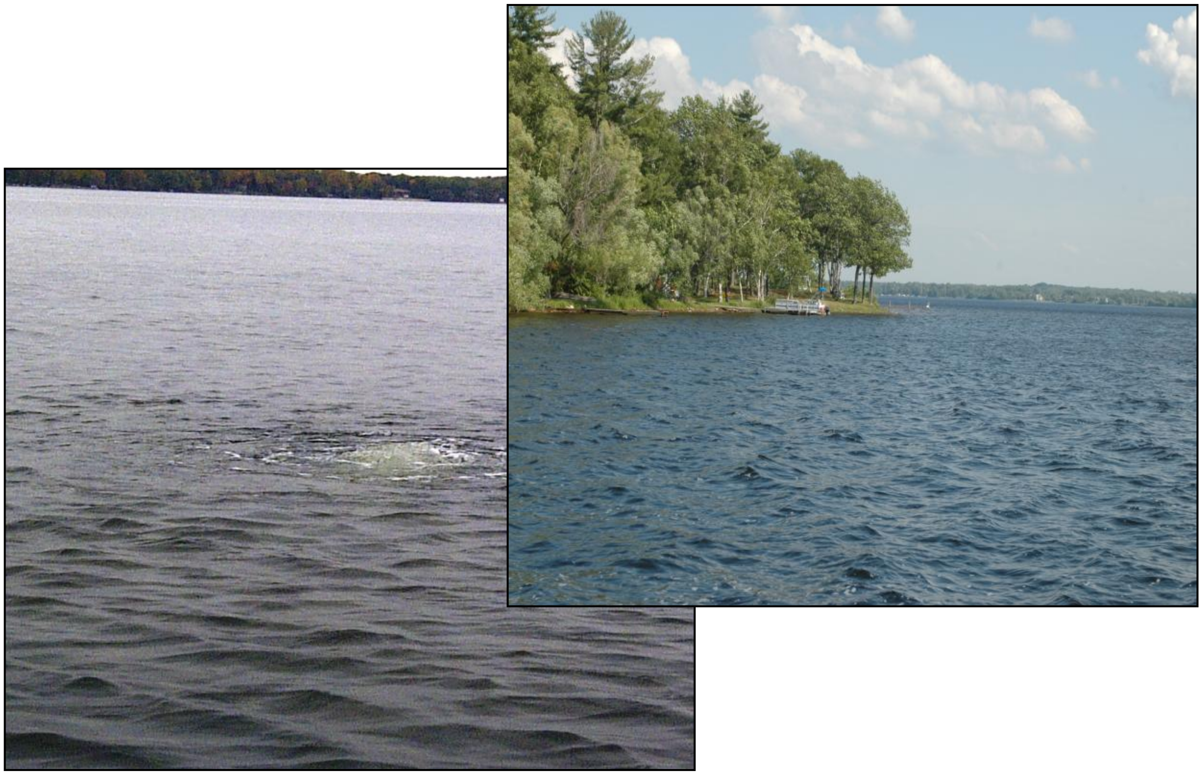
Evaluation of Laminar Flow Aeration, Bioaugmentation, and Biological Control for Improvements to Paradise Lake, Emmet and Cheboygan Counties, Michigan



Prepared for:	**The Paradise Lake Improvement Board** **Attn: Mr. Jim Tamlyn, Chair** **PO Box 52** **Carp Lake, MI 49718**
Prepared by:	**Jennifer L. Jermalowicz-Jones, Professional Limnologist** **Water Resources Director** **Lakeshore Environmental, Inc.** **803 Verhoeks Road** **Grand Haven, Michigan 49417**

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October, 2012

1.0 PARADISE LAKE PROJECT SUMMARY

Paradise Lake is a 1,900-acre meso-eutrophic lake that is surrounded by 9.52 miles of shoreline and has a maximum depth of 15 feet in Emmet and Cheboygan Counties, Michigan. The lake contains a moderate diversity of native submersed aquatic plants with 13 submersed, 1 floating-leaved, and 2 emergent plant species (Lakeshore Environmental, Inc. study, September, 2012) for a total of 16 species. Sediments within Paradise Lake may either originate from the surrounding watershed (allochthonus inputs) or from within the lake (autochthonous inputs). The overall high mean organic matter content of the sediments (mean =57.6%, n=8 samples) indicates that the majority of the organic materials is derived from years of decayed aquatic plant and other biota. The sediments contained very high levels of organic matter which are biodegradable with a combination of laminar flow aeration and bioaugmentation (addition of microbes and enzymes).

The purpose of this study was to investigate the efficacy of both laminar flow aeration with bioaugmentation and biological control (weevils) on the management of the exotic, invasive, submersed aquatic plant, Eurasian Watermilfoil (*Myriophyllum spicatum*). Both abiotic (non-living, chemical, physical) and biotic (living) parameters determine the overall health of Paradise Lake.

Major concerns regarding excessive rooted aquatic plant growth in some areas and large accumulations of organic deposits necessitated the improvements.

Since the overall depth of Paradise Lake is shallow, the lake exhibits minimal thermal stratification during the summer and experiences frequent mixing. In the West Basin where the laminar flow aeration system was placed, the basin exhibits complete mixing. Although the concentrations of dissolved oxygen were adequate in the water column prior to the study, the bottom sediments were lacking sufficient dissolved oxygen which reduced the aerobic bacteria population. Aerobic bacteria are necessary to effectively break down organic matter or "muck".

The south and east shores of Paradise Lake are surrounded primarily by mucky loamy sands and peats. The potential for erosion is low around the entire lake but the potential for ponding and runoff is very high in the mucky areas. Additionally, regular maintenance of septic systems in these areas is critical.

Water quality parameters such as water temperature, dissolved oxygen, pH, conductivity, total dissolved solids, oxidation-reduction potential, Secchi transparency, water column total phosphorus, water column total kjeldahl nitrogen, and total alkalinity were measured at each of the four deep basins on June 16, 2012. Additionally, sediment organic matter was measured at each of eight sampling sites on June 16, 2012. The overall water quality of Paradise Lake is good with high dissolved oxygen, moderate pH, moderate nutrients, and moderate water clarity.

Approximately 60 stems of Eurasian Watermilfoil were collected in the summer and early fall of 2012 at the West, South, and North basins of the lake, and assessed for weevil damage. The overall results indicate that the greatest extent of damage occurred in the South Basin, followed by the West Basin. The North Basin exhibited little weevil damage and future stocking efforts should be concentrated in that region. Protection of shoreline vegetation will be critical for future sustained weevil populations.

Additionally, over 220 sampling locations in the West Basin were selected for aeration sampling and there was a 10% reduction in dense milfoil in the West Basin in a four month period of system operation. The density and quantity of milfoil is expected to decline by at least 20% per year. Although aquatic herbicides may knock the milfoil down more quickly, the plants often return and require constant application. This natural approach to milfoil control is sustainable and helps to reduce nutrient levels in the lake sediments that fuel increased milfoil growth.

Future recommendations include stocking of more weevils in the North Basin with possible mechanical removal methods for dense Fernleaf Pondweed growth and the continuation of the laminar flow aeration system in the West Basin to further reduce organic matter and milfoil growth.

2.0 SEDIMENTS AND THE WATERSHED

2.1 Lake Sediment Information

The following terms are provided for a more thorough understanding of the forthcoming lake management recommendations for sediment reduction and reduction of nuisance aquatic plant growth within Paradise Lake. A basic knowledge of sedimentary processes is necessary to understand the complexities involved and how management techniques are applicable to the current conditions in Paradise Lake. Although laboratory analyses are used to determine the composition of the lake sediment, it must be realized that detailed records of the Paradise Lake sediments have changed with time due to dynamic wind and lake energy processes, which redistribute sediments among the entire lake basin.

2.1.1 Lake Sediment Composition and Biogeochemistry

The sediments at the lake bottom have important functions in the biogeochemical cycling of nutrients within the lake (Wetzel, 2001) and in the ultimate classification of lake trophic status (Golterman, 1966). Lake sediments originate from external (allochthonus) and internal (autochthonous) sources within a lake system. External sources include materials such as pollen, terrestrial vegetation, pollutants, and erosion matter that enter the lake from the drainage basin (immediate watershed). Additionally, pollen, metals and particulates may enter the lake from the atmosphere. The majority of such substances settles at the lake bottom, but may be resuspended during climatic events and lead to redistribution of the sediments. Internal sources of sediment are produced from the decay of organic materials such as aquatic plant, phytoplankton (algae), zooplankton, and other higher organisms. The less consolidated or flocculent component of sediment is derived from internal sources (i.e., decayed aquatic plant and algae) and is generally much higher in organic matter content than external sources. In lake systems with an abundant microbial community, the organic fraction is usually bio-degraded as an energy source for the microbes, resulting in a reduction of the organic matter content in lake sediments. Studies which evaluate sediment microbial activity are scarce and many more are needed to adequately understand the changes in lake biogeochemical cycles.

The majority of sediment within the Paradise Lake is highly organic (mean = 57.6%; n=8 samples; Lakeshore Environmental, Inc., 2012). Ammonia (NH_3+) in the sediments is rapidly converted to nitrate (NO_3-), nitrite (NO_2-), nitrous oxide (NO), and finally nitrogen N_2 gas in the presence of oxygen. Denitrifying bacteria in the sediment and sediment porewater then convert most of the nitrate to nitrogen gas. Nitrogen in the sediments is derived primarily from decayed plant matter. The redox potentials in the lake sediment after aeration are sufficient for the ammonia in the sediment to be converted to nitrite. The conversion of ammonia (NH_3+) to organic nitrogen is necessary for the formation of lake bottom sediment and adds bulk density.

The release of NH_3+ under anoxic conditions follows the accumulation of NH_3+ in sediments where nitrification cannot occur, and NH_3+ assimilation by anaerobic microbes declines. The imminent accumulation of NH_3+ then results in toxicity to aquatic organisms (Camargo et *al*., 2005; Beutel, 2006). Beutel (2006) found that NH_3+ release rates in anoxic sediment were > 15 mg N m^{-2} day^{-1}, but were nearly absent in oxic (oxygen-rich) conditions. Allen (2009) demonstrated that NH_3+ oxidation in aerated sediments was significantly higher than that of control mesocosms with a relative mean of 2.6 ± 0.80 mg N g dry weight day^{-1} for aerated mesocosms and 0.48 ± 0.20 mg N g dry weight day^{-1} in controls. Conversely, a study by Engstrom and Wright (2002) found no significant differences between aerated and non-aerated lakes with respect to reduction in organic sediments. This study was however limited to one sediment core per lake and given the high degree of heterogeneous sediments in inland lakes may not have accurately represented the conditions present throughout much of the lake bottom.

Low oxygen levels near the sediment allow release of phosphorus into the water column and reduce the oxidation-reduction potential, which results in the formation of black sediments rich in hydrogen sulfide (H_2S). Phosphorus cycling occurs between the sediments and overlying water and is significantly influenced by wind action and resuspension of particulate matter in lakes (Krogerus and Ekholm, 2003). A study conducted by Ramco in 1993 on Austin Lake in Kalamazoo County, Michigan, utilized a Biological Activity Reaction Test (BART) to determine the degree of activity by various bacteria, such as iron and sulfate metabolism microbes, slime-forming bacteria, fluorescing pseudomonads, cyanobacteria, and total aerobes. The result of their study indicated that the numbers of aggressive aerobic bacteria increased with an increase in aeration relative to the non-aerated control region. The BART test indicated higher activity of sulfate-reducing bacteria, slime-forming bacteria, iron-related bacteria, fluorescing pseudomonas, and total aerobes in the barge-aerated and tube-aerated sites than in the control (non-aerated) site. Such data suggests a strong synergy between bioaugmentation and aeration, which may be adequately utilized to decompose organic matter in the sediments.

2.1.2 Lake Sediment Functions

The majority of inland lake sediment in the region originated from glacial material that was deposited in lake basins nearly 8,000 years ago (Straw et *al.*, 1978). Lake sediments may function as a rooting medium and source of nutrients for rooted aquatic plant. In addition, lake sediments are active components of the biogeochemical cycles present in aquatic ecosystems in that they recycle nutrients and organic matter via microbial metabolism. Odum (1971) showed that lake bottom sediments regulated the metabolism of aquatic ecosystems. In general, lake sediments with coarse particle size (such as sands and gravels) are associated with higher water clarity, while those with smaller particle size such as silts and clays are usually correlated with increased turbidity. Coarse sediment particles tend to appear near shore, whereas finer particles settle out in the deeper portions of a lake. Sediments with large particle size may inhibit rooted aquatic plant growth through mechanical impedance, whereas sediments with smaller particle sizes tend to favor rooted aquatic plant growth unless those sediments are highly flocculent and rooting is not possible.

Sediments may also receive oxygen from the roots of some species of aquatic plant. A study by Bodelier et *al.* (1996) determined that the emergent macrophyte, *Glyceria maxima* utilized root aerenchymatous tissue to oxidize an anoxic (oxygen-deficient) portion of the lake sediment, which previously encouraged growth of ammonia-oxidizing bacteria.

In general, sediments in lake systems are highly heterogeneous having been derived from glacial and anthropogenic (man-induced) activities over time. Lake circulation patterns ultimately dictate the distribution of sediments in a lake ecosystem. Sediments may also be utilized as a source of siliceous diatoms and other macrobiota that form the base of the food chain for higher organisms that feed on benthic biota. Thus some quantity of sediment is essential for the overall metabolic functions and health of a lake ecosystem.

2.1.3 Lake Sediments and the Watershed

The accumulation of lake sediment in areas of Paradise Lake causes limitations in navigational activities due to less water depth. Boats may easily contact the lake bottom and re-suspend sediments which result in degradation of water quality or damage to boat components. Furthermore, the high organic nutrient content of the sediments also contributes to overgrowth of aquatic plants in some areas.

Most of the external sources of sediment are derived from the immediate watershed around Paradise Lake. A watershed may be defined as an area of land that drains to a common point and is influenced by both surface water and groundwater sources that are often impacted from land use activities. In general, a large watershed of a particular lake possesses more opportunities for pollutants to enter the system and alter water quality and ecological communities. In addition, watersheds that contain heavy development and agriculture are more vulnerable to water quality degradation since the fate of pollutant transport may be increased whether directly affected by surface waters and/or indirectly by groundwater. Land use activities have a dramatic impact on the quality of surface waters and groundwater. Engstrom and Wright (2002) cite the significant reduction in sediment flux of one non-aerated lake which was attributed to substantial reduction of sediment loading from the surrounding catchment (watershed). The topography of the land and the morphometry of the lake dictate the ultimate fate transport of pollutants and nutrients into the lake within a particular watershed. Steep slopes on the land surrounding a lake may cause surface runoff to enter the lake more readily than if the land surface was at grade relative to the lake. In addition, lakes with a steep drop-off may act as collection basins for substances that are transported to the lake from the land.

The land around Paradise Lake is mostly flat and so inputs of sediments to the lake from erosion are minimal. Erosion of the land into the water in can cause significant impacts to water quality through the addition of sediments and nutrients. The south and east shores of Paradise Lake are surrounded primarily by mucky loamy sands and peats (USDA-NRCS soil codes Br, Rc, Se, Ta, 2, 8, 9, 10, 61, 63, 78, 85, and 179; USDA-NRCS soil map, Figure 1). The potential for erosion is low around the entire lake but the potential for ponding and runoff is very high in areas with mucky soils. Additionally, regular maintenance of septic systems in these areas is critical. Vegetation buffers around the shoreline should be protected and bare sand should be vegetated to reduce wind-borne erosion and prevent subsidence of the land into the lake during high wave activity.

Many types of land use activities can influence the watershed of a particular lake. Such activities include residential land use, industrial land, agricultural land, water supply land, wastewater treatment land, and stormwater management. All land uses may contribute to the water quality of the lake through the influx of pollutants from non-point (loosely regulated) and point sources (more easily regulated). Non-point sources are often diffuse and arise when climatic events carry pollutants from the land into the lake. Point source pollutants exit from pipes or input devices and empty directly into a lake or watercourse. Residential land use activities involve the use of lawn fertilizers on lakefront lawns, the utilization of septic tank systems for treatment of residential sewage, the construction of impervious (impermeable, hard-surfaced) surfaces on lands within the watershed, the burning of leaves near the lakeshore, the dumping of leaves or other pollutants into storm drains, and removal of vegetation from the land and near the water. In addition to residential land use activities, agricultural practices by crop and cattle farmers contribute nutrient, sediment, and potential pathogen loads to lakes and streams. Industrial land use activities may include possible contamination of groundwater through discharges of chemical or thermal pollution.

The Paradise Lake immediate watershed is the area around the lake draining directly to the lake and is approximately 29,588 acres (46.2 mi^2) in size, which is roughly 15.6 times the size of the lake. The extended watershed is the Boardman-Charlevoix Watershed (HUC 04060105) which is approximately 1,064,960 acres (1,664 mi^2) in size. A thorough investigation of the Critical Source Areas (CSA's) around Paradise Lake that contribute nutrient, sediment, and pathogen loads to the lake could be pursued in future years in an effort to reduce these loads and prescribe Best Management Practices (BMP's) within the immediate watershed.

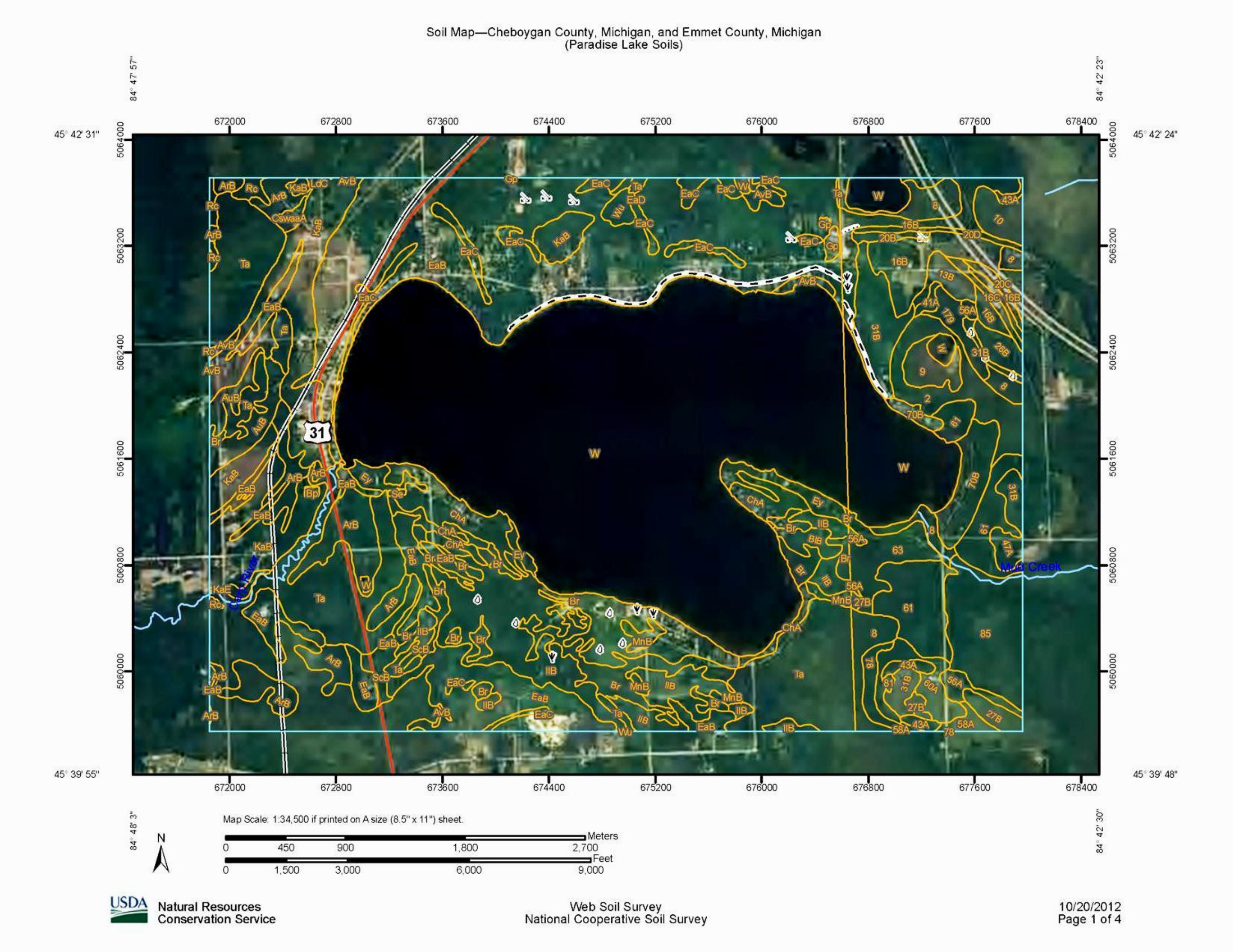
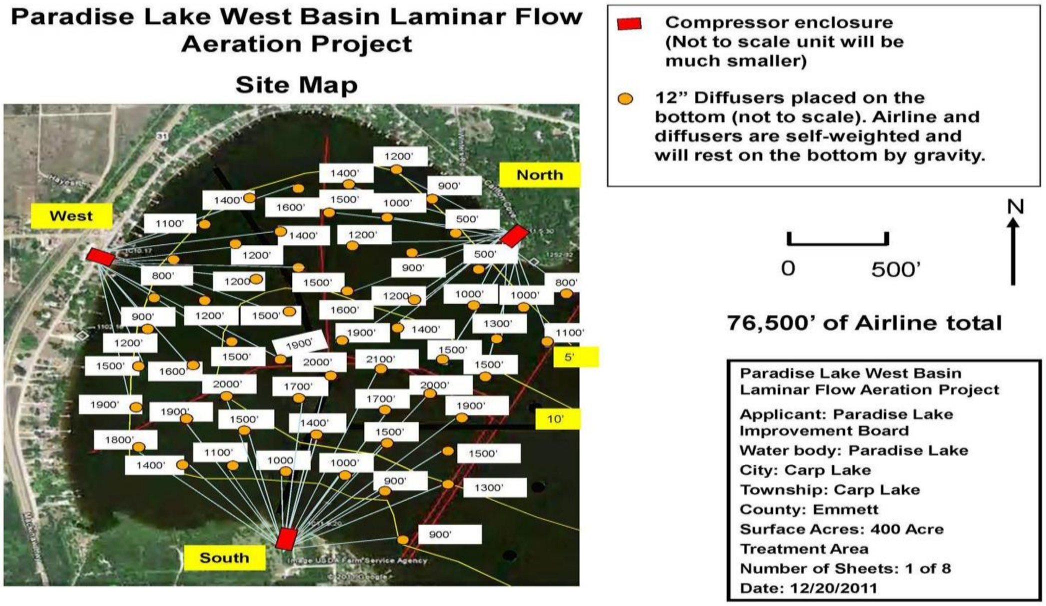


Figure 1. Aerial map showing different soil types around Paradise Lake. Data from the USGS-NRCS Web Soils Survey (1999).

3.0 LAMINAR FLOW AERATION BACKGROUND INFORMATION

3.1 The Mechanics of Laminar Flow Aeration

Laminar flow aeration systems are retrofitted to a specific site and account for variables such as water depth and volume, depth contours, water flow rates, and thickness and composition of lake sediment. Figure 2 shows the retrofitted design for the West Basin of Paradise Lake (courtesy of Lake-Savers, LLC, 2011). The systems are designed to completely mix the surrounding waters with convectional currents and evenly distribute dissolved oxygen throughout the lake sediments for efficient aerobic microbial utilization.



Paradise Lake West Basin
Laminar Flow Aeration Project
Applicant: Paradise Lake Improvement Board
Water body: Paradise Lake
City: Carp Lake
Township: Carp Lake
County: Emmett
Surface Acres: 400 Acre Treatment Area
Number of Sheets: 1 of 8
Date: 12/20/2011

Figure 2. Retrofitted laminar flow aeration system design for the West Basin of Paradise Lake.

A laminar flow aeration system utilizes diffusers which are powered by onshore air compressors. The diffusers are connected via extensive self-sinking airlines which help to purge the lake sediment porewater of benthic carbon dioxide (CO_2), which is a primary nutrient necessary aquatic plant photosynthetic growth and productivity and is also a byproduct of microbial metabolism. Other gasses such as H_2S are also purged out from the sediments. In addition to the placement of the diffuser units, the concomitant use of non-pathogenic bacteria and enzymes to facilitate the microbial breakdown of organic sedimentary constituents is also used as a component of bioaugmentation.

The need for adequate oxygen levels at the sediment-water interface cannot be overemphasized. The philosophy and science behind the laminar flow aeration system is to reduce the organic matter in the sediment so that a significant amount of nutrient and rooting medium is removed from the sediments, thus reducing the pool of organic deposits and increasing water depths. Figures 3 and 4 below show some of the components used during the 2012 system installation.

Figure 3. LFA System Installation, 2012
Photo courtesy of Cathy Freebairn

Figure 4. LFA System Installation, 2012
Photo courtesy of Cathy Freebairn

3.1.1 Benefits and Limitations of Laminar Flow Aeration

It must be realized that there are different forms of aeration, including laminar flow aeration, hypolimentic aeration, fountain aeration, and ozonation aeration (Verma and Dixit, 2006) among others. Furthermore, the technologies used for these aeration devices are designed to deliver aerated water to different regions of lake systems. For optimum performance, designs should be retrofitted to the bathymetry of the lake (such as the laminar flow aeration system that Clean-Flo® designs). Johnson (1984) emphasized the importance of matching the appropriate aeration system design to the lake management application. Installation of a retrofitted aeration system allowed for a basin-wide complete mixing of the water volume.

The use of microbial applications (bioaugmentation) with laminar flow aeration has been studied and has determined that the bioaugmentation is critical. Bacteria are the primary decomposers of organic matter in lakes (Fenchel and Blackburn, 1971). Research on the colony counts of microbes added to lake sediments through bioaugmentation is scarce but would be valuable for determining ideal doses given known background microbial populations for a particular lake ecosystem. Duvall et *al.* (2001) found significant augmentations for microbial applications using certain products of microbes. Historically, bacteria have been used to biodegrade sewage and toxic pollutants (Madigan et *al*., 1997).

Furthermore, laminar flow aeration may reduce the total lake ecosystem respiration in that a constant supply of air can override the accumulated respiratory demands of aerobes that degrade organic materials and use oxygen and also oxidation of reduced compounds resulting from anaerobic respiration. Thus, laminar flow may be an effective tool in maintaining a balance in lake metabolism for sites where respiration activities exceed gross primary production. Staehr and Sand-Jensen (2007) define a balanced lake metabolism as one where the gross primary production (GPP) to Respiration (R) ratio is equal to 1.0.

Lastly, laminar flow aeration may also offer benefits that traditional methods such as dredging cannot provide. These benefits usually include the manipulation of nutrients that may not be successfully reduced from sediments after dredging activities due to the presence of more sediment with anoxic properties. Annadotter et *al*. (1999) mentioned that dredging activities previously implemented in Lake Finjasjön, a shallow eutrophic lake in Sweden, were terminated when sediments left after removal failed to halt the release of phosphorus into the water column. Since many lakes contain several meters of sediments, it is unlikely that dredging could affordably remove all sediments and some degree of continual phosphorus release from sediments will occur in eutrophic systems where the sediment layer is anoxic. This particular realization strengthens the argument for the use of laminar flow aeration as a restorative technique to reduce phosphorus release from sediments.

The laminar flow aeration system has some limitations including the inability to biodegrade mineral sediments, the requirement of a constant single phase electrical energy source to power the units, and unpredictable response by various species of rooted aquatic plants. Thus, the main objective of laminar flow aeration system use should be related primarily to sediment parameters and not in generalized aquatic plant control. However, in lakes with both prominent algal blooms and nuisance aquatic plant, laminar flow aeration offers continuous and sustainable benefits relative to other management methods that are executed only a few times per season or that need to be re-applied.

4.0 PARADISE LAKE WATER QUALITY DATA (2012)

The quality of water is highly variable among Michigan inland lakes, although some characteristics are common among particular lake classification types. The water quality of each lake is affected by both land use practices and climatic events. Climatic factors (i.e., spring runoff, heavy rainfall) may alter water quality in the short term; whereas, anthropogenic (man-induced) factors (i.e., shoreline development or lawn fertilizer use) alter water quality over longer time periods. Since many lakes have a fairly long hydraulic residence time, the water may remain in the lake for years and is therefore sensitive to nutrient loading and pollutants. Furthermore, lake water quality helps to determine the classification of particular lakes. Lakes that are high in nutrients (such as phosphorus and nitrogen) and chlorophyll-*a* (the primary pigment of algae), and low in transparency are classified as **eutrophic**; whereas those that are low in nutrients and chlorophyll-*a*, and high in transparency are classified as **oligotrophic**. Lakes that fall in between these two categories are classified as **mesotrophic**. Paradise Lake is considered meso-oligotrophic due to its clear water and low nutrients and chlorophyll-*a*, but moderate to heavy aquatic plant growth.

4.1 Water and Sediment Parameter Methods, Data, and Discussion

Water quality parameters such as dissolved oxygen, water temperature, conductivity, pH, oxidation-reduction potential (ORP), Secchi transparency, water column total phosphorus and total kjeldahl nitrogen, all respond to changes in water quality and consequently serve as indicators of water quality change. Sediment nutrients (such as organic matter and sediment total phosphorus) are generally more consistent with time, but are usually several orders of magnitude higher than water column concentrations. Sediments are highly heterogeneous among sites and exhibit strong variability based on site-specific characteristics. An aerial map showing the deep basin water quality and sediment sampling locations is shown below in Figure 5. Water quality data for the deep basins can be found in Tables 1-4 and sediment organic matter data in Table 5.

The sections below describe the methods used to measure the parameters, along with measured data and discussion of results.

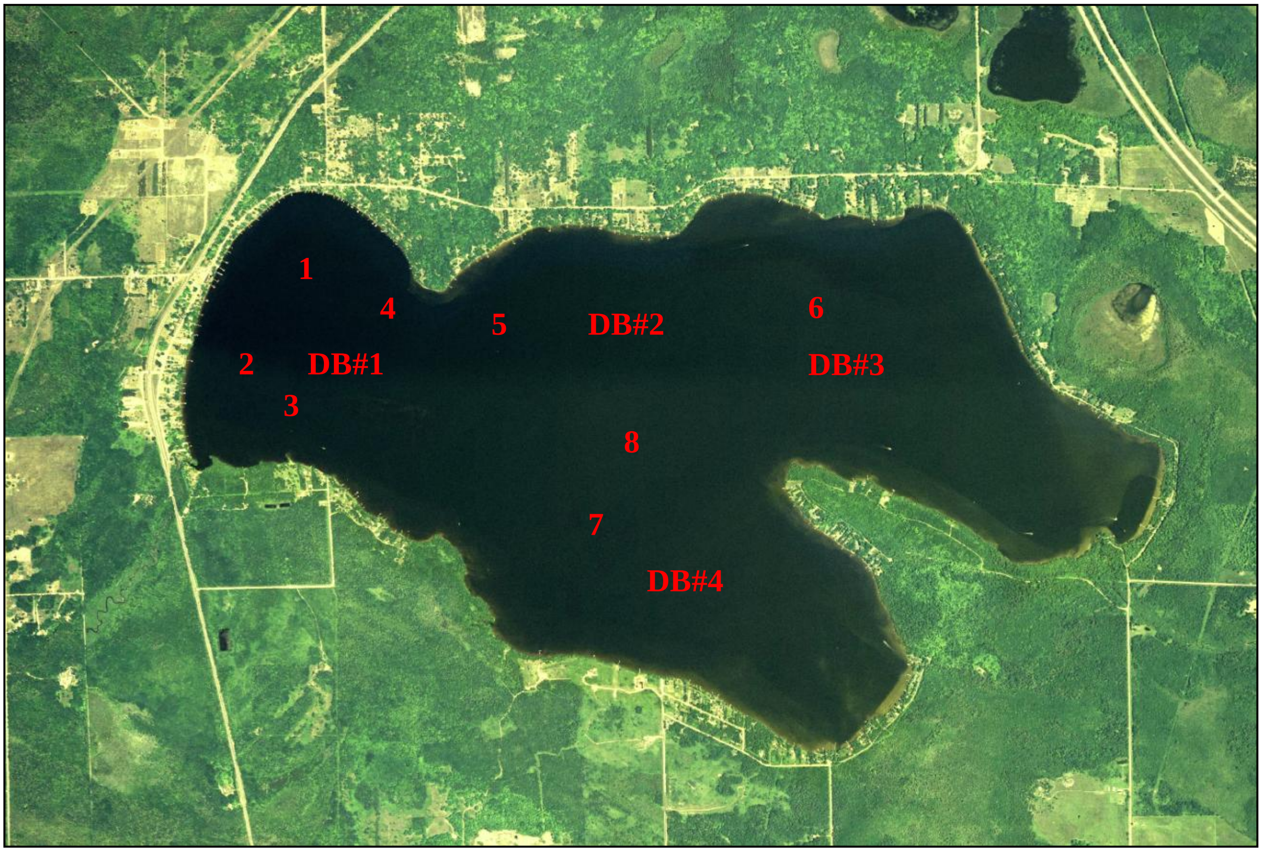


Figure 5. Water quality and sediment sampling locations around Paradise Lake. Note: Sampling sites 1-8 denote sediment sampling locations and DB #1-DB #4 denote deep basin water quality sampling sites.

4.1.1 Dissolved Oxygen

Dissolved oxygen (DO) is a measure of the amount of oxygen that exists in the water column. In general, DO levels should be greater than 5 mg L^{-1} to sustain a healthy warm-water fishery. DO concentrations may decline if there is a high biochemical oxygen demand (BOD) where organismal consumption of oxygen is high due to respiration. DO is generally higher in colder waters. DO was measured in milligrams per liter (mg L^{-1}) with the use of a calibrated dissolved oxygen meter (Hanna Model HI 9828).

The DO concentrations in Paradise Lake ranged between 9.3-12.5 mg L^{-1} in June of 2012. The West Basin (DB#1) exhibited higher DO levels than the other basins at the surface and at depth. This is direct evidence of the efficacy of the laminar flow aeration system for the increase in DO at the West Basin. During summer months, DO at the surface is generally higher due to the exchange of oxygen from the atmosphere with the lake surface, whereas DO is lower at the lake bottom due to decreased contact with the atmosphere and increased biochemical oxygen demand (BOD) from microbial activity. A decline in DO may cause increased release rates of phosphorus from lake bottom sediments if DO levels drop to near 0 mg L^{-1}. Fortunately the lowest concentrations measured in Paradise Lake were not below 9.3 mg L^{-1}. A study by Verma and Dixit (2006) evaluated aeration systems in Lower Lake, Bhopal, India, and found that the aeration increased overall dissolved oxygen, and reduced BOD, chemical oxygen demand (COD), and total coliform counts.

4.1.2 Water Temperature

The water temperature of lakes varies within and among seasons and is nearly uniform with depth under winter ice cover because lake mixing is reduced when waters are not exposed to wind. When the upper layers of water begin to warm in the spring after ice-off, the colder, dense layers remain at the bottom. This process results in a “thermocline” that acts as a transition layer between warmer and colder water layers. During the fall season, the upper layers begin to cool and become denser than the warmer layers, causing an inversion known as “fall turnover”. In general, shallow lakes such as Paradise Lake will not exhibit a major thermal stratification while deeper lakes may experience marked stratification. Water temperature was measured at depth (just above the lake bottom) in degrees Fahrenheit (°F) with the use of a calibrated submersible thermometer probe (Hanna Model HI 9828).

Water temperatures at sampling ranged between 72.0-73.1°F at the surface and 69.3-70.1°F at depth. Differences in water temperatures among sampling sites may be due to variations in solar irradiance, aquatic plant biomass, or relative position to surface water movements.

4.1.3 Conductivity

Conductivity is a measure of the amount of mineral ions present in the water, especially those of salts and other dissolved inorganic substances. Conductivity generally increases as the amount of dissolved minerals and salts, and temperature in a lake increases. Conductivity was measured in micro Siemens per centimeter ($\mu S\ cm^{-1}$) with the use of a calibrated conductivity probe (Hanna Model HI 9828).

Conductivity values for Paradise Lake ranged between 253-269 $\mu S\ cm^{-1}$. These values are normal for an inland lake and reflect a moderate concentration of dissolved solids.

4.1.4 pH

pH is the measure of acidity or basicity of water. The standard pH scale ranges from 0 (acidic) to 14 (alkaline), with neutral values around 7. Most Michigan lakes have pH values that range from 6.5 to 9.5. Acidic lakes ($pH < 7$) are rare in Michigan and are most sensitive to inputs of acidic substances due to a low acid neutralizing capacity (ANC). pH was measured with a calibrated pH electrode (Hanna Model HI 9828) in Standard Units (S.U).

The pH of Paradise Lake water ranged between 7.8-7.9 S.U. The pH of lakes is generally dependent upon submersed aquatic plant growth and underlying geological features. From a limnological perspective, Paradise Lake is considered above neutral on the pH scale.

4.1.5 Secchi Transparency

Secchi transparency is a measure of the clarity or transparency of lake water, and is measured with the use of an 8-inch diameter standardized Secchi disk. Secchi disk transparency was measured in feet (ft) at each individual sampling site (n=4) by lowering the disk over the shaded side of a boat around noon and taking the mean of the measurements of disappearance and reappearance of the disk. Elevated Secchi transparency allows for more aquatic plant and algae growth. Eutrophic systems generally have Secchi disk transparency measurements less than 7.5 feet due to turbidity caused by excessive planktonic algae growth. Secchi transparency is variable and depends on the amount of suspended particles in the water (often due to windy conditions of lake water mixing) and the amount of sunlight present at the time of measurement. The Secchi transparency for Deep Basin 1 was 11.0+ feet, while the Secchi transparency for Deep Basins 2 and 3 was 9.0+ feet (to the bottom) and Deep Basin 4 was 4.6+ feet (to the bottom). These transparency measurements are moderately high for a shallow inland lake and have increased from filtration of the water by zebra mussels.

4.1.6 Oxidation-Reduction Potential

The oxidation-reduction potential (ORP or E_h) of lake water describes the effectiveness of certain atoms to serve as potential oxidizers and indicates the degree of reductants present within the water. In general, the E_h level (measured in millivolts) decreases in anoxic (low oxygen) waters. Low E_h values are therefore indicative of reducing environments where sulfates (if present in the lake water) may be reduced to hydrogen sulfide (H_2S). Decomposition by microorganisms in the hypolimnion may also cause the E_h value to decline with depth during periods of thermal stratification.

The E_h values for Paradise Lake ranged between 98.2-145.2 mV. The high variability could be due to numerous factors such as degree of microbial activity near the sediment-water interface, quantity of phytoplankton in the water, or mixing of the lake water.

4.1.7 Water Column Total Phosphorus

Total phosphorus (TP) is a measure of the amount of phosphorus (P) present in the water column. Phosphorus is the primary nutrient necessary for abundant algae and aquatic plant growth. Lakes which contain greater than 20 µg L^{-1} or 0.020 mg L^{-1} of TP are defined as eutrophic or nutrient-enriched. TP concentrations are usually higher at increased depths due to higher release rates of P from lake sediments under low oxygen (anoxic) conditions. Phosphorus may also be released from sediments as pH increases. Total phosphorus is measured in micrograms per liter (µg L^{-1}) or milligrams per liter (mg L^{-1}) with the use of a chemical auto analyzer or titration methods. The TP values for Paradise Lake are within the meso-eutrophic range of 0.010-0.020 mg L^{-1}.

4.1.8 Water Column Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) is the sum of nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+), and organic nitrogen forms in freshwater systems. Much nitrogen (amino acids and proteins) also comprises the bulk of living organisms in an aquatic ecosystem. Nitrogen originates from atmospheric inputs (i.e. burning of fossil fuels), wastewater sources from developed areas (i.e. runoff from fertilized lawns), agricultural lands, septic systems, and from waterfowl droppings. It also enters lakes through groundwater or surface drainage, drainage from marshes and wetlands, or from precipitation (Wetzel, 2001). In lakes with an abundance of nitrogen (N: P > 15), phosphorus may be the limiting nutrient for phytoplankton and aquatic macrophyte growth. Alternatively, in lakes with low nitrogen concentrations (and relatively high phosphorus), the blue-green algae populations may increase due to the ability to fix nitrogen gas from atmospheric inputs. Lakes with a mean TKN value of 0.66 mg L^{-1} may be classified as oligotrophic, those with a mean TKN value of 0.75 mg L^{-1} may be classified as mesotrophic, and those with a mean TKN value greater than 1.88 mg L^{-1} may be classified as eutrophic. The TKN values for Paradise Lake ranged 1.0-4.1 mg L^{-1} within the meso-eutrophic range.

Depth ft	*Water Temp ºF*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*TDS mg L^{-1}*	*ORP mV*	*Total Kjeldahl Nitrogen mg L^{-1}*	*Total Alk. mgL^{-1} $CaCO_3$*	*Total Phos. mg L^{-1}*
0	70.3	12.5	7.9	253	127	102.9	1.0	98	0.010
5.5	68.6	12.0	7.9	261	132	145.2	2.3	100	0.010
11	67.1	11.2	7.8	263	132	103.9	2.4	98	0.015

Table 1. Paradise Lake water quality parameter data collected over Deep Basin 1 on June 15, 2012.

Depth ft	*Water Temp ºF*	*DO mg L^{-1}*	*pH S.U.*	*Cond. µS cm^{-1}*	*TDS mg L^{-1}*	*ORP mV*	*Total Kjeldahl Nitrogen mg L^{-1}*	*Total Alk. mgL^{-1} $CaCO_3$*	*Total Phos. mg L^{-1}*
0	71.8	11.7	7.9	259	134	132.1	2.0	101	0.010
5	69.8	10.4	7.8	262	128	128.6	2.7	97	0.010
10	67.9	9.8	7.8	264	132	120.1	3.9	100	0.020

Table 2. Paradise Lake water quality parameter data collected over Deep Basin 2 on June 15, 2012.

Depth ft	*Water Temp ºF*	*DO mg L⁻¹*	*pH S.U.*	*Cond. µS cm⁻¹*	*TDS mg L⁻¹*	*ORP mV*	*Total Kjeldahl Nitrogen mg L⁻¹*	*Total Alk. mgL⁻¹ CaCO₃*	*Total Phos. mg L⁻¹*
0	72.0	12.5	7.9	254	128	134.6	1.5	98	0.005
5	69.1	11.4	7.8	263	132	139.4	2.8	98	0.010
9.5	69.0	9.3	7.8	269	132	108.1	4.1	100	0.020

Table 3. Paradise Lake water quality parameter data collected over Deep Basin 3 on June 15, 2012.

Depth ft	*Water Temp ºF*	*DO mg L⁻¹*	*pH S.U.*	*Cond. µS cm⁻¹*	*TDS mg L⁻¹*	*ORP mV*	*Total Kjeldahl Nitrogen mg L⁻¹*	*Total Alk. mgL⁻¹ CaCO₃*	*Total Phos. mg L⁻¹*
0	72.2	10.9	7.9	254	128	98.2	1.5	101	0.012
5	70.0	11.6	7.8	259	128	103.2	3.6	99	0.016

Table 4. Paradise Lake water quality parameter data collected over Deep Basin 4 on June 15, 2012.

4.1.9 Sediment Organic Matter

Organic matter (OM) contains a high amount of carbon which is derived from biota such as decayed plant and animal matter. Detritus is the term for all dead organic matter which is different than living organic and inorganic matter. OM may be autochthonous or allochthonous in nature where it originates from within the system or external to the system, respectively. Sediment OM is measured with the ASTM D2974 Method and is usually expressed in a percentage (%) of total bulk volume. Many factors affect the degradation of organic matter including basin size, water temperature, thermal stratification, dissolved oxygen concentrations, particle size, and quantity and type of organic matter present. There are two major biochemical pathways for the reduction of organic matter to forms which may be purged as waste. First, the conversion of carbohydrates and lipids via hydrolysis are converted to simple sugars or fatty acids and then fermented to alcohol, CO_2, or CH_4. Second, proteins may be proteolyzed to amino acids, deaminated to NH_3+, nitrified to NO_2- or NO_3-, and denitrified to N_2 gas.

Bacteria are the major factor in the degradation of organic matter in sediments (Fenchel and Blackburn, 1979) so the concomitant addition of microbes to lake sediments will accelerate that process. A reduction in sediment organic matter would likely decrease aquatic plant growth as well as increase water depth.

Wang et *al*. (2008) showed that although organic matter in sediments may restrict the release of soluble reactive phosphorus (SRP) to overlying waters, the fraction of dissolved organic phosphorus (DOP) is readily released by organic matter under anoxic conditions. Thus, reduction of the organic matter layer may reduce the total nutrient pool available for release in eutrophic lake systems. The concentrations of phosphorus in both sediments and the water column fluctuate seasonally in lakes with reported increases occurring during the summer (Clay and Wilhm, 1979).

Laing (1978) demonstrated an annual loss of 49-82 cm of organic sediment in a study of nine lakes which received aeration and bioaugmentation. It was further concluded that this sediment reduction was not due to redistribution of sediments since samples were collected outside of the aeration “crater” that is usually formed.
Other inland lakes in Michigan such as Chippewa Lake (Mecosta County, Michigan), Keeler Lake (Van Buren County, Michigan), and Sherman Lake (Kalamazoo County, Michigan) have successfully used laminar flow technology to reduce organic matter accumulation in lake sediments and reduce nuisance algal and aquatic plant growth.

Eight sediment samples were collected by hand with a hand-held (Ekman) dredge from eight areas throughout the lake (Table 5). Each sediment sample was kept on ice prior to analysis in the laboratory for percentage of OM. The mean percentage of organic matter among all of the samples was 57.6%, with a high of 71% and a low of 47%. The highest concentrations of organic matter were found near the western and northern portions of the lake with the lowest values near the southern basin. Additionally, 4 samples were collected from the southeast shoreline to assess the constituency of the materials that washed ashore during late summer of 2012 (Figures 6 and 7). Analysis of the samples determined that the content was primarily decayed submersed aquatic plant tissue that consisted primarily of Eurasian Watermilfoil and Fernleaf Pondweed. The origin of the plant material could have been generated from anywhere within the lake and was transported to this region during a strong north or northwest wind.

Figure 6. SE Shoreline debris, October, 2012.

Figure 7. SE Shoreline debris, October, 2012.

Sampling* *Site	***Sediment* *% Organic Matter***
1	62
2	57
3	47
4	52
5	68
6	49
7	55
8	71

Table 5. Paradise Lake sediment data collected around the lake on June 15, 2012.

4.2 Phytoplankton Methods, Data, and Discussion

4.2.1 Phytoplankton Sampling Methods

Water samples were collected via a composite sample from above the sediment to the surface using a composite sampler as described by Nicholls (1979). Samples were placed in dark brown polyethylene bottles and maintained at 4°C until microscopic analysis could be executed. All samples were preserved with buffered glutaraldehyde and analyzed within 48 hours of collection.

Prior to microscopic analysis, each sample bottle was inverted twenty times prior to selection of each aliquot to evenly distribute phytoplankton in the sample. A calibrated Sedgwick-Rafter counting cell (50 mm x 20 mm in area with etched squares in mm) with 1-ml aliquots (n=5 per water sample) was used under a bright-field compound microscope to determine the identity and quantity of the most dominant phytoplankton genera from each Paradise Lake water samples (n=4). For identification of the individual dominant algal taxa, algal samples were keyed to genus level with Prescott (1970).

Phytoplankton Data and Discussion

Algal genera present in Paradise Lake include the following as determined through analysis under a compound bright field microscope. The genera present included the Chlorophyta (green algae): *Haematococcus* sp., *Chlorella* sp., *Scenedesmus* sp., *Ulothrix* sp., *Euglena* sp., *Chloromonas* sp., *Mougeotia* sp., *Staurastrum* sp., and *Pediastrum* sp.; the Cyanophyta (blue-green algae): *Gleocapsa* sp.; the Bascillariophyta (diatoms): *Stephanodiscus* sp., *Synedra* sp., *Navicula* sp., *Tabellaria* sp., *Cymbella* sp., and *Pinnularia* sp., and *Rhoicosphenia* sp*.* The aforementioned species indicate a diverse algal flora and represent a relatively balanced freshwater ecosystem, capable of supporting a strong zooplankton community in favorable water quality conditions.

Blue-green algae such as *Microcystis* sp. are capable of producing micro toxins (Rinehart et *al*. 1994) that can cause neurologic or hepatic (liver) dysfunction in animals or humans if ingested in large quantities. Blue-green blooms are usually visible as a bluish tinted surface “scum layer” on lake waters when they are a threat and these areas should be avoided when obvious surface layer blooms are present. The relative abundance of the blue-green algae was very low compared to green algae and diatoms, which are the preferred food source for zooplankton. At the present time, the only blue-green algae found, *Gleocapsa* sp. is not known to produce potent toxins like *Microcystis* sp. Table 6 below shows the relative number of algae by taxa for a composite water sample.

Site	Mean # Blue-Green Algae	Mean # Green Algae	Mean # Diatoms
Deep Basin #1	2	41	78
Deep Basin #2	4	52	89
Deep Basin #3	8	67	74
Deep Basin #4	5	60	66

Table 6. June 15, 2012 phytoplankton data

There has been considerable variability in the responses of biotic and abiotic parameters to aeration. For example, some studies have cited increases in green algae (Boehmke, 1984; Toetz, 1981), or blue-green algae (Knoppert et *al*., 1970) and others have observed declines in blue-green algae such as *Microcystis* (Malueg et *al*., 1973; Toetz, 1981). A study by Burns (1994) found that annual aeration prevented the formation of reducing conditions which in turn reduced available nutrients for blue-green phytoplankton growth.

Toetz (1981) found evidence of a decline in *Microcystis* algae (toxin-producing blue - green algae) in Arbuckle Lake in Oklahoma. Other studies (Weiss and Breedlove, 1973; Malueg et *al*., 1973) have also shown declines in overall algal biomass.

Chorus and Bartram (1999) reiterate that bathing waters with < 20,000 cyanobacteria cells per ml are considered not hazardous to public health. Paradise Lake water samples were found to contain no *Microcystis* cells. However, a few cells of *Gleocapsa* were noted and this alga is not currently known to produce toxins.

Currie and Kalff (1984) found that bacteria can be more efficient in the uptake of phosphorus in the epilimnion compared to different types of phytoplankton. This could have favorable ramifications for laminar flow aeration since augmentation of bacteria in sediments through bioaugmentation could increase bacterial population densities to lead to increased uptake of phosphorus which becomes less available in the sediment pore water or sediments.

Blue-green algae are highly resistant to photo-inhibition and thus can continue to photosynthesize during exposure to high light conditions (Paerl et al., 1995). *Microcystis* contains cellular toxins that can cause liver (Hughes et *al*., 1958; Falconer et *al.*, 1983) and nerve damage in humans and animals. A historical study by Gerloff and Skoog in 1957 of lakes in southern Wisconsin determined that the abundance of *Microcystis* was dependent on adequate levels of nitrogen in the water, since this nutrient was the most limited.

Boyd et *al.* (1984) showed no significant effects on total phosphorus, nitrogen, or chlorophyll-a, or phytoplankton quantities with the applications of microbes.

A recent study by Vanderploeg et *al*. (2001) on Saginaw Bay (Lake Huron) and Lake Erie showed that *Microcystis* became much more prominent after the introduction of zebra mussels (*Dreissena polymorpha*). This is because the mussels filter the lake water for valuable phytoplankton and expel the blue-green algae (such as *Microcystis*) that are relatively undesirable. The increase in zebra mussels within Paradise Lake may make the lake more vulnerable to *Microcystis* growth; however, given the low nutrient concentrations of the lake, it is unlikely that a large infestation of *Microcystis* would occur since it desires hyper-eutrophic (very nutrient-rich) conditions.

4.3 Submersed Aquatic Plant Sampling Methods, Data, and Discussion

4.3.1 Submersed Aquatic Plant Sampling Methods

The GPS Point-Intercept Survey method was developed by the Army Corps of Engineers to assess the presence and relative abundance of submersed and floating-leaved aquatic plants within the littoral zones of Michigan lakes. With this survey method, individual GPS points are sampled for relative abundance of aquatic plant species. Each macrophyte species corresponds to an assigned number designated by the MDEQ. In addition to the particular species observed (via assigned numbers), a relative abundance scale is used to estimate the percent coverage of each species within the GPS site.

The surveys on June 15, 2012 and October 2, 2012 consisted of 220 sampling locations in the West Basin of Paradise Lake. A combination of rake tosses, visual observations, and bioaccoustic methods were executed throughout the West Basin area. The primary objective of these surveys was to assess the conditions of the submersed aquatic plant communities before and after implementation of the laminar flow aeration system with bioaugmentation. The secondary objective was to assess the evidence of weevil damage throughout different regions of the lake and make management recommendations for future years.

4.3.2 Paradise Lake Exotic Aquatic Plants

Exotic aquatic plants (aquatic plants) are not native to a particular site and are introduced by some biotic (living) or abiotic (non-living) vector. Such vectors include the transfer of aquatic plant seeds and fragments by boats and trailers (especially if the lake has public access sites), waterfowl, or by wind dispersal. In addition, exotic species may be introduced into aquatic systems through the release of aquarium or water garden plants into a water body. An aquatic exotic species may have profound impacts on the aquatic ecosystem. The majority of exotic aquatic plants do not depend on high water column nutrients for growth, as they are well-adapted to using sunlight and minimal nutrients for successful growth. These species have similar detrimental impacts to lakes in that they decrease the quantity and abundance of native aquatic plants and associated macroinvertebrates and consequently alter the lake fishery.

Education and awareness are key ingredients for the reduction of transfers of these and other invasive species. All boats placed into Paradise Lake should be thoroughly steam-washed if previously in another water body. Additionally, any bait used for fishing should be discarded of properly and should not consist of invasive species. Lastly, if water gardens are created on residential properties, then imported aquatic plants should never be released into Paradise Lake. The new boat-washing station will help make resources for rinsing boats and trailers available for lake users. Figure 8 shows a boat washing station on Wolverine Lake in Oakland County, MI.

Figure 8. A boat washing and educational station on Wolverine Lake, Oakland County, MI.

The only invasive found in Paradise Lake was the exotic, invasive submersed aquatic plant (*Myriophyllum spicatum*; Figures 9), which has been previously treated with weevils and is currently being treated with both aeration and bioaugmentation and sustained weevil populations. Figures 10 and 11 show the conditions of the milfoil canopy in 2009 relative to that observed in 2012. Even despite low water levels during the October 2012 sampling, the canopy was absent in the West Basin and the amount of dense milfoil declined from 61 sites to 39 sites after exposure to aeration for a 3 month period. Eurasian Watermilfoil was first documented in the United States in the 1880's (Reed 1997), although other reports (Couch and Nelson 1985) suggest it was first found in the 1940's. *M. spicatum* has since spread to thousands of inland lakes in various states through the use of boats and trailers, waterfowl, seed dispersal, and intentional introduction for fish habitat. *M. spicatum* is a major threat to the ecological balance of an aquatic ecosystem through causation of significant declines in favorable native vegetation communities within lakes (Madsen et al. 1991), and may limit light from reaching native plant species (Newroth 1985; Aiken et al. 1979). Additionally, *M. spicatum* can alter the macroinvertebrate populations associated with particular native plants of certain structural architecture (Newroth 1985). Within the past decade, research has been conducted on the genotype of hybrid watermilfoil species (Moody and Les, 2002; 2007) which are commonly a result of cross-pollination between *M. spicatum* and other native species such as Northern Watermilfoil (*M. sibiricum*), and Variable Watermilfoil (*M. heterophyllum*). Since the introduction of Eurasian Watermilfoil, many nuisance aquatic plant management techniques such as chemical herbicides, mechanical harvesting, and biological control have been implemented. Mechanical harvesting is generally not recommended for the control of Eurasian Watermilfoil since it causes fragmentation of the plant which dramatically increases the spread of the plant, with each fragment possessing the potential to root into the sediment and grow as a new plant. Chemical aquatic herbicides are commonly used but require a permit from the Michigan Department of Environmental Quality and must be registered with the U.S. EPA and U.S. Department of Agriculture. Biological control may be a preferred method that is chemicalfree and target-specific, and will not cause fragmentation of Eurasian Watermilfoil. Additionally, laminar flow aeration appears to be reducing Eurasian Watermilfoil in many inland lakes including Paradise Lake.

Figure 9. Eurasian Watermilfoil
© *Superior Photique, 2006*

Figure 10. Eurasian Watermilfoil canopy on West Basin, 2009.

Figure 11. Eurasian Watermilfoil canopy on West Basin, 2012.

4.3.3 Assessment of the Weevil on Paradise Lake Eurasian Watermilfoil

The aquatic weevil, *Euhrychiopsis lecontei* naturally exists in many of our lakes; however, the lack of adequate populations in many lakes requires that they be implanted or stocked for successful control of the milfoil. The weevil feeds almost entirely on Eurasian Watermilfoil and will leave native aquatic species unharmed. The weevil burrows into the stems of the milfoil and removes the vascular tissue, thereby reducing the plant's ability to store carbohydrates (Newman et al. 1996). Eventually, the milfoil stems lose buoyancy and the plant decomposes on the lake bottom. Recent research has shown that the weevils require a substantial amount of aquatic plant biomass for successful control of Eurasian Watermilfoil. In addition, the weevils require adequate over-wintering habitat since they over-winter within shoreline vegetation. Lakes with sparse milfoil distribution and abundant metal and concrete seawalls are not ideal candidates for the milfoil weevil. There is an adequate amount of overwintering vegetation around the Paradise Lake shoreline to support a sustained weevil population.

The native weevil, *Euhrychiopsis lecontei* (Coleoptera: Curculionidae; Figure 12) has been shown to cause detrimental impacts on the exotic aquatic macrophyte Eurasian Watermilfoil (Creed et al. 1992, Creed and Sheldon 1995, Newman et al. 1996). The weevil life cycle consists of larval, pupae, and adult life stages, which all are involved in the destruction of the milfoil plants. In the initial stages of biological control, larvae are applied to the apical (top) portions of stems and destroy the vascular tissue (Creed and Sheldon 1993, 1994a, Newman et al. 1996), which significantly hinders stem elongation. During the pupation stage, stem vascular tissue is further destroyed during the construction of the pupal chamber (Creed and Sheldon 1993). During the adult phase, mature weevils feed on the milfoil leaves and stems (Creed and Sheldon 1993).

Figure 12. The milfoil weevil, *Euhrychiopsis lecontei,*
used with permission from R. Newman.

Observed impacts include the devascularization of stem tissue which causes buoyancy loss (due to a loss of stored CO_2 gases in stem epithelial cells) and photosynthetic growth inhibition of milfoil plants (Creed et al. 1992; Newman et al. 1996). Other herbivore species such as *Phytobius leucogaster* and *Acentria ephemerella* showed negligible results in the reduction of Eurasian Watermilfoil (Sheldon 1995; Creed and Sheldon 1994). It is possible that many water physical, chemical, and biological variables could affect the success of the *E. lecontei* control method. As a result, weevil evaluation treatments should minimize variables to the extent possible.

Milfoil Stem Collection

On June 15, 2012 and on October 2, 2012 60 milfoil stems were collected from the West, South, and North basins. Individual milfoil stems were randomly selected and placed into a labeled 2-gallon ziplock® plastic collection bag for analysis.

Laboratory Methods and Analyses

After milfoil stems were collected in the field and transported to the laboratory, they were cleaned and sorted prior to being inspected under the dissection microscope.

Each milfoil stem that was collected at each of the three sampling sites was sorted and untangled prior to analysis under the microscope. In order to avoid washing any delicate life cycle stages (i.e. newly laid eggs or larvae) off of the exterior of the milfoil stems, washing of the stems was conducted only after an initial scan of the stem was completed and any of the associated weevil life cycle stages (if any present) were recorded. Milfoil stems that could not be immediately analyzed were placed between constantly moistened paper towels which were refrigerated to halt tissue degradation. If necessary, stems with thick encrustations of zebra mussels (*Dreissena polymorpha*) or other debris, were cleaned with deionized water and a steady stream of cold and lightly pressurized water. Whenever possible, tissue analyses occurred as soon as the dissection microscope was available after each sample.

Stem damage parameters such as stem diameter was measured and recorded. Stem diameter was measured in (mm) with the use of a set of calibrated, digital calipers, which was re-calibrated between each reading for enhanced accuracy.

The condition of the milfoil stems (index of stem damage, Jermalowicz-Jones et *al*., 2007) was measured on each of the collected stems. The index of stem damage includes a stem tissue damage scale that ranges from 0 to 5. The index ranged from 0 - 5 with a value of “0” denoting no weevil damage visible, a “2” denoting the presence of larvae or eggs on or in the stem, a “3” indicated the presence of larvae in the stem tissues and vascular tissue damage, “4” indicated the presence of larvae or pupae and severe necrosis of the stem tissue, and a “5” denoted both severe tissue necrosis, weevil pupae or larvae, and the loss of foliar leaves. To assess for weevil damage, each individual milfoil stem was placed under the dissection microscope (first under the 10x objective power and then under the 20x objective power) to look at the plant from the apical tip to the roots. Both overhead and base-lighting are used to illuminate the plant specimens and determine if weevil larvae or other life cycle stages are present in or on the individual stems. If weevil stages were located in or on the stems, they were recorded.

The data show that the stem diameter is highly variable and is not an adequate indicator of weevil damage. The stem damage index, however, showed no significant damage at the North basin during the 2012 season. The largest increase in stem damage was at the South and West basins, respectively. It is too early to determine if the weevils are working synergistically with the laminar flow aeration system and thus bi-seasonal sampling is recommended for 2013. Furthermore, Figure 13 shows the changes in milfoil density at the West Basin sampling site before and after the implementation of laminar flow aeration.

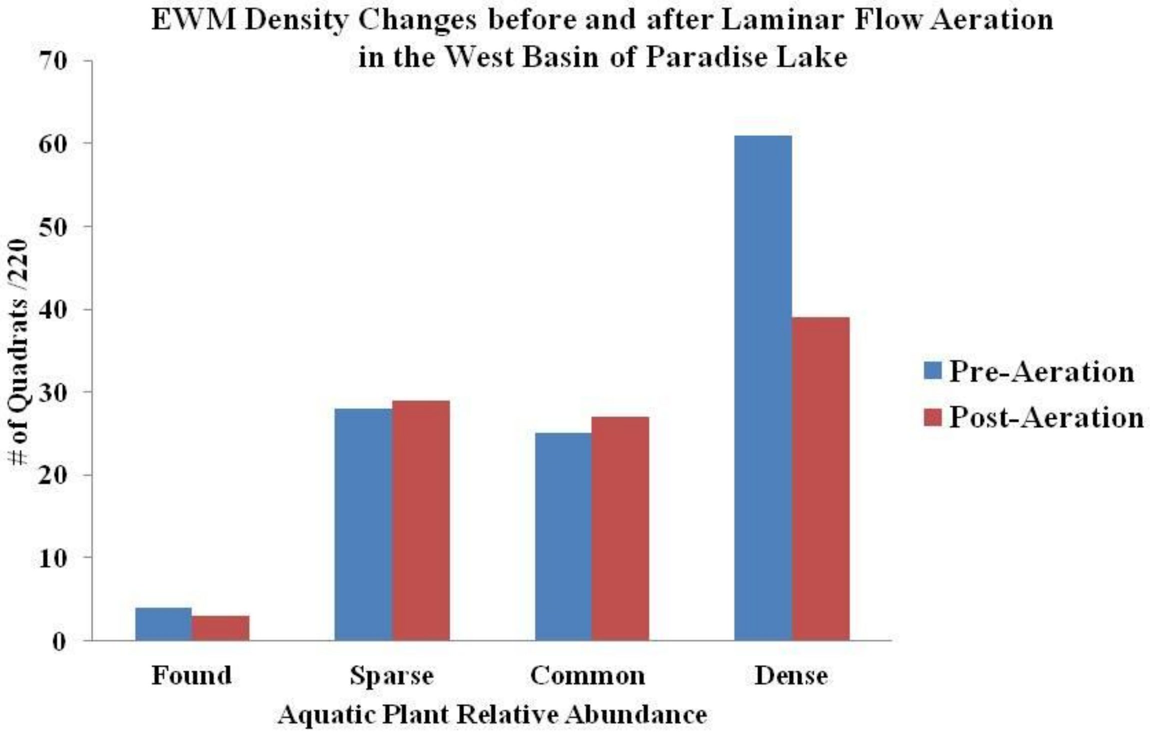


Figure 13. Changes in EWM density at West Basin sampling sites before and after laminar flow aeration.

EWM Stem Sampling Location	***June Mean Stem Diameter (mm)***	***June Mean Damage Index (0-5)***	***October Mean Stem Diameter (mm)***	***October Mean Damage Index (0-5)***
West Basin	1.89 ± 0.36	1.7 ± 1.5	1.56±0.22	2.5±1.7
South Basin	1.86 ± 0.32	1.6 ± 0.9	1.79±0.30	3.3±1.4
North Basin	2.00 ± 0.40	0.6 ± 0.7	2.24±0.45	1.0±0.9

Table 7. Summary data table showing responses of EWM to weevil predation in June and October of 2012 in the West, South, and North basins of Paradise Lake.

4.3.4 Paradise Lake Native Aquatic Plants

There are hundreds of native aquatic plant species in the waters of the United States. The most diverse native genera include the Potamogetonaceae (Pondweeds) and the Haloragaceae (Milfoils). Native aquatic plants may grow to nuisance levels in lakes with abundant nutrients (both water column and sediment) such as phosphorus, and in sites with high water transparency. The diversity of native aquatic plants is essential for the balance of aquatic ecosystems, because each plant harbors different macroinvertebrate communities and varies in fish habitat structure.

Paradise Lake contains 7 submersed, 2 floating-leaved, and 4 emergent aquatic plant species (Table 8), for a total of 13 native aquatic plant species. The majority of the emergent macrophytes may be found along the shoreline of the lake. Additionally, the majority of the floating-leaved macrophyte species can be found near the perimeter of the lake. This is likely due to enriched sediments and shallower water depth with reduced wave energy, which facilitates the growth of aquatic plants with various morphological forms. Figure 14 shows the relative abundance of all aquatic plant species before and after implementation of the laminar flow aeration system.

The dominant native submersed aquatic plants included Fernleaf Pondweed (*Potamogeton robbinsii*; Figure 15) which occupied over 35% of the West Basin during both June and October of 2012. The second most abundant submersed plant was Whitestem Pondweed (*Potamogeton praelongus*; Figure 16), which occupied approximately 11.5% of the West Basin in June and 21.1% of the West Basin in October. Such an increase in growth may be due to the seasonal increases that would occur between June and October and not necessarily from the laminar flow aeration system. This aquatic plant is seldom a nuisance in natural aquatic systems, but can grow tall in the water column and create navigational issues in dense quantities. The third most abundant aquatic plant was Clasping-leaf Pondweed (*Potamogeton richardsonii*), which has increased dramatically over the past few years. The dominance of rooted submersed aquatic plants in the lake suggests that the lake sediments are the primary source of nutrients (especially nitrogen), since most submersed aquatic plants obtain most of their nutrition from the sediments.

Other aquatic plants found in Paradise Lake can be seen in Figure 18-27. Only moderate densities of most native aquatic plant species were noted and careful management strategies are needed to manage exotic aquatic plant species and protect native species, while preserving the delicate balance of native vegetation communities.

The Michigan Department of Environmental Quality has designated abundance codes for the aquatic plant surveys, where a = found (occupying < 2% of the surface area of the lake), b = sparse (occupying 2-20% of the surface area of the lake), c = common, (occupying 21-60% of the surface area of the lake), and d = dense (occupying > 60% of the surface area of the lake).

Aquatic Plant Species And MDEQ code	***Aquatic Plant Common Name***	***% West Basin Covered Pre-Aeration***	***% West Basin Covered Post-Aeration***
Chara vulgaris, 3	Muskgrass	0.2	1.6
Stuckenia pectinatus, 4	Thinleaf Pondweed	0.0	0.3
Potamogeton zosteriformis, 5	Flatstem Pondweed	5.1	1.1
Potamogeton robbinsii, 6	Fernleaf Pondweed	35.2	35.5
Potamogeton gramineus, 7	Variableleaf Pondweed	4.0	2.7
Potamogeton praelongus, 8	Whitestem Pondweed	21.1	11.5
Potamogeton richardsonii, 9	Claspingleaf Pondweed	17.3	3.1
Potamogeton illinoensis, 10	Illinois Pondweed	11.5	1.7
Potamogeton amplifolius, 11	Largeleaf Pondweed	16.6	1.2
Vallisneria americana, 15	Wild Celery	8.3	2.5
Myriophyllum verticillatum, 18	Whorled Watermilfoil	4.3	4.3
Elodea canadensis, 21	Common Waterweed	8.4	4.4
Utricularia vulgaris, 22	Bladderwort	2.6	4.7
Najas flexilis, 26	Slender Naiad	4.8	1.8

Table 8. Paradise Lake changes in aquatic plant species and relative abundance prior to and after laminar flow aeration (June and October, 2012).

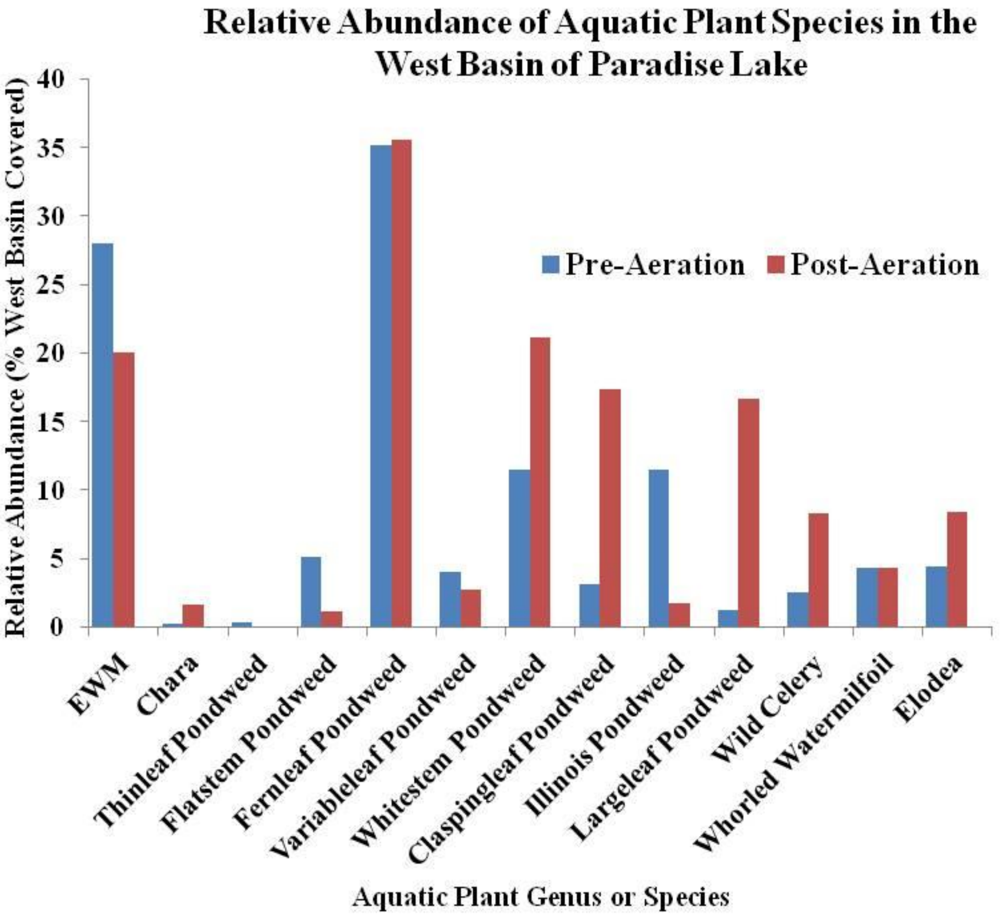


Figure 14. Changes in submersed aquatic plant relative abundance in the West Basin of Paradise Lake before and after laminar flow aeration.

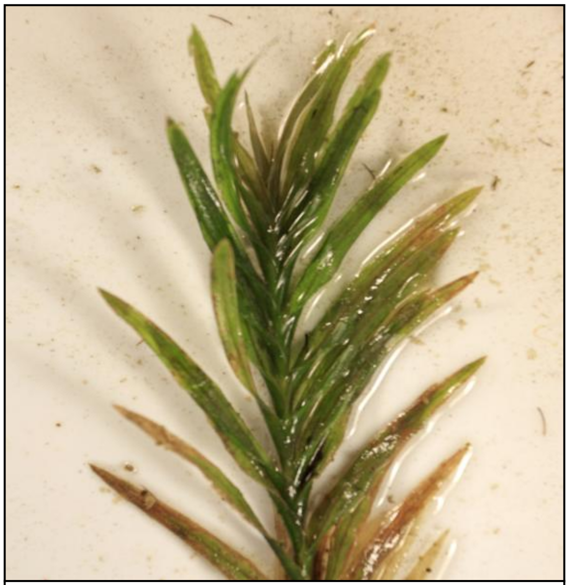


Figure 15. Fernleaf Pondweed
(*Potamogeton robbinsii*)
© *Superior Photique, 2008*

Figure 16. Whitestem Pondweed
(*Potamogeton praelongus*)
© *Superior Photique, 2008*

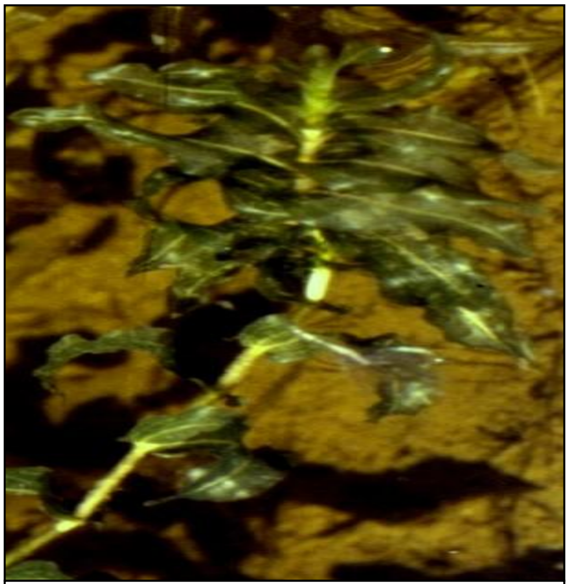


Figure 17. Claspingleaf Pondweed
(*Potamogeton richardsonii*)

Figure 18. Largeleaf Pondweed
© *Superior Photique, 2008*

Figure 19. Common Waterweed
(*Elodea canadensis*)
© *Superior Photique, 2006*

Figure 20. Wild Celery
(*Vallisneria americana*)
© *Superior Photique, 2006*

Figure 21. Slender Naiad
(*Najas flexilis*)
© *Superior Photique, 2006*

Figure 22. Whorled Watermilfoil
(*Myriophyllum verticillatum*)
© *Superior Photique, 2012*

Figure 23. Variableleaf Pondweed
(*Potamogeton gramineus*)
© *Superior Photique, 2008*

Figure 24. Bladderwort
(*Uricularia vulgaris*)
© *Superior Photique, 2008*

Figure 25. Illinois Pondweed
(*Potamogeton illinoensis*)
© *Superior Photique, 2008*

Figure 26. Muskgrass
(*Chara vulgaris*)

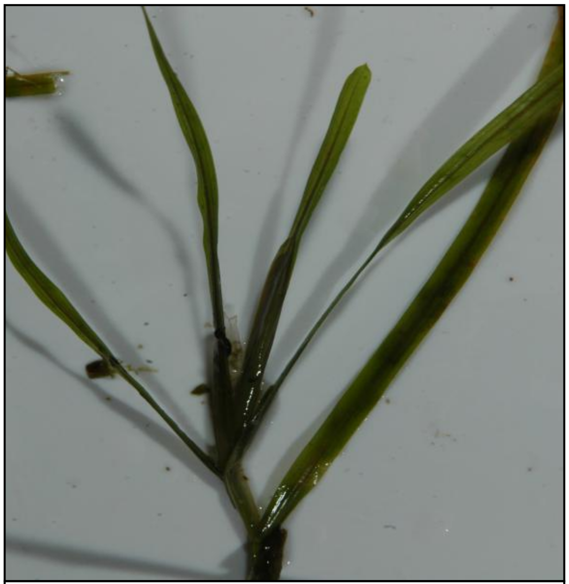


Figure 27. Flatstem Pondweed
(*Potamogeton zosteriformis*)
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5.0 Conclusions and Future Recommendations for Paradise Lake

It is important that any improvement method used on Paradise Lake be sustainable to allow for the best long-term results. A lake management method that is sustainable means that it will continuously drive its functions with little maintenance while allowing the lake ecosystem to maintain a healthy balance.

Paradise Lake is a lake ecosystem with overall good water quality and a healthy balance of phytoplankton (algae) and zooplankton as well as a diverse fishery. The major impairments of the lake include the presence of the invasive submersed Eurasian Watermilfoil and the presence of highly organic sediments that contribute to muck accumulation.

The laminar flow aeration system will continue to deliver multiple benefits for quality improvements to Paradise Lake. Specifically, it would reduce the depth of organic muck and help to keep algal and submersed aquatic plant communities in balance. Thus, reduction of the sediment organic matter would also likely reduce sediment nutrients that are available to the aquatic plants. Additionally, it appears that it is not having significant negative impacts on native aquatic plant species. **Continued bi-seasonal monitoring of the West Basin is critical to differentiate the differences between season impacts on plant growth and those of the laminar flow aeration system with bioaugmentation.**

Although reduction of watershed inputs and future BMP's may significantly reduce new nutrient loads to the lake, the nutrient-rich sediments will continue to support abundant and nuisance-level submersed aquatic plant growth. The need to understand the behaviors outside of the lake area and within the immediate watershed and also to understand the impact and magnitude of watershed externalities cannot be underestimated (Carpenter and Lathrop, 1999). Protection of the shoreline vegetation around the lake is critical for sustain weevil population growth due to overwintering capacity.

For the North Basin that has showed little weevil damage and the presence of late season milfoil canopies, additional weevils (approximately 50,000) could be planted in a 10 acre area to facilitate a large colony. If management of excessive Fernleaf Pondweed is desired, mechanical removal may also be used in those areas.

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