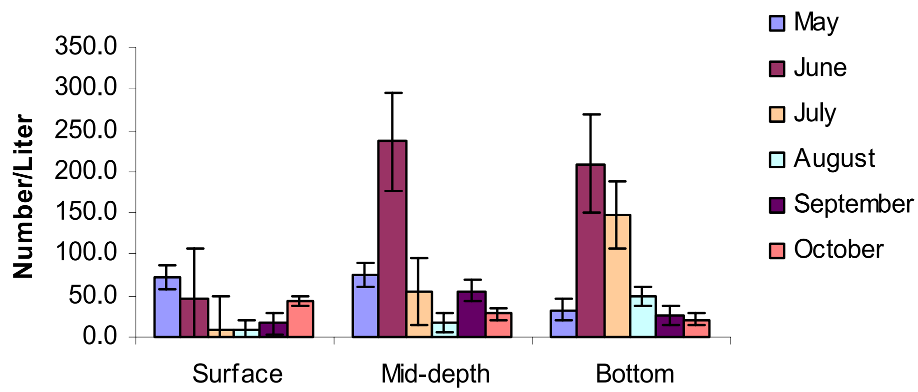

Figure 12: Average number of zooplankton per liter of water in the east end of Pewaukee Lake, WI, from May to October of 2002.

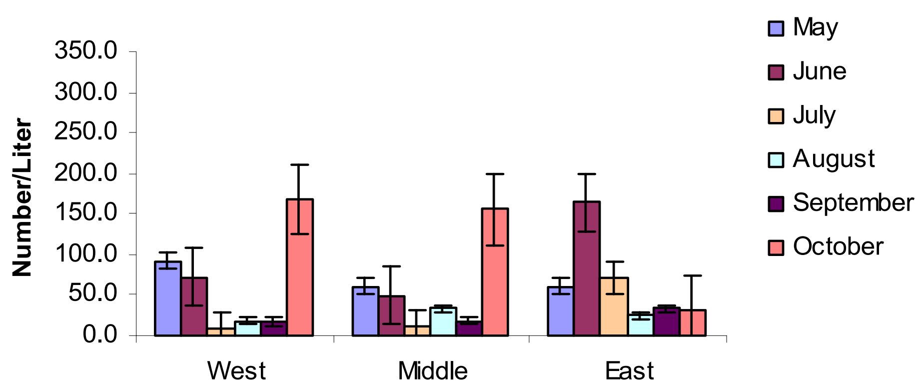

Figure 13: Average number of zooplankton per liter of water in the west, middle, and east sections of Pewaukee Lake, WI, from May to October of 2002.

Aquatic Plants - A total of nineteen species of aquatic plants were found in samples collected from Pewaukee Lake from June to October (Table 3). Eurasian water milfoil, *Myriophyllum Spicatum*, was the most abundant species found throughout the entire lake. Diversity of species decreased as the water depth increased (Figures 14 and 16). All of the species occurred in the 1.5 and 5 foot depths, and eleven species were found at the 9 foot depth. Only five species were found at the 11 foot depth in June; however, by

October only two species were found, Eurasian Water Milfoil and Coontail. The average frequency of most plants decreased from June to October; however July had an unusually low average frequency (Figure 15). The average density of plants decreased from summer into the fall (Figure 17). Overall, Eurasian Water Milfoil had the greatest density each month. Of the native plant species occurring in the lake, coontail, bushy pond weed and eel grass were the most abundant (Figures 15,16 and 17).

Table 3: Aquatic macrophyte species found each month, June to October of 2002, in Pewaukee Lake, WI. (X - "found at least once", XX - "found in each depth at every transect".)

	June	July	August	September	October
Coontail - *Ceratophyllum Demersum*	XX	XX	X	X	X
Muskgrass - *Chara Sp.*	X	X	X	X	X
Elodea - *Elodea Canadensis*	X	X	X	X	X
Water Star Grass - *Zosterella Dubia*	X	X	X		
Eurasian Water Milfoil - *Myriophyllum Spicatum*	XX	XX	XX	XX	XX
Native Water Milfoil - *Myriophyllum Sibiricum*	X			X	X
Bushy Pondweed - *Najas Flexilis*	XX	X	X	X	X
Large Leaf Pondweed - *P. Amplifolius*	X	X	X	X	X
Curly Leaf Pondweed - *P. Crispus*	X	X	X		
Sago - *P. Pectinatus*	X	X	X	X	X
Clasping Leaf Pondweed - *P. Richardsonii*		X	X		
Variable Pondweed - *P. Gramineus*	X	X	X	X	
Flatstem Pondweed - *P. Zosteriformis*	X	X	X	X	
Floating Leaf Pondweed - *P. Natans*			X		
Leafy Pondweed - *P. Foliosus*	X				
Bladderwort - *Utricularia Sp.*			X		
Eel Grass - *Vallisneria Americana*	X	X	X	X	X
White Water Lilly - *Nymphaea Tuberosa*	X			X	

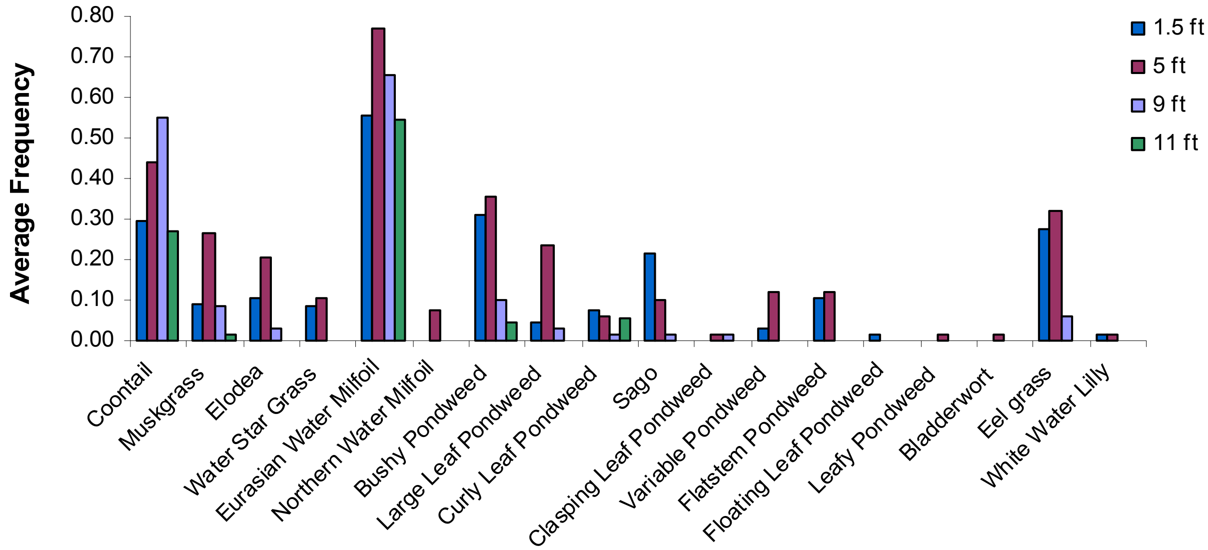

Figure 14: Average frequency per depth of aquatic macrophytes in Pewaukee Lake, WI, from June to October of 2002.

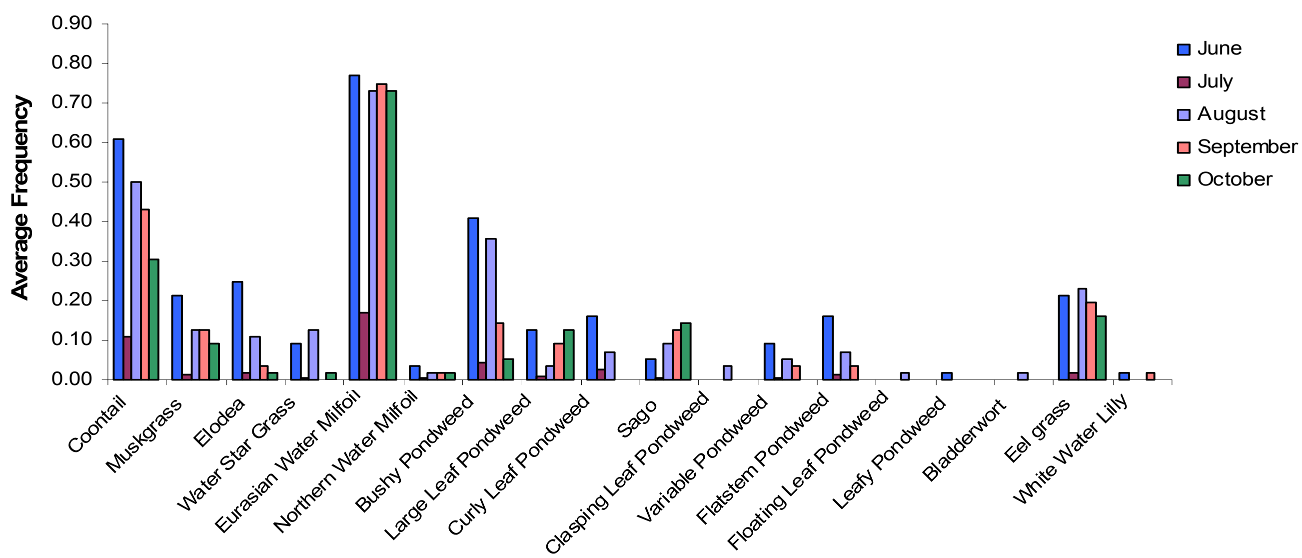

Figure 15: Average frequency of aquatic macrophytes per month in Pewaukee Lake, WI, from June to October of 2002.

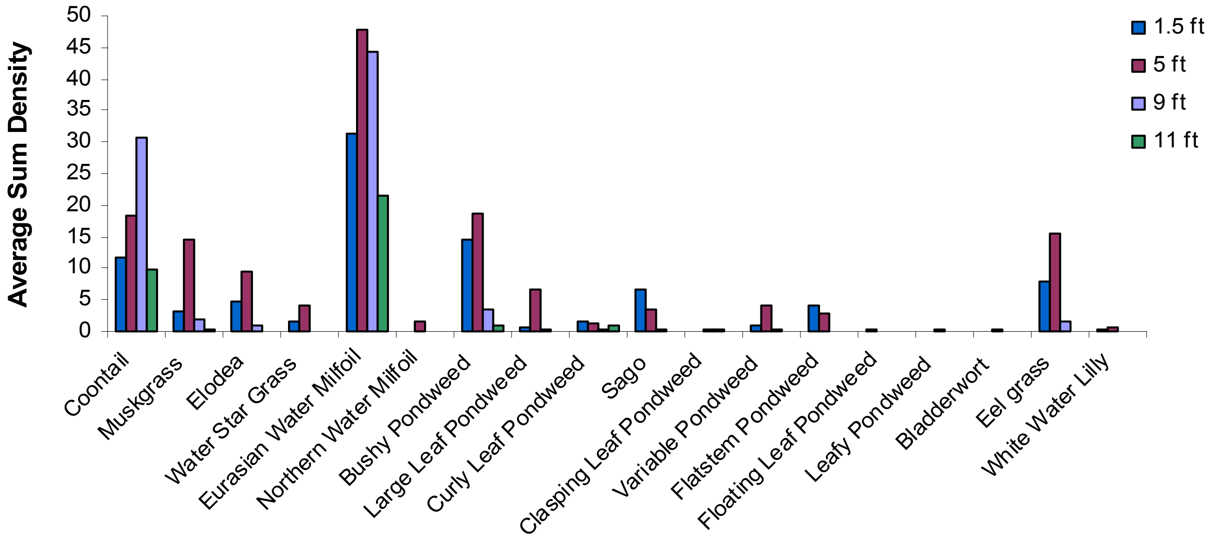

Figure 16: Average sum density of aquatic macrophytes per depth in Pewaukee Lake, WI, from June to October of 2002.

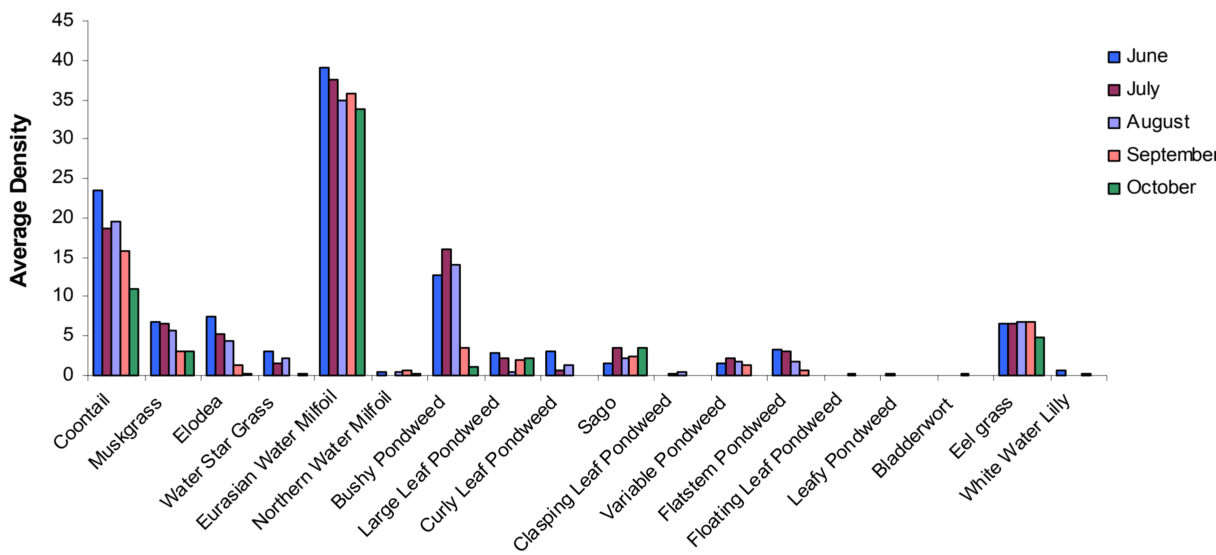

Figure 17: Average density of aquatic macrophytes per month in Pewaukee Lake, WI, from June to October of 2002.

Water Chemistry – Chemical levels in Pewaukee Lake were determined based on samples collected in June through October (Figure 18). Total phosphorus, a key nutrient in lakes, fluctuated between 0.02 mg/L and 0.03 mg/L until September when it increased to 0.05 mg/L in the east end of the Lake. Total kjeldahl nitrogen, another key nutrient, increased from 0.55 mg/L in June to 1.25 mg/L in September. The ratio of total nitrogen to total phosphorus is about 29:1. The chlorophyll-*a* levels increased from June to October, with the lowest average reading of 2.3 µg/L in June and the highest reading of 76.5 µg/L in September (Figure 18).

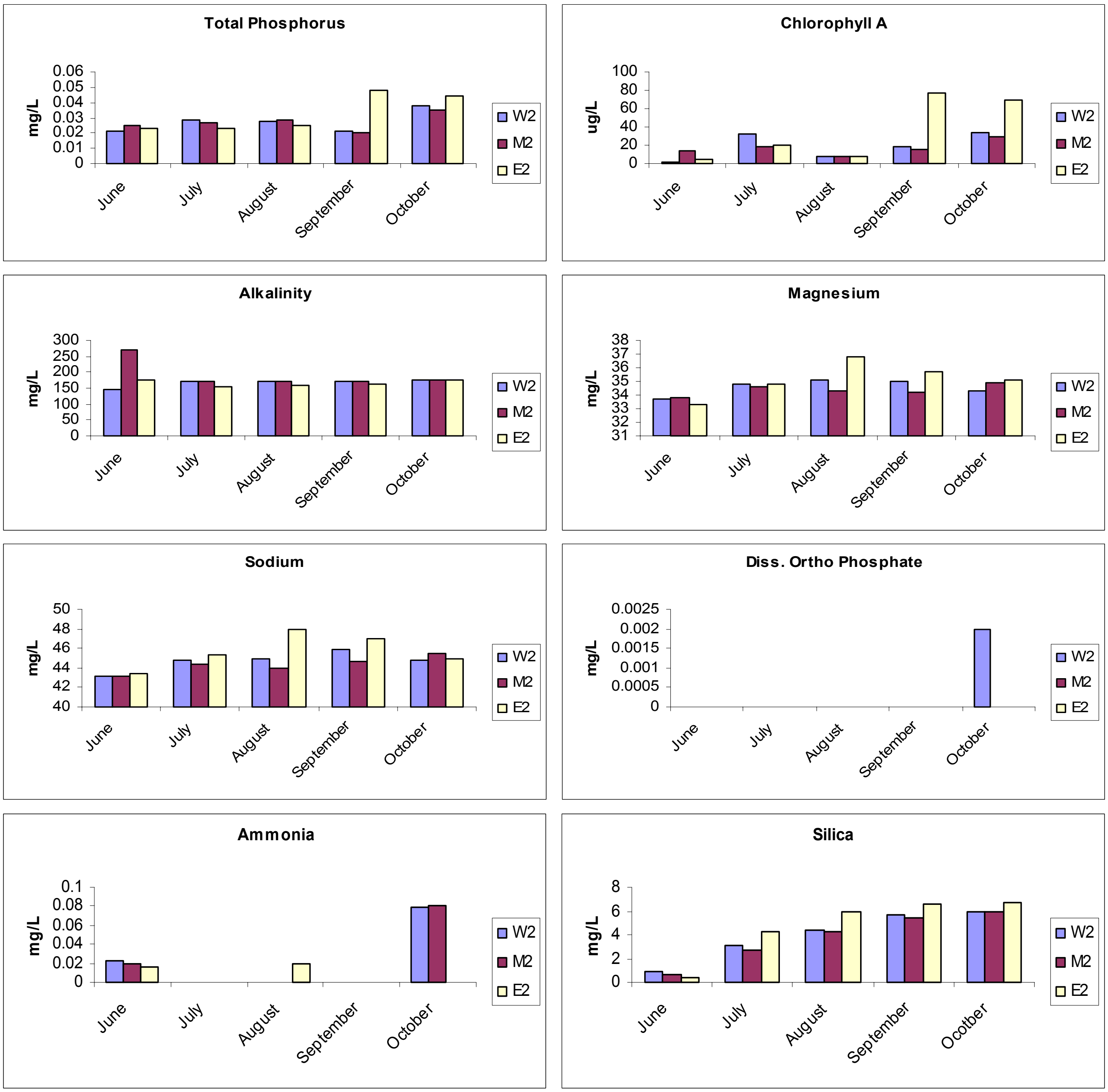

Figure 18: Chemical levels found in the western (W2), central (M2), and eastern (E2) basins of Pewaukee Lake, WI, from June to October of 2002.

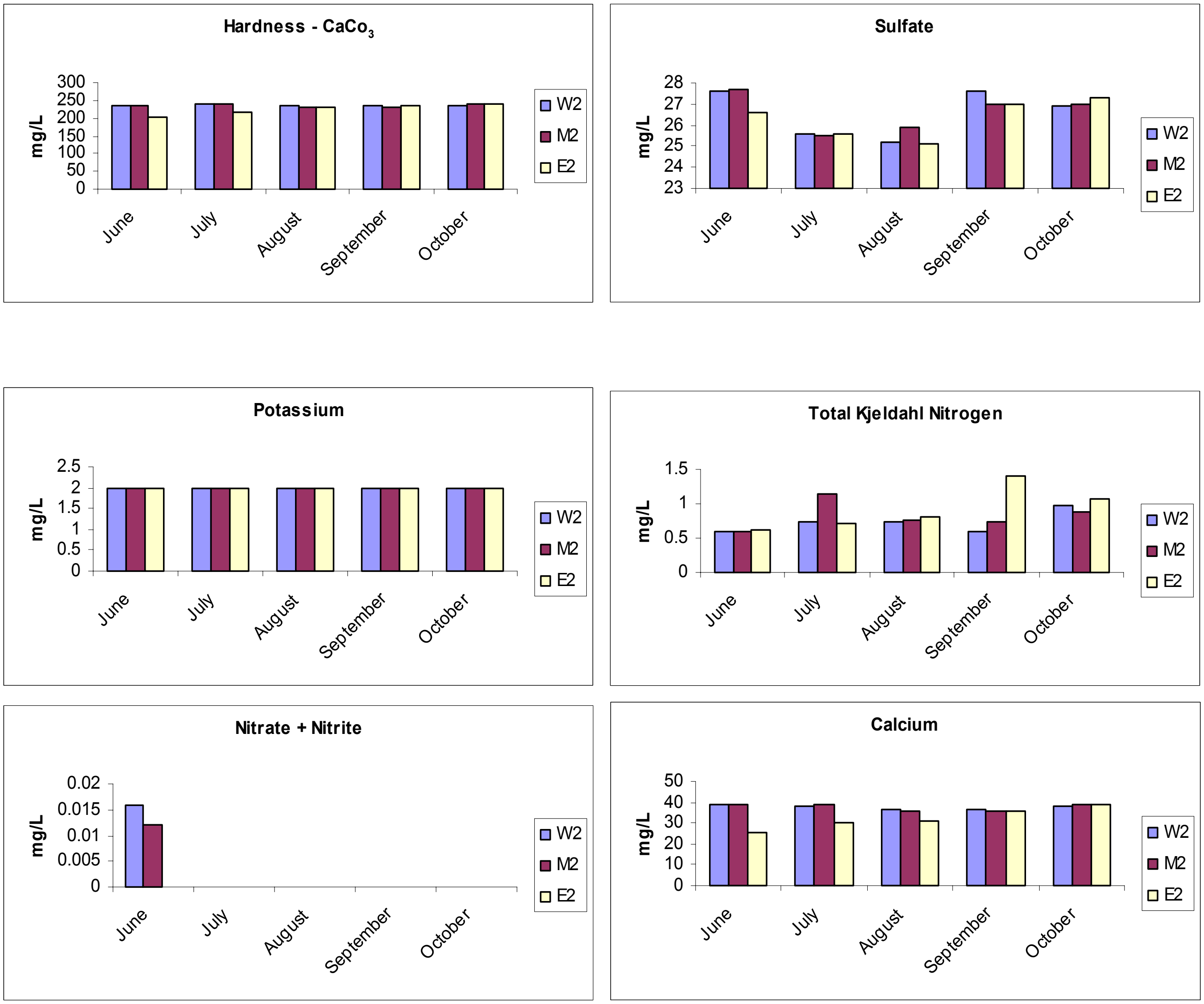

Figure 18 (continued): Chemical levels found in the western (W2), central (M2), and eastern (E2) basins of Pewaukee Lake, WI, from June to October of 2002.

The physical parameters of Pewaukee Lake changed from May to October due to summer stratification and fall turnover. In June, a noticeable thermocline developed in the central basin of the lake (Figure 20). From July to September, the dissolved oxygen concentrations dropped to zero below the thermocline (7 – 9 M depth). It is evident that fall turnover occurred prior to sampling in October since the dissolved oxygen concentrations do not fall below 8 mg/l throughout the water column in the central basin of the lake (Figure 20). In the west end of the lake, the warmest temperature in the water column ranged from 11.5°C in October to 26.7°C in July, and the lowest level of dissolved oxygen ranged from 9.4 mg/L in May to 5.9 mg/L in August (Figure 19). In the central basin the warmest temperatures were 8.0°C in October and 26.9°C in July, while the lowest concentrations of dissolved oxygen went from 11.5 mg/L in October to 0mg/L at 12 meters below the surface in July (Figure 20). In the east end, the warmest temperatures ranged from 11.6°C in October to 27.1°C in July, and the lowest levels of dissolved oxygen were 9.5 mg/L in May and 0.02 mg/L in September (Figure 21).

On average, water clarity, based on secchi disk measurements, decreased from May to August, however, it did increase in September (Figure 22). This decrease in clarity can be expected when looking at the chlorophyll-α levels, which increased from May to October (Figure 18). The seasonal pattern of water clarity varied in different sections of the lake. Clarity was very similar from month to month on the east side and tended to be lower that the central basin and the west side of the lake. Clarity in the central basin was greatest in May, decreased through June and July, increased slightly in August and improved greatly in September. A similar pattern was seen on the west side of the lake (Figure 18).

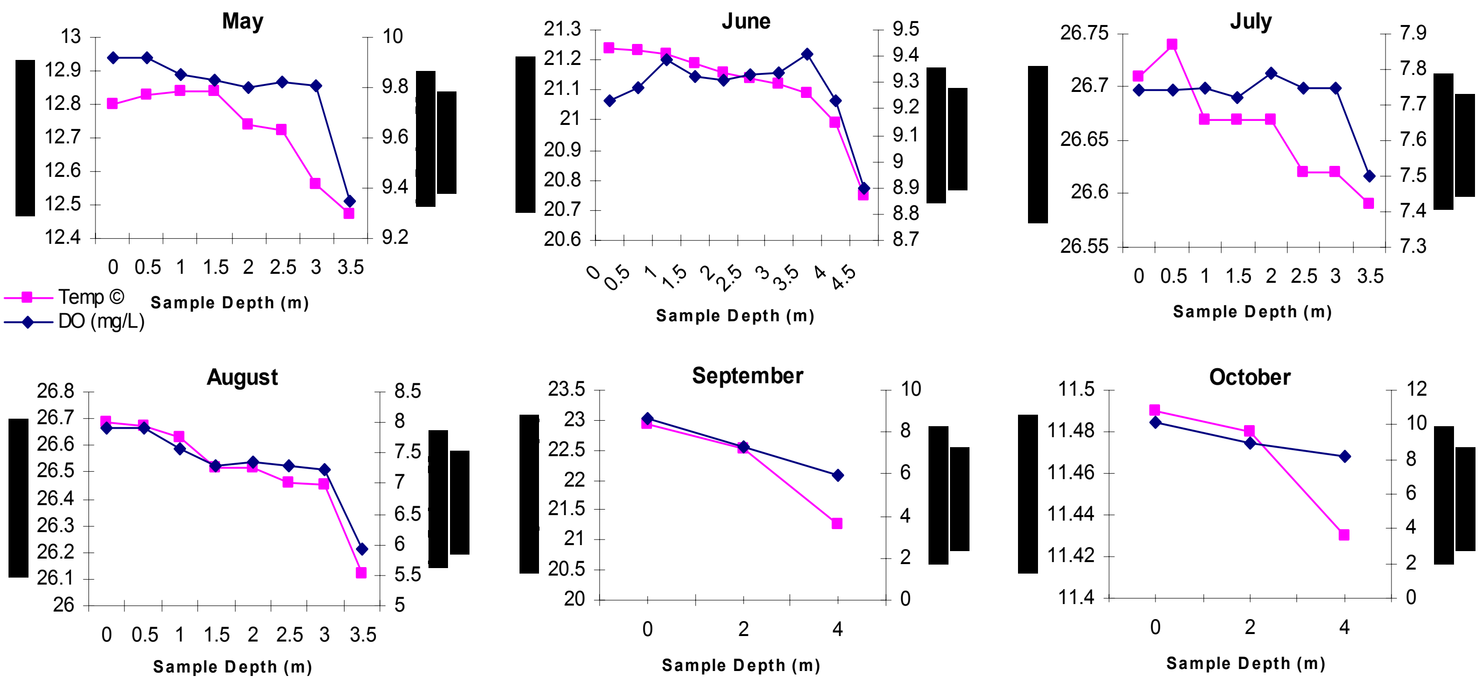

Figure 19: Temperature © and dissolved oxygen (mg/L) readings in Pewaukee Lake, WI, from May to October at sample site W2; taken with the Data Sonde 4 Hydrolab.

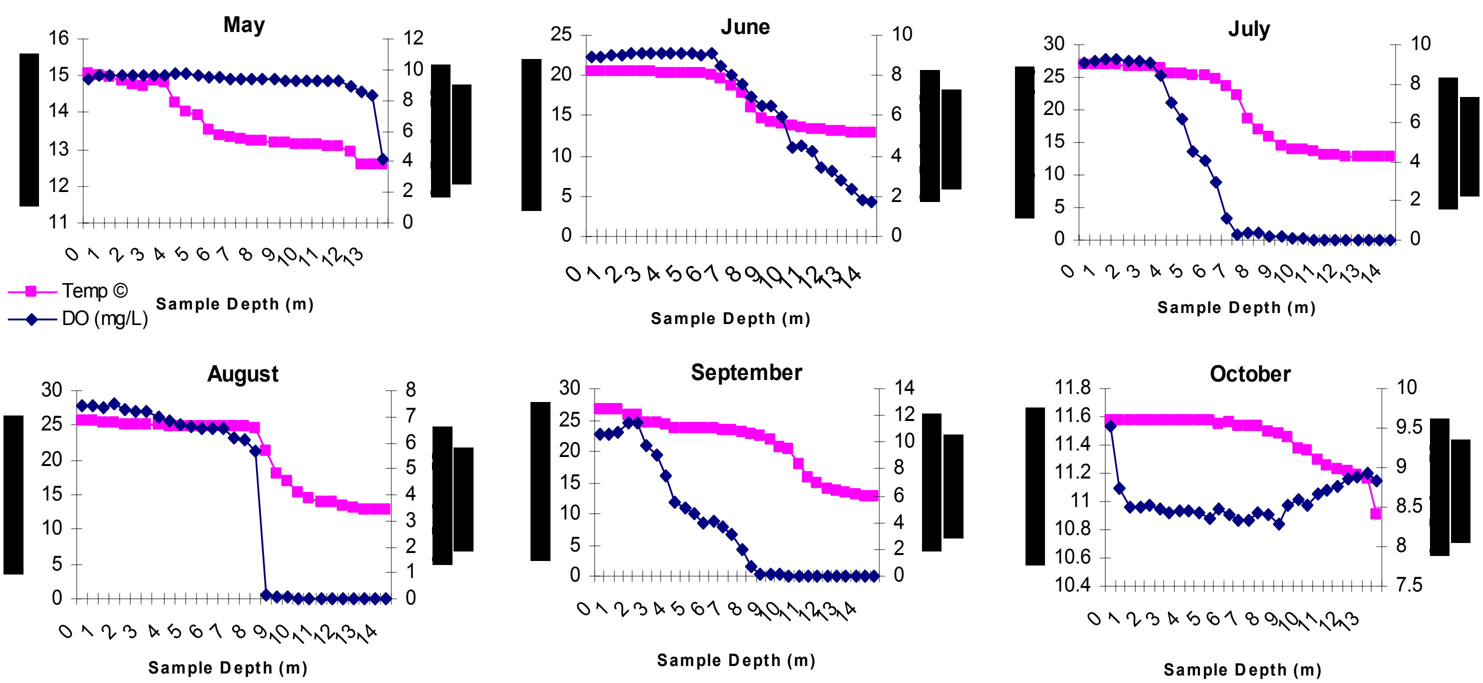

Figure 20: Temperature © and dissolved oxygen (mg/L) readings in Pewaukee Lake, WI, from May to October of 2002 at sample site M2; taken with the Data Sonde 4 Hydrolab.

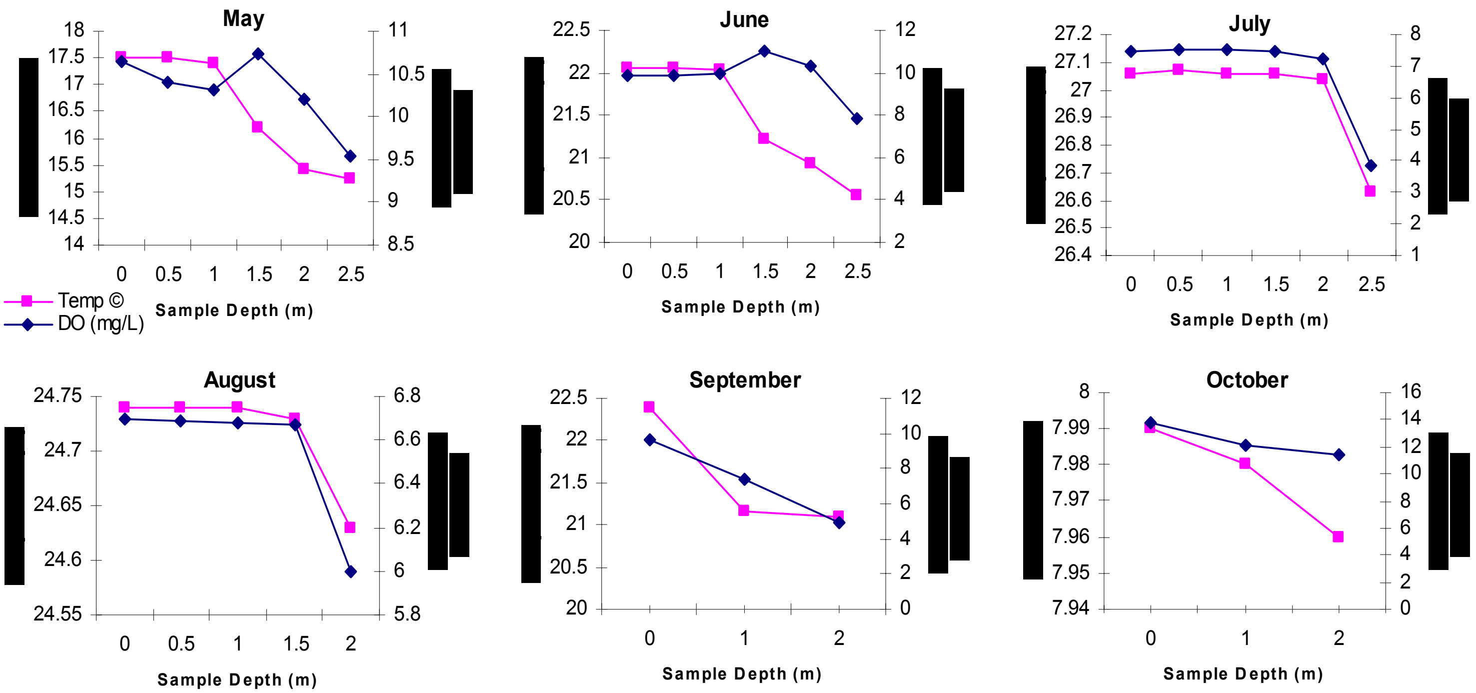

Figure 21: Temperature © and dissolved oxygen (mg/L) readings in Pewaukee Lake, WI, from May to October of 2002 at sample site E2; taken with the Data Sonde 4 Hydrolab.

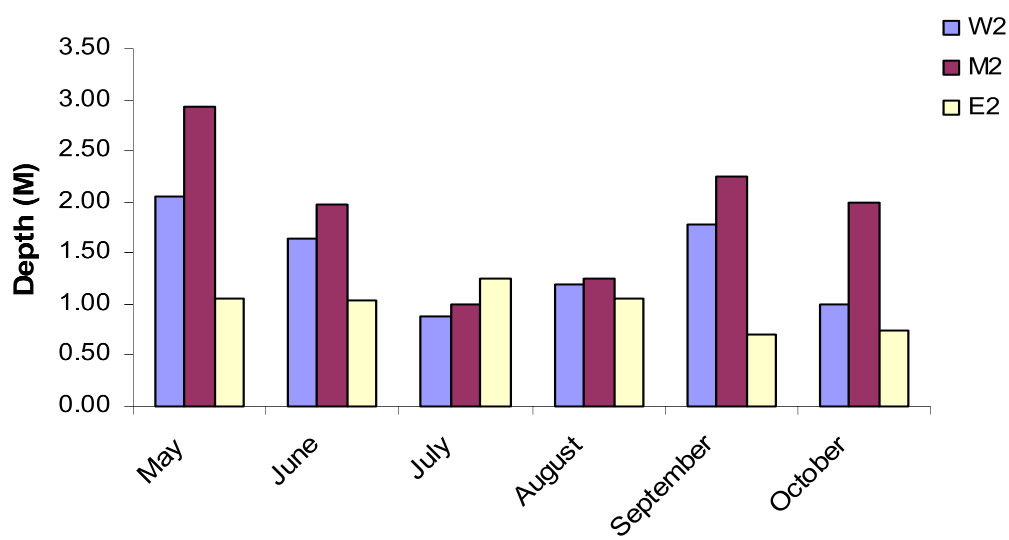

Figure 22: Secchi disk readings taken at sample stations W2, M2, and E2 in Pewaukee Lake, WI, from May to October of 2002.

Discussion

The goal of this study was to monitor and evaluate the present state of Pewaukee Lake by determining the chemical and physical properties of the water and sampling the plant and animal communities within the lake. These characteristics can be used to determine its trophic status (Carlson 1977, Kevern et al 1999, Shaw et al. 2000, USEPA 2000). Lakes can be divided into three main trophic categories; oligotrophic, mesotrophic, and eutrophic. The productivity of a lake increases as it acquires more nutrients, which in turn causes its trophic status to move from oligotrophic through mesotrophic and into a eutrophic condition. A eutrophic lake is nutrient rich, and is characterized by high plant populations, deep muck, anoxic conditions in deep water, and often good fishing. Lakes generally start as oligotrophic with clear, deep, and weed-free water. The natural aging process of lakes causes oligotrophic lakes to eventually become eutrophic lakes. This process which normally takes thousands of years is accelerated in many farming communities and urban areas due to excessive use of fertilizers and soil runoff. Phosphorus levels alone have been used to evaluate water quality in lakes (Table 4). However a combination of parameters such as Secchi disc readings, total phosphorus concentrations, and chlorophyll-α concentrations can provide stronger evidence for the trophic classification (Table 5).

Table 4: Total Phosphorus concentrations for Wisconsin's Natural Lakes and Impoundments. (Adopted from Lillie and Mason, 1983) in Shaw et al. (2000)

Water Quality Index	**Total Phosphorus** (μg/l)
VeryPoor	150
	130
Poor	90
	70←Average for impoundments
	50
Fair	40
	30
Good	25←Average for natural lakes
	20
Very Good	10
Excellent	

Table 5: Trophic classification of Wisconsin lakes based on Chlorophyll a, water clarity measurements, and total phosphorus values. (Adopted from Lilie and Mason, 1983) in Shaw et al. (2000).

Trophic class	**Total Phosphorus** μg/l	**Chlorophyll a** μg/l	**Secchi Disc** ft.
Oligotropic	3	2	12
	10	5	8
Mesotrophic	18	8	6
	27	10	6
Eutrophic	30	11	5
	50	15	4

Total phosphorus concentrations play a large role in algae growth and water clarity in lakes. A surplus of phosphorus stimulates plant growth since this nutrient is often a limiting factor. Algae which are mainly single cell plants drifting in the water column can increase in number very quickly resulting in a "bloom". As these plants grow and die they release chlorophyll a which can be measured in water samples. A high concentration of chlorophyll a indicates high production of algae at the time of sampling. Since algae cells are suspended in the water column these plants reduce water clarity which is measured directly by secchi disc. Therefore, high levels of phosphorus are associated with high levels of algae (chlorophyll-α), which are associated with low Secchi disc readings (Shaw et al. 2000).

In Pewaukee Lake, the total phosphorus readings ranged from 20µg/L to 48µg/L between June and October, 2002. This level indicates that Pewaukee Lake ranges from mesotrophic to eutrophic (Table 5) and has a water quality index of good to fair (Table 4). These levels have improved since the early 1970's when annual means were 75µg/L. A major improvement was seen between 1975 and 1980 with the establishment of a public sanitary sewerage system. Since implementing this system annual mean total phosphorus concentrations have ranged from just over 10 µg/L to slightly over 30µg/L (SEWRPC 2003). This range has been maintained despite increased development in the watershed during the past 25 years (SEWRPC 2003).

The chlorophyll-α concentration ranged from 2.3µg/L to 76.5µg/L in the summer of 2002. This variation provides a good picture of the variation that can occur in a dynamic system like Pewaukee Lake. Even with good to fair phosphorus levels environmental conditions can develop that result in algal blooms and high levels of chlorophyll-α. Anything above 10µg/L has been known to reflect algae blooms considered to impair recreational activities (SEWRPC 1984). Comparing the chlorophyll-α concentrations to the Secchi disc readings is a good technique to see the algae bloom density. As the chlorophyll-α concentrations increase, the Secchi disc readings decrease (Figure 23). Therefore the algae blooms cause a decrease in water clarity; an indication of a eutrophic lake (EPA 1973).

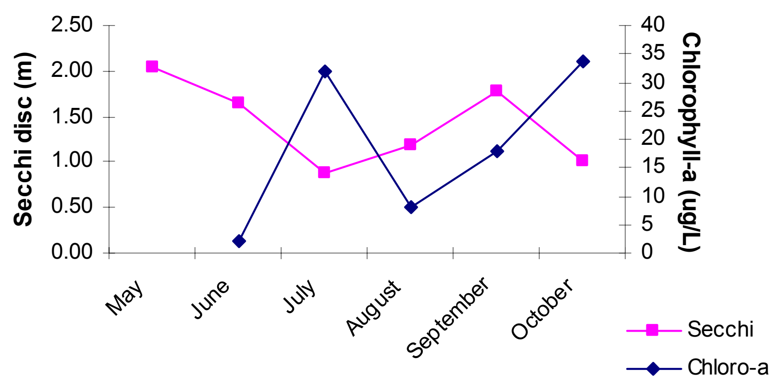

Figure 23: Chlorophyll-α concentrations compared to Secchi disc readings from the west end of Pewaukee Lake, WI during 2002.

The condition of a lake can also be determined based on species present in the lake. The most prominent effect of excessive nutrients is the decrease in the number of species present (species diversity) and dramatic increase in number of a few pollution tolerant species. Other general features of declining lake conditions include changes in plant, macroinvertebrate, and zooplankton species composition (EPA 1973 Stemberger et al. 1994, Gurtz 1994, Weiderholm 1980, Cheruvelil 2002, Hall et al. 1999).

The dominant plant species in Pewaukee Lake since at least the mid 1960's is the invasive species Eurasian milfoil (SEWRPC 1984). It can be found in just about every part of the lake. In some deeper sections of the lake, Eurasian Milfoil was the only species found. Schumacher (1988) indicated that the morphology of Pewaukee Lake may have a great deal to do with its aquatic macrophyte problem. The eastern end of the lake is very shallow and is covered with nutrient rich substrate. The highly organic substrate and shallow water is the ideal place for macrophyte growth. Despite the wide distribution of Eurasian Water milfoil a wide variety of native plant species are maintained in Pewaukee Lake through mechanical harvesting (SEWRPC 2003). Native plant species found in September of 2002 provide an example of their extensive distribution despite the presence of Eurasian milfoil (Figures 24 and 25). A regular selective harvesting program is necessary to maintain native species since Eurasian Water milfoil has been shown to out compete native North American aquatic plant species (Boylen et al. 1999).

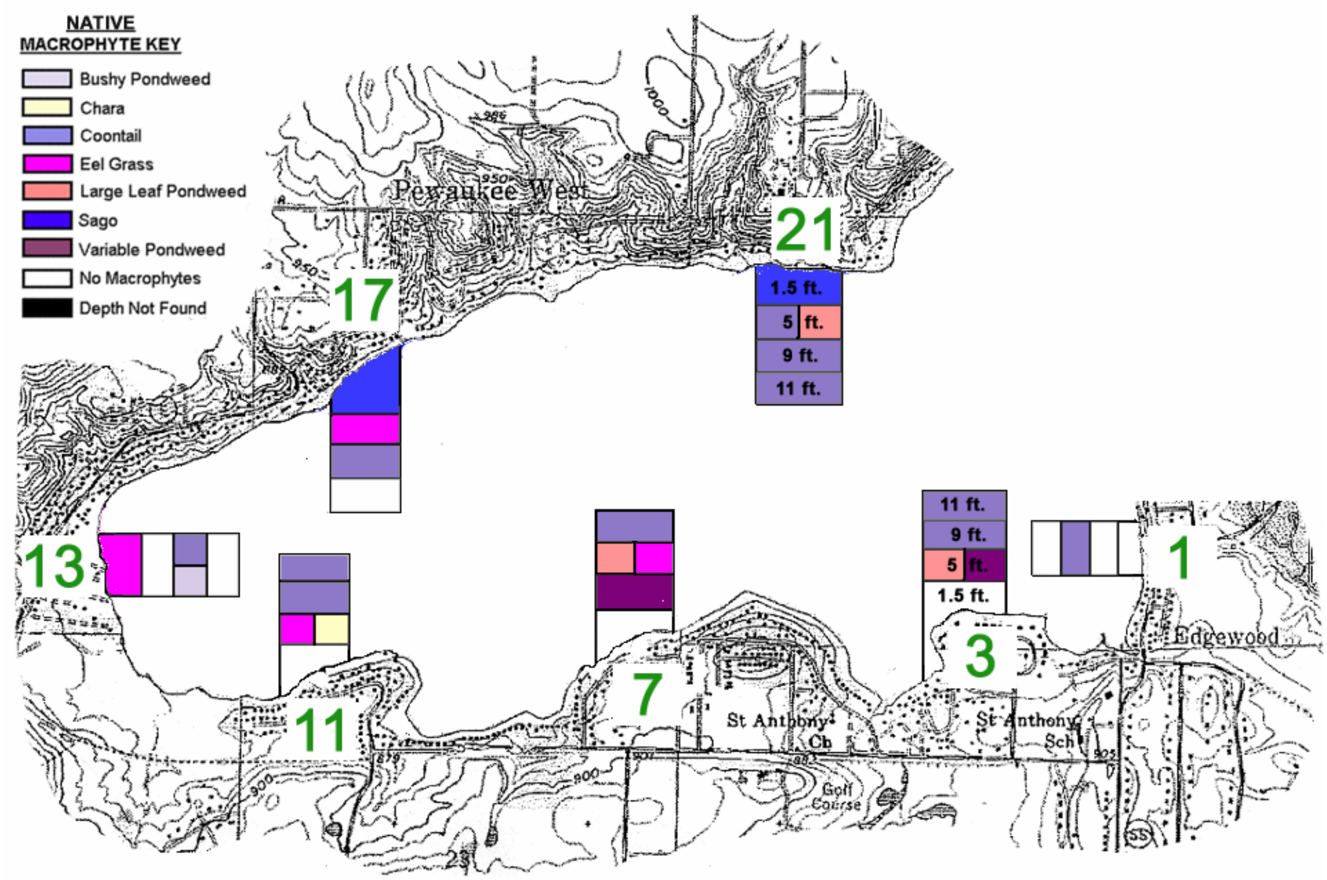

Figure 24: Prevalent native macrophytes at each depth during September of 2002 on the western basin of Pewaukee Lake, Pewaukee, Wisconsin.

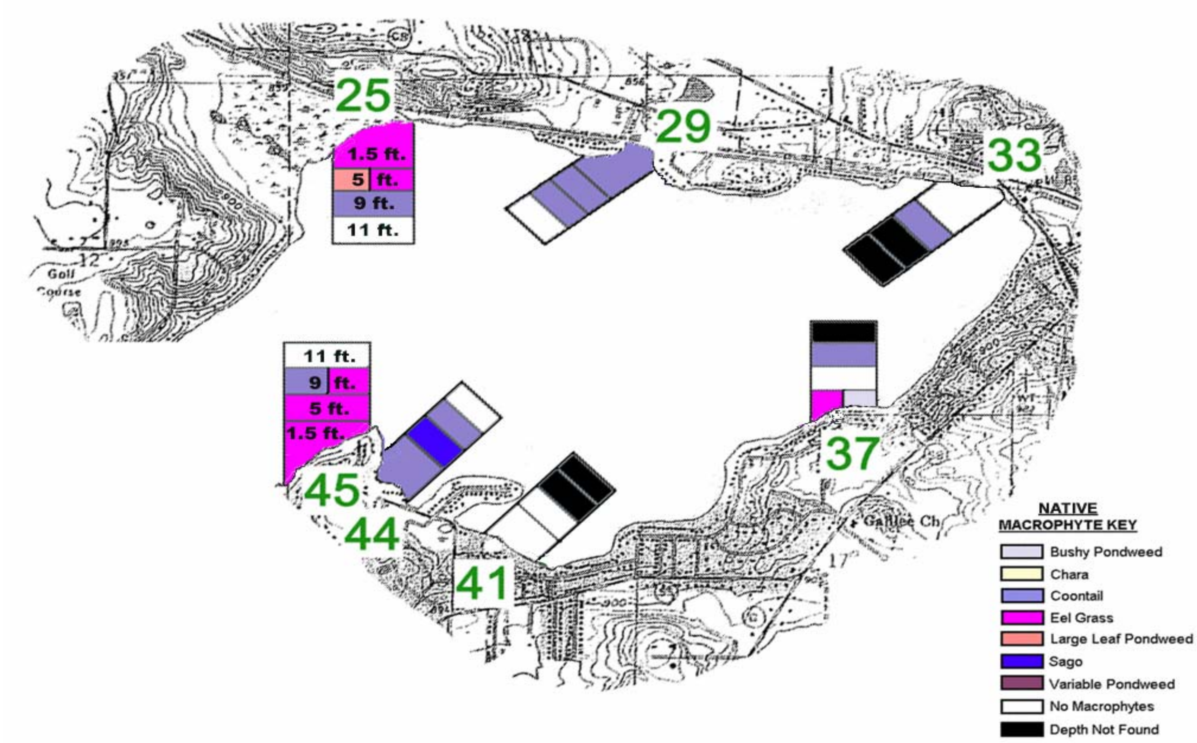

Figure 25: Prevalent native macrophytes at each depth during September of 2002 on the eastern basin of Pewaukee Lake, Pewaukee, Wisconsin.

Macroinvertebrates are often used as indicators of lake quality (USEPA 2003). One of the key indicators of a stressed lake is the predominance of one type of macroinvertebrate. As was found in Pewaukee Lake samples taken during the summer of 2000 (Schmoldt and Anderson 2000) chironomid species (nonbiting midge larvae) were by far the most abundant macroinvertebrate in 2002 samples. Dominance of chironomid species may be the result of low dissolved oxygen levels on bottom of the lake (table 4). Reice and Wohlenberg (1993) explain that predominance of chironomid larvae may indicate increased pollution or reduced dissolved oxygen levels near the substrate. The loss of oxygen from bottom waters is a characteristic of excessive nutrients and organic inputs (EPA 2001). The second most abundant macroinvertebrate in samples collected in

2002 was *Chaoborus* the phantom midge. This larvae is also an inhabitant of low oxygen sediments and an indicator of high nutrient levels (Merrit and Cummins 1978).

Table 4: Dissolved oxygen (mg/L) levels in the deepest part of the lake for July and August since 1971.*

	Aug., 1971	July, 1976	Aug., 1976	July, 2000	Aug., 2000	July, 2002	Aug., 2002
Suface	7.1	8.5	5.5	9	7.5	9.1	7.5
Mid-depth	5.7	4	4	2.5	6.8	0.3	6.2
Bottom	0	0	0	0	0	0	0

*Data Source for 1971: Aqua Tech, Inc., 1971
Data Source for 1976: SEWRPC, 1984
Data Source for 2000: Schmoldt and Anderson 2000

Zooplankton, on the other hand, live independently of the benthic habitat. These organisms are known for eating algae and other small organisms (EPA 1973). One of the key characteristics of the zooplankton community that indicates increased eutrophication in a lake is a decrease in the percent calanoid copepods (Gulati 1982). There has been little change in this parameter since 1976 indicating that nutrient levels in the water column have not change significantly enough to cause major changes in the zooplankton population (Figure 26).

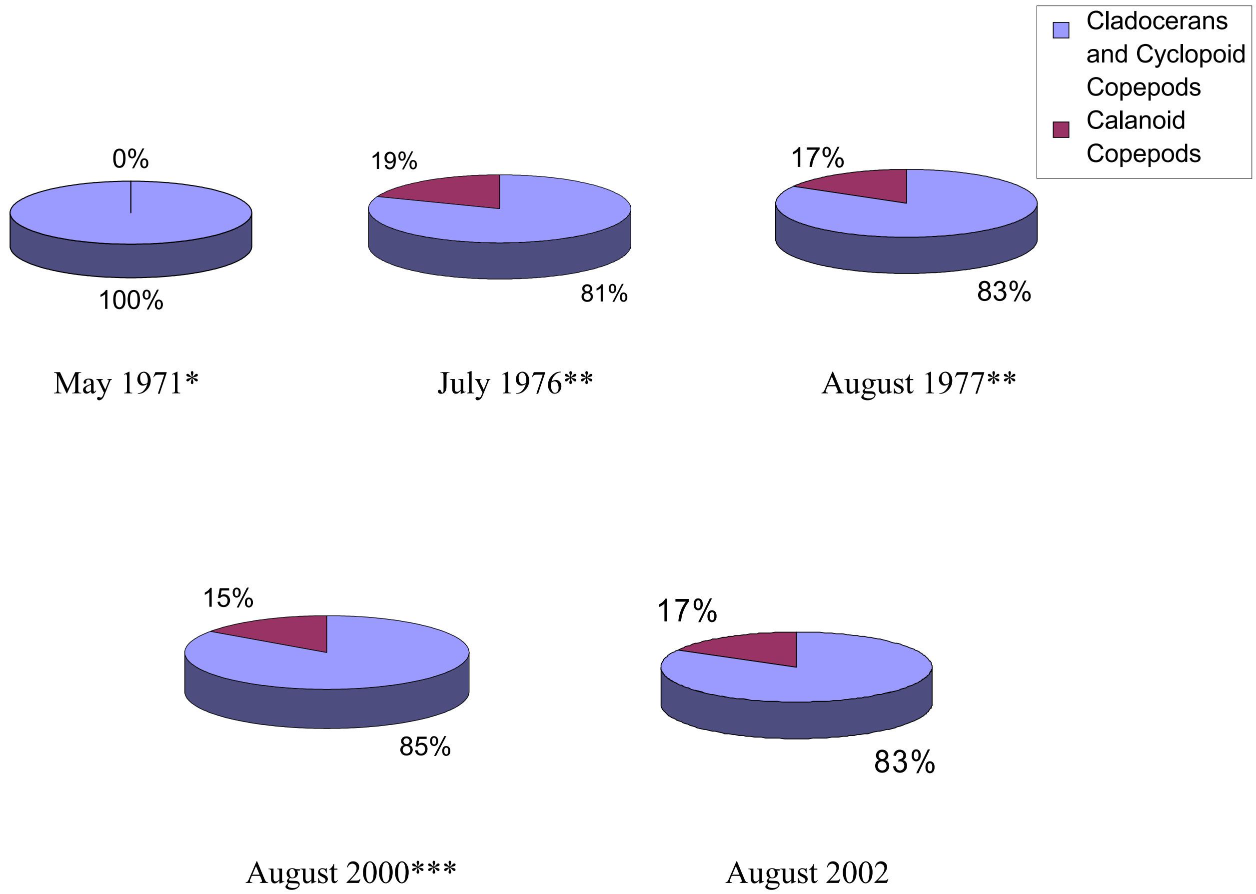

Figure 26: Percentage of total populations of Cladocerans and Cyclopoid Copepods compared to percentage of total population of Calanoid Copepods in 1971, 1976,1977, 2000 and 2002.

*Data Source: Aqua Tech, Inc. 1972
**Data Source: SEWRPC 1984
***Schmoldt and Anderson 2000

Overall, the results of this study indicate that Pewaukee Lake has not changed notably in the level of nutrient richness or overall pollution since the 2000 study (Schmoldt and Anderson 2000). One key change that has occurred however is the introduction of another non native invasive species the zebra mussel (*Dreissena polymorpha*). This small clam like creature is a filter feeder that can over run rocky fish spawning areas and disrupt the existing food web (Cairns and Bidwell 1996). The long term impact of this new introduction can not be predicted however continued biological monitoring may provide insight into the effects on Pewaukee Lake that could be applied to other lakes as well.

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(http://www.epa.gov/owow/monitoring/tech/lakes.html)

Appendix A

Table A1: Estimated number of benthic macroinvertebrates per square meter in Pewaukee Lake, WI, based on Eckman dredge samples taken in May, 2002.

	W1	W2	W3	M1	M2	M3	E1	E2	E3
Subclass: Hirudinea		28.99				14.49			57.97
Order: Ephemeroptera	304.35	14.49	14.49						130.44
Order: Oligochaeta	14.49	28.99	86.96	72.47		28.99	14.49		
Family: Dixidae		14.49							
Family: Ceratopogonidae	14.49	28.99							
Family: Chaoboridae					420.29				
Family: Chironomidae	405.80	478.27	463.77	463.77	86.96	14.49	159.42	57.97	536.23
Family: Chironomidae pupa	57.97		43.48		28.99				
Family: Physidae									14.49
Family: Haustoriidae	159.42							14.49	318.84
Order: Hydracarina	57.97								28.99
Genus: *Planaria*	43.48								43.48
Order: Trichoptera	14.49								14.49
Order: Odonata	14.49								
Genus: *Dreissena (polymorpha)*	43.48								

Table A2: Estimated number of benthic macroinvertebrates per square meter in Pewaukee Lake, WI, based on Eckman dredge samples taken in June, 2002.

	W1	W2	W3	M1	M2	M3	E1	E2	E3
Subclass: Hirudinea						159.42			
Order: Ephemeroptera	72.46							115.94	28.99
Order: Oligochaeta		14.49	28.99	130.43		14.49			14.49
Family: Dixidae									
Family: Ceratopogonidae	14.49								
Family: Chaoboridae					1202.90				
Family: Chironomidae	1420.29	507.25	318.84	797.10		246.38	492.75	681.16	115.94
Family: Chironomidae pupa			14.49	14.49				14.49	
Family: Physidae									
Family: Haustoriidae	14.49							43.48	
Order: Hydracarina	14.49								
Genus: *Planaria*									
Order: Trichoptera									
Order: Odonata									
Genus: *Dreissena (polymorpha)*	14.49								

Table A3: Estimated number of benthic macroinvertebrates per square meter in Pewaukee Lake, WI, based on Eckman dredge samples taken in July, 2002.

	W1	W2	W3	M1	M2	M3	E1	E2	E3
Subclass: Hirudinea									
Order: Ephemeroptera							14.49		
Order: Oligochaeta				159.42	28.99		14.49		
Family: Dixidae									
Family: Ceratopogonidae									
Family: Chaoboridae					188.41				
Family: Chironomidae	391.30	826.09	826.09	304.35	28.99	289.86	231.88	188.41	72.47
Family: Chironomidae pupa			14.49	14.49					
Family: Physidae									
Family: Haustoriidae									
Order: Hydracarina					14.49				14.49
Genus: *Planaria*									
Order: Trichoptera									
Order: Odonata									
Genus: *Dreissena (polymorpha)*	14.49								

Table A4: Estimated number of benthic macroinvertebrates per square meter in Pewaukee Lake, WI, based on Eckman dredge samples taken in August, 2002.

	W1	W2	W3	M1	M2	M3	E1	E2	E3
Subclass: Hirudinea									
Order: Ephemeroptera							43.48		
Order: Oligochaeta	28.99	72.46							
Family: Dixidae									
Family: Ceratopogonidae									
Family: Chaoboridae					101.45				
Family: Chironomidae	463.77	101.45	28.99	115.94		57.97	101.45		28.99
Family: Chironomidae pupa							14.49		
Family: Physidae									
Family: Haustoriidae									
Order: Hydracarina							14.49		
Genus: *Planaria*							14.49		
Order: Trichoptera									
Order: Odonata									
Genus: *Dreissena (polymorpha)*									

Table A5: Estimated number of benthic macroinvertebrates per square meter in Pewaukee Lake, WI, based on Eckman dredge samples taken in September, 2002.

	W1	W2	W3	M1	M2	M3	E1	E2	E3
Subclass: Hirudinea									
Order: Ephemeroptera									
Order: Oligochaeta		14.49	14.49						
Family: Dixidae									
Family: Ceratopogonidae									
Family: Chaoboridae					420.29				14.49
Family: Chironomidae	101.45	14.49	130.44	57.97		28.99	14.49		43.48
Family: Chironomidae pupa									
Family: Physidae									
Family: Haustoriidae									
Order: Hydracarina			14.49						14.49
Genus: *Planaria*									
Order: Trichoptera									
Order: Odonata									
Genus: *Dreissena (polymorpha)*									

Table A6: Estimated number of benthic macroinvertebrates per square meter in Pewaukee Lake, WI, based on Eckman dredge samples taken in October, 2002.

	W1	W2	W3	M1	M2	M3	E1	E2	E3
Subclass: Hirudinea									
Order: Ephemeroptera							14.49	14.49	86.96
Order: Oligochaeta									
Family: Dixidae									
Family: Ceratopogonidae									
Family: Chaoboridae					217.39				43.48
Family: Chironomidae	72.46	115.95	43.48	72.47		72.46	86.96	28.99	14.49
Family: Chironomidae pupa									
Family: Physidae									
Family: Haustoriidae									
Order: Hydracarina									
Genus: *Planaria*									
Order: Trichoptera									
Order: Odonata									
Genus: *Dreissena (polymorpha)*									

Appendix B

Table 1B: Estimated number of zooplankton per liter of water from Pewaukee Lake, WI, in May of 2002.

	WEST			MIDDLE		EAST		
	Surface	Middle	Bottom	Surface	Middle	Surface	Middle	Bottom
Copepoda Cyclopoida	30.24	23.19	27.01	15.26	13.5	21.14	27.3	7.05
Copepoda Calanoida	26.71	16.73	12.62	16.73	12.04	4.4	2.05	19.08
Copepoda Harpacticoida								
Nauplii	9.39	19.67	7.34	25.83	0.29	3.23	2.64	2.05
Allona costata		0.88	0.29					
Chydorus sphaericus	4.4	2.94	4.11	1.47	1.47	2.35	14.09	25.25
Eubosmina coregoni	2.64	0.59	2.64	0.59	1.17	0.29	6.75	6.16
Bosmina longirostris	1.17	4.11	4.11		0.88	10.57	150.89	119.18
Ceriodaphnia sp.						1.47	19.96	22.9
Ceriodaphnia reticulata								
Diaphanosoma leuchtenbergianum							9.69	2.94
Daphnia longispina	3.82	1.76	1.47	3.23	0.29		1.47	
Daphnia pulex	2.64	0.59			6.16	0.59		
Leptodora kindtii	0.29							
Leydigia acanthocercoides				0.29				
Ostracod *Ostracoda*								
Unidentified Copepoda	0.88					0.88		0.59
Unidentified Cladocera	1.17	0.88		0.29	1.76	1.47	1.76	4.11
Copepoda Total	67.22	59.59	46.97	57.82	25.83	29.65	31.99	28.77
Cladocera Total	16.13	11.75	12.62	5.87	11.73	16.74	204.61	180.54
Total	83.35	71.34	59.59	63.69	37.56	46.39	236.6	209.31

Table 2B: Estimated number of zooplankton per liter of water from Pewaukee Lake, WI, in June of 2002.

	WEST			MIDDLE		EAST		
	Surface	Middle	Bottom	Surface	Middle	Surface	Middle	Bottom
Copepoda Cyclopoida	30.24	23.19	27.01	15.26	13.5	21.14	27.3	7.05
Copepoda Calanoida	26.71	16.73	12.62	16.73	12.04	4.4	2.05	19.08
Copepoda Harpacticoida								
Nauplii	9.39	19.67	7.34	25.83	0.29	3.23	2.64	2.05
Allona costata		0.88	0.29					
Chydorus sphaericus	4.4	2.94	4.11	1.47	1.47	2.35	14.09	25.25
Eubosmina coregoni	2.64	0.59	2.64	0.59	1.17	0.29	6.75	6.16
Bosmina longirostris	1.17	4.11	4.11		0.88	10.57	150.89	119.18
Ceriodaphnia sp.						1.47	19.96	22.9
Ceriodaphnia reticulata								
Diaphanosoma leuchtenbergianum							9.69	2.94
Daphnia longispina	3.82	1.76	1.47	3.23	0.29		1.47	
Daphnia pulex	2.64	0.59			6.16	0.59		
Leptodora kindtii	0.29							
Leydigia acanthocercoides				0.29				
Ostracod *Ostracoda*								
Unidentified Copepoda	0.88					0.88		0.59
Unidentified Cladocera	1.17	0.88		0.29	1.76	1.47	1.76	4.11
Copepoda Total	67.22	59.59	46.97	57.82	25.83	29.65	31.99	28.77
Cladocera Total	16.13	11.75	12.62	5.87	11.73	16.74	204.61	180.54
Total	83.35	71.34	59.59	63.69	37.56	46.39	236.6	209.31

Table 3B: Estimated number of zooplankton per liter of water from Pewaukee Lake, WI, in July of 2002.

	WEST			MIDDLE		EAST		
	Surface	Middle	Bottom	Surface	Middle	Surface	Middle	Bottom
Copepoda Cyclopoida	0.29	1.47	2.35	1.17	9.98	4.11	18.49	23.19
Copepoda Calanoida	3.23	0.88	0.88	0.29	0.88	0.29	21.43	13.5
Copepoda Harpacticoida								
Nauplii	0.29	0.29	0.59	0.88	0.59	3.23	3.82	2.94
Allona costata								
Chydorus sphaericus	0.88	0.59		0.29				0.29
Eubosmina coregoni	0.59	0.59						
Bosmina longirostris	3.52	2.05	0.88	1.47			0.29	18.49
Ceriodaphnia sp.	0.59	0.29		0.59		1.76	9.39	87.19
Ceriodaphnia reticulata								
Diaphanosoma leuchtenbergianum				0.29	0.29		1.76	0.88
Daphnia longispina		0.29			0.29			
Daphnia pulex								
Leptodora kindtii								
Leydigia acanthocercoides								
Ostracod *Ostracoda*								
Unidentified Copepoda		0.29						
Unidentified Cladocera	0.59	0.29						
Copepoda Total	3.81	2.93	3.82	2.34	11.45	7.63	43.74	39.63
Cladocera Total	6.17	4.1	0.88	2.64	0.58	1.76	11.44	106.85
Total	9.98	7.03	4.7	4.98	12.03	9.39	55.18	146.48

Table 4B: Estimated number of zooplankton per liter of water from Pewaukee Lake, WI, in August of 2002.

	WEST			MIDDLE		EAST		
	Surface	Middle	Bottom	Surface	Middle	Surface	Middle	Bottom
Copepoda Cyclopoida	1.17	0.88	1.17	0.29	18.79	2.94	4.7	5.28
Copepoda Calanoida	4.99	6.46	3.82	0.88	34.93	4.7	3.52	4.4
Copepoda Harpacticoida								
Nauplii				0.29		0.88	0.88	1.76
Allona costata								
Chydorus sphaericus								
Eubosmina coregoni								
Bosmina longirostris	5.58	1.47		0.29			1.17	2.05
Ceriodaphnia sp.	7.63	2.64		0.29	0.29	0.29	4.11	9.98
Ceriodaphnia reticulata								
Diaphanosoma leuchtenbergianum	1.17	5.28	10.27	3.82	38.46		3.23	24.37
Daphnia longispina					1.47			
Daphnia pulex					0.59			
Leptodora kindtii								
Leydigia acanthocercoides								
Ostracod *Ostracoda*							0.29	0.59
Unidentified Copepoda								
Unidentified Cladocera		0.59						
Copepoda Total	6.16	7.34	4.99	1.46	53.72	8.52	9.1	11.44
Cladocera Total	14.38	9.98	10.27	4.4	40.81	0.29	8.51	36.4
Total	20.54	17.32	15.26	5.86	94.53	8.81	17.9	48.43

Table 5B: Estimated number of zooplankton per liter of water from Pewaukee Lake, WI, in September of 2002.

	WEST			MIDDLE		EAST		
	Surface	Middle	Bottom	Surface	Middle	Surface	Middle	Bottom
Copepoda Cyclopoida	3.52	4.4	4.4	0.88	37.57	2.94	5.28	1.76
Copepoda Calanoida	8.51	12.92	12.33		0.59	10.86	21.43	1.47
Copepoda Harpacticoida								
Nauplii	0.59		0.29	0.29			0.29	
Allona costata		0.88		0.29			0.29	
Chydorus sphaericus								0.88
Eubosmina coregoni								0.59
Bosmina longirostris				3.23	1.17	1.76	24.37	12.04
Ceriodaphnia sp.								1.47
Ceriodaphnia reticulata								
Diaphanosoma leuchtenbergianum	1.17	0.88	0.59	0.59			0.59	0.29
Daphnia	0.29				3.23		2.64	1.76
Leptodora kindtii			0.59	0.59	0.88			
Leydigia acanthocercoides								
Ostracod *Ostracoda*							0.59	1.47
Unidentified Copepoda								
Unidentified Cladocera						0.59	0.59	1.76
Copepoda Total	12.62	17.32	17.02	1.17	38.16	13.8	27	3.23
Cladocera Total	1.46	1.76	1.18	4.7	5.28	2.35	28.48	18.79
Total	14.08	19.08	18.2	5.87	43.44	16.15	56.07	23.49

Table 6B: Estimated number of zooplankton per liter of water from Pewaukee Lake, WI, in October of 2002.

	WEST			MIDDLE		EAST		
	Surface	Middle	Bottom	Surface	Middle	Surface	Middle	Bottom
Copepoda Cyclopoida	19.08	36.99	31.41	21.14	15.85	8.51	7.93	7.05
Copepoda Calanoida	21.43	34.93	52.84	29.94	45.21	15.26	5.58	1.17
Copepoda Harpacticoida								
Nauplii								
Allona costata								
Chydorus sphaericus							2.35	1.17
Eubosmina coregoni								
Bosmina longirostris	0.29	0.29		1.17	0.29	3.82	11.16	11.45
Ceriodaphnia sp.								
Ceriodaphnia reticulata								
Diaphanosoma leuchtenbergianum	0.59	4.7	0.59	1.76				
Daphnia	23.78	122.12	154.12	27.59	116.25	15.26	0.88	0.59
Leptodora kindtii								
Leydigia acanthocercoides								
Ostracod *Ostracoda*								
Unidentified Copepoda								
Unidentified Cladocera								
Copepoda Total	40.51	71.92	84.25	51.08	61.06	23.77	13.51	8.22
Cladocera Total	24.66	127.11	154.71	30.52	116.54	19.08	14.39	13.21
Total	65.17	199.03	238.96	81.6	177.6	42.85	27.9	21.43

Appendix C

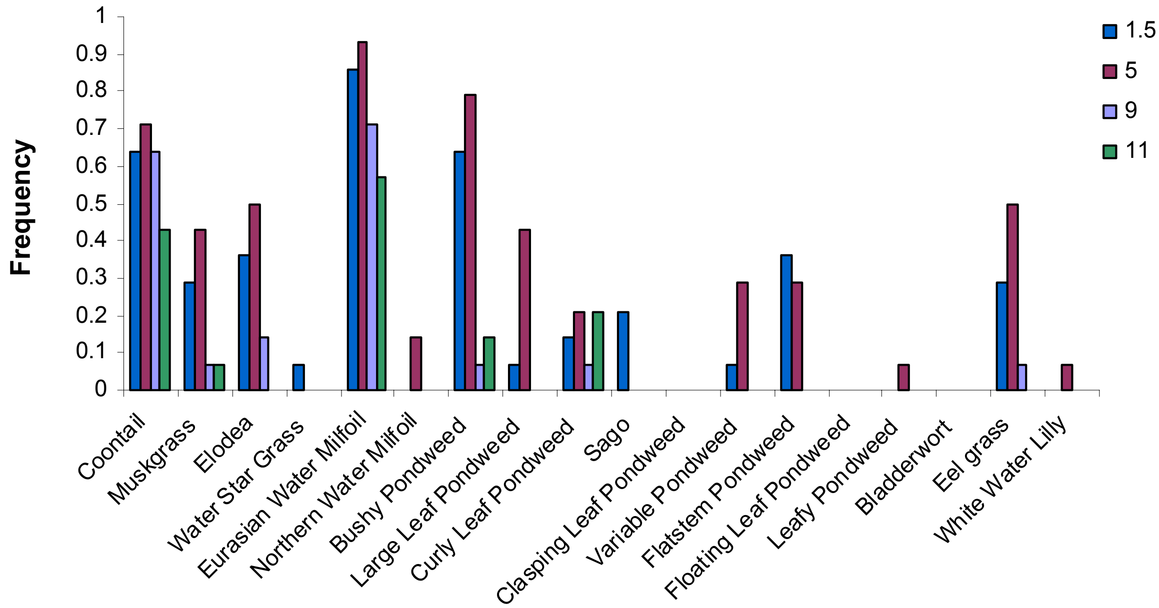

Figure 1C: Estimated frequency percent of aquatic macrophytes per depth in Pewaukee Lake, WI, in June of 2002.

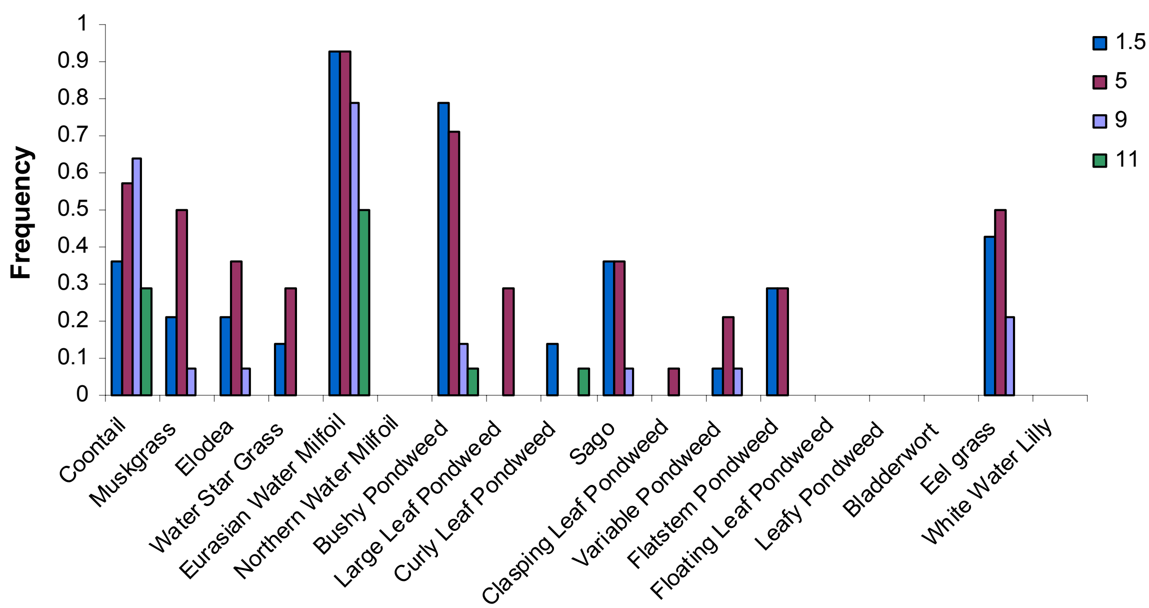

Figure 2C: Estimated frequency percent of aquatic macrophytes per depth in Pewaukee Lake, WI, in July of 2002.

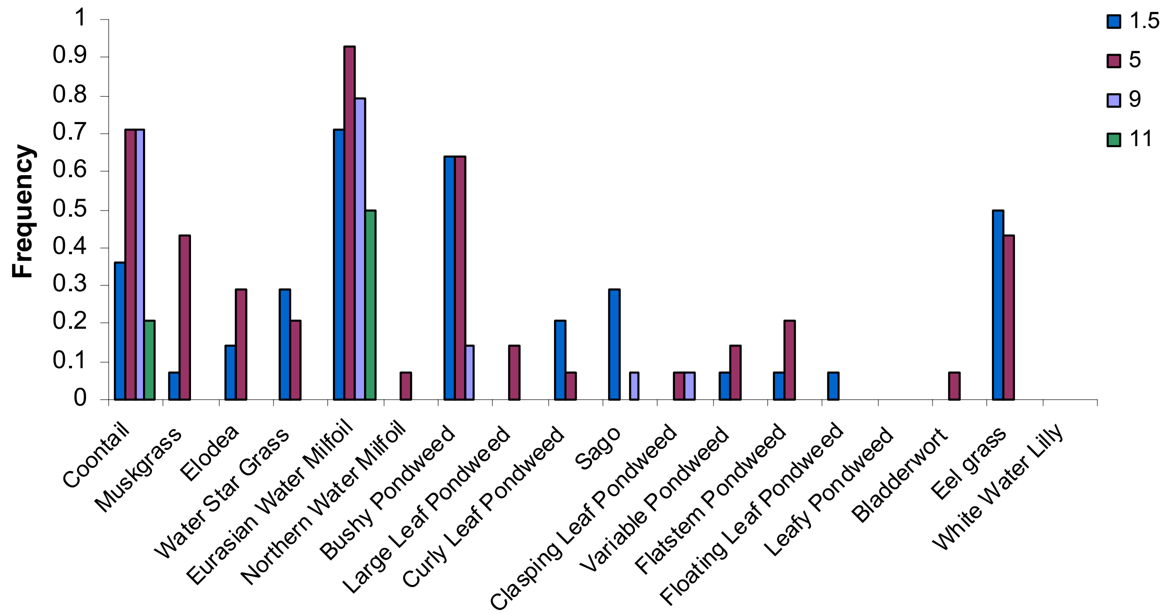

Figure 3C: Estimated frequency percent of aquatic macrophytes per depth in Pewaukee Lake, WI, in August of 2002.

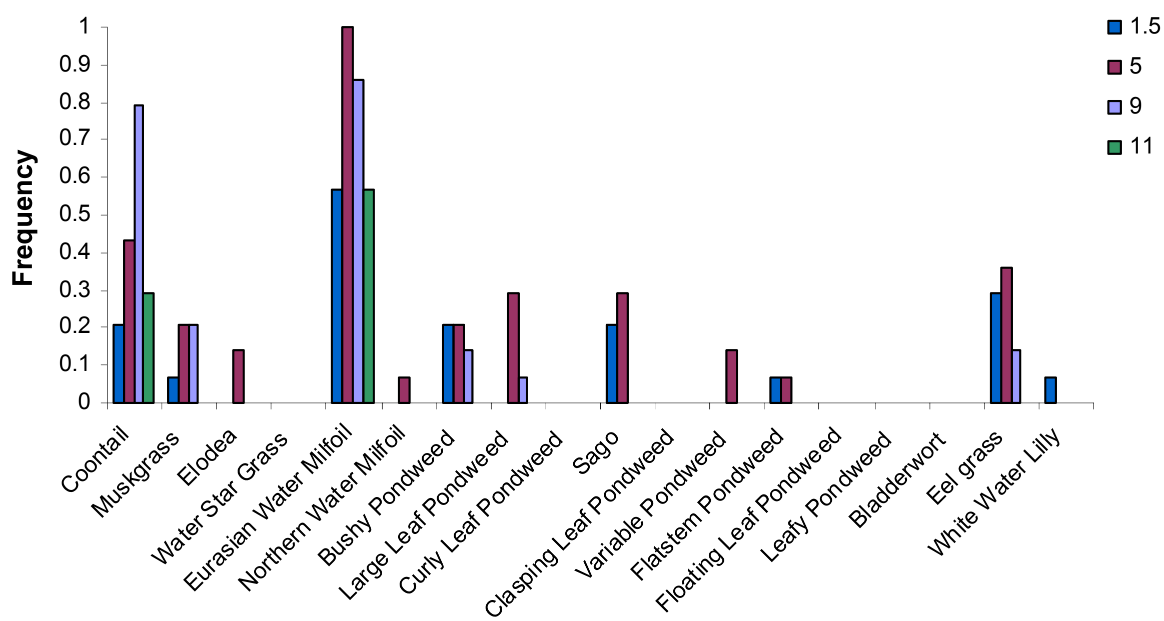

Figure 4C: Estimated frequency percent of aquatic macrophytes per depth in Pewaukee Lake, WI, in September of 2002.

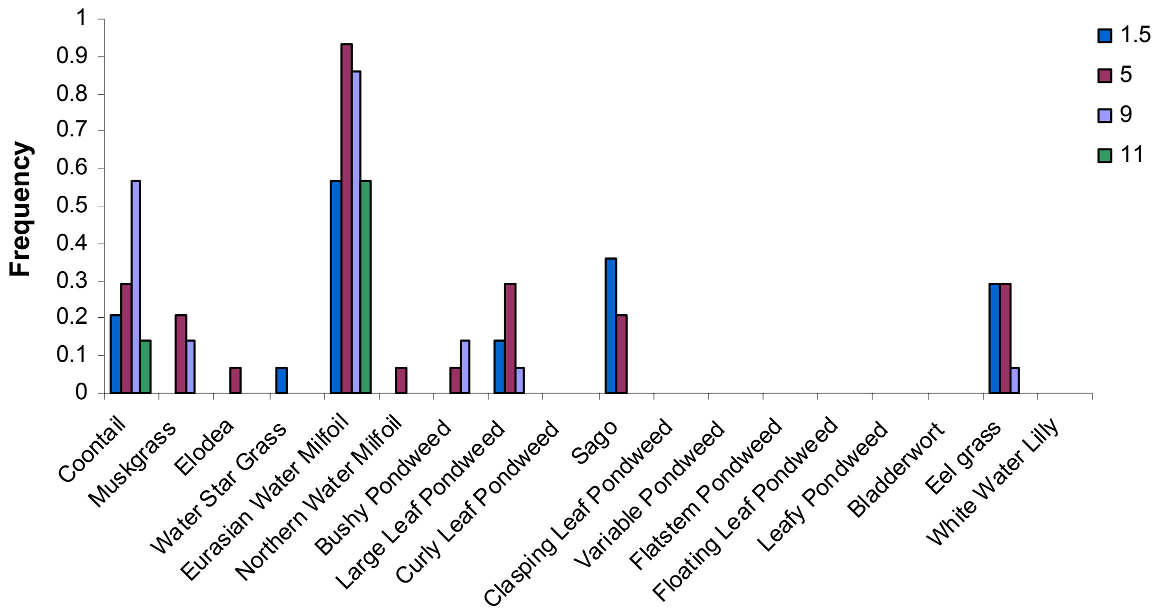

Figure 5C: Estimated frequency percent of aquatic macrophytes per depth in Pewaukee Lake, WI, in October of 2002.

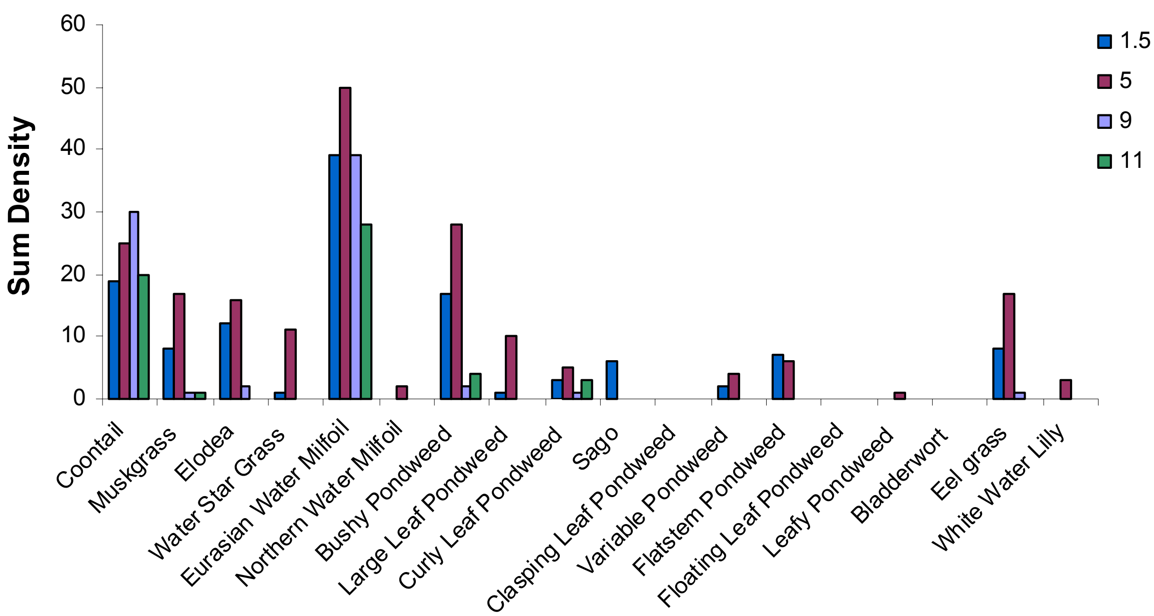

Figure 6C: Estimated sum density of aquatic macrophytes per depth in Pewaukee Lake, WI, in June of 2002.

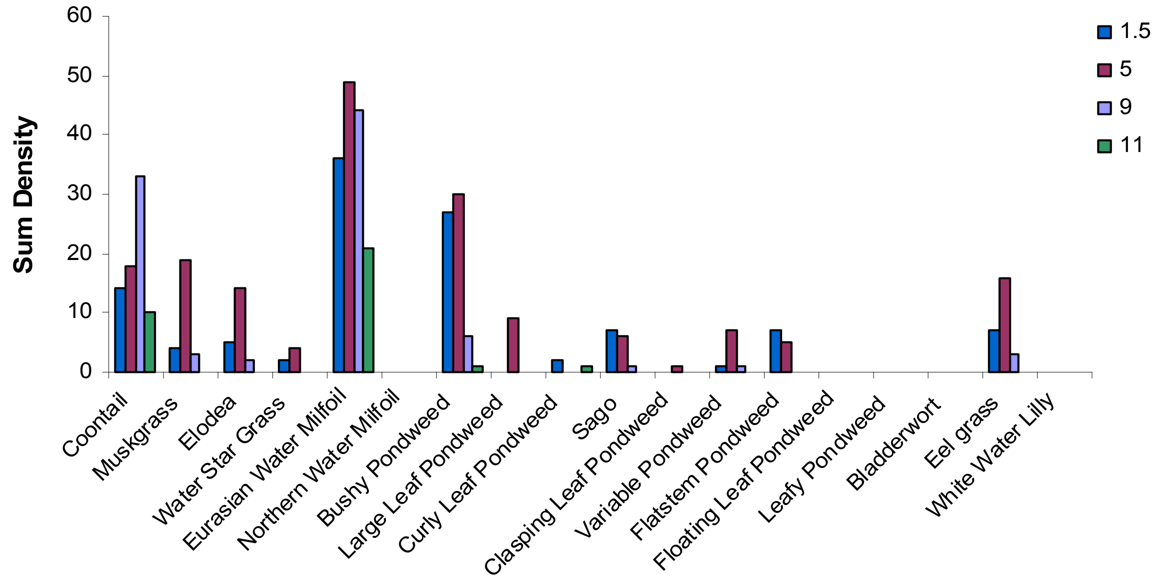

Figure 7C: Estimated sum density of aquatic macrophytes per depth in Pewaukee Lake, WI, in July of 2002.

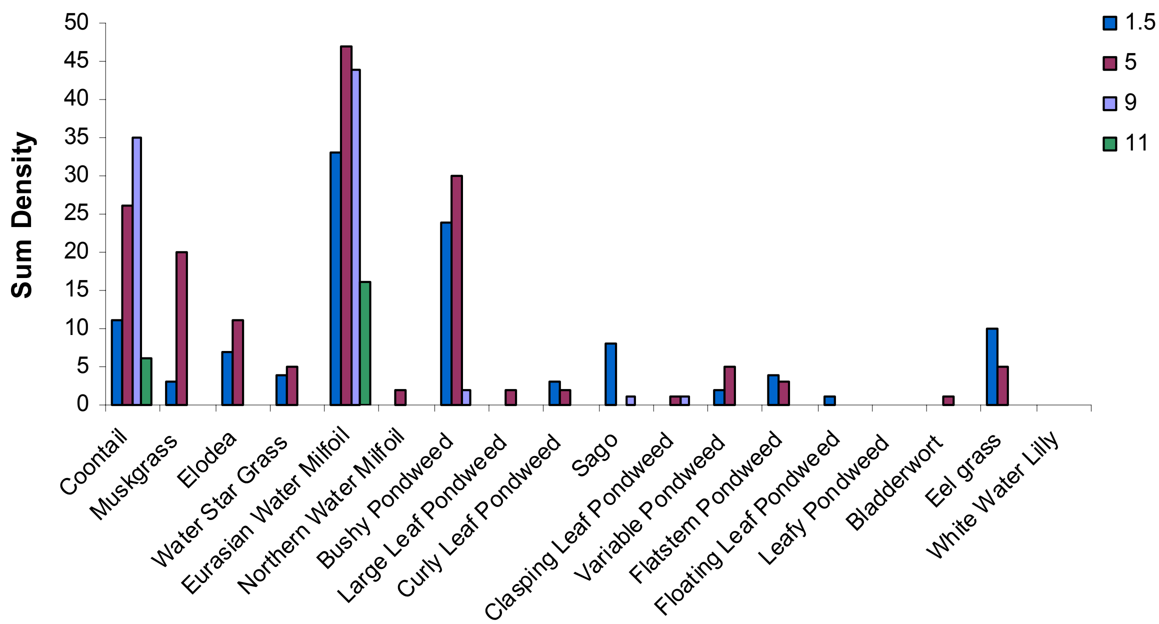

Figure 8C: Estimated sum density of aquatic macrophytes per depth in Pewaukee Lake, WI, in August of 2002.

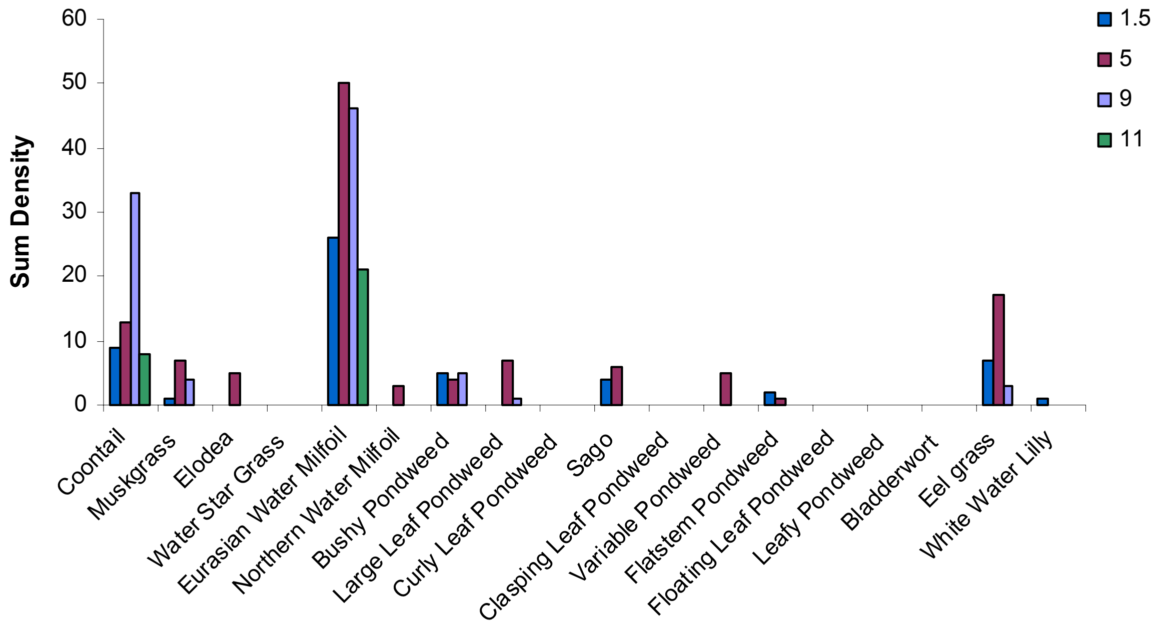

Figure 9C: Estimated sum density of aquatic macrophytes per depth in Pewaukee Lake, WI, in September of 2002.

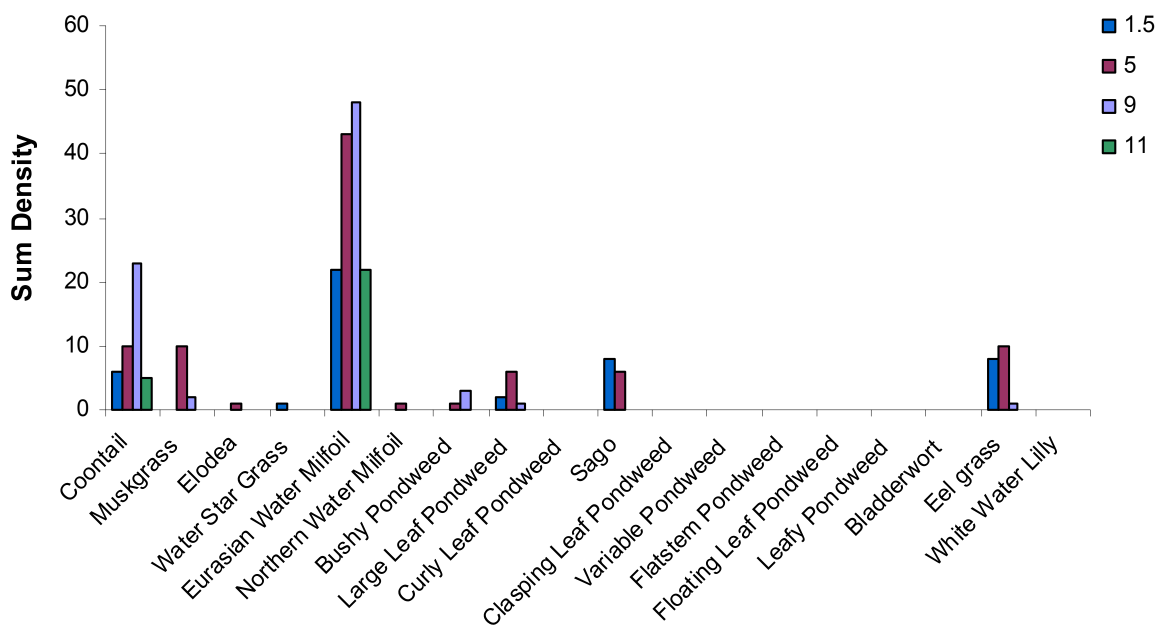

Figure 10C: Estimated sum density of aquatic macrophytes per depth in Pewaukee Lake, WI, in October of 2002.