Restorative Lake Sciences, LLC

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

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1.0 PARADISE LAKE PROJECT SUMMARY & CONCLUSIONS

Evaluation of the laminar flow aeration system during the 2013 season has demonstrated that the system will continue to deliver multiple benefits for quality improvements to Paradise Lake. Specifically, it will continue to reduce nutrients in the lake and help to keep algal and submersed aquatic plant communities in balance. Additionally, it appears that the system is not having significant negative impacts on native aquatic plant species in terms of species diversity but some species have increased while others have experienced a modest decrease. Such a community composition shift is normal in aquatic ecosystems so it is difficult to conclude that these impacts are due to the system and not normal ecological change. Continued monitoring of the West Basin in 2014 will help distinguish among system and normal ecological changes.

The Paradise Lake ecosystem continues to have good water quality and a healthy balance of phytoplankton (algae), with the abundance of favorable algae such as diatoms and small unicellular green algae. Although no fishery studies have been completed by RLS, anecdotal reports on large fish being caught by local anglers have been recently received.

Protection of the shoreline emergent vegetation is critical for the reduction of sediment and nutrient loads to the lake, especially through erosion in areas with high slope. In addition, the high biodiversity of emergent vegetation found during 2013 is critical for weevil overwintering habitat. Weevils were stocked in the northeast region of the lake during July of 2013 to reduce the density of the milfoil beds in that area. Analysis of weevil stems from the north, west and south shores of the lake showed that the greatest amount of weevil damage has occurred on milfoil stems in the South Basin (this also occurred in 2012). Statistically, however, the weevil damage in all areas is similar with a mean stem damage index around 2.0 on a scale of 5.0. This damage has been enough to reduce the milfoil bed density so that no canopy is visible near the surface.

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 (expect for one area on the West shore) but the potential for ponding and runoff is very high in the mucky areas (primarily the east and southeast shores). Additionally, regular maintenance of septic systems in these areas is critical.

Future recommendations further monitoring of the aeration and weevil activity with comparisons to pre-implementation data. In addition, a program that encourages annual septic system inspections and maintenance is desired for further water quality protection. The shoreline around Paradise Lake contains a high biodiversity of emergent vegetation which should be protected for water quality protection and the habitat used by weevils for overwintering.

2.0 PARADISE LAKE WATER QUALITY DATA (2013)

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.

2.1 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 1. 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.

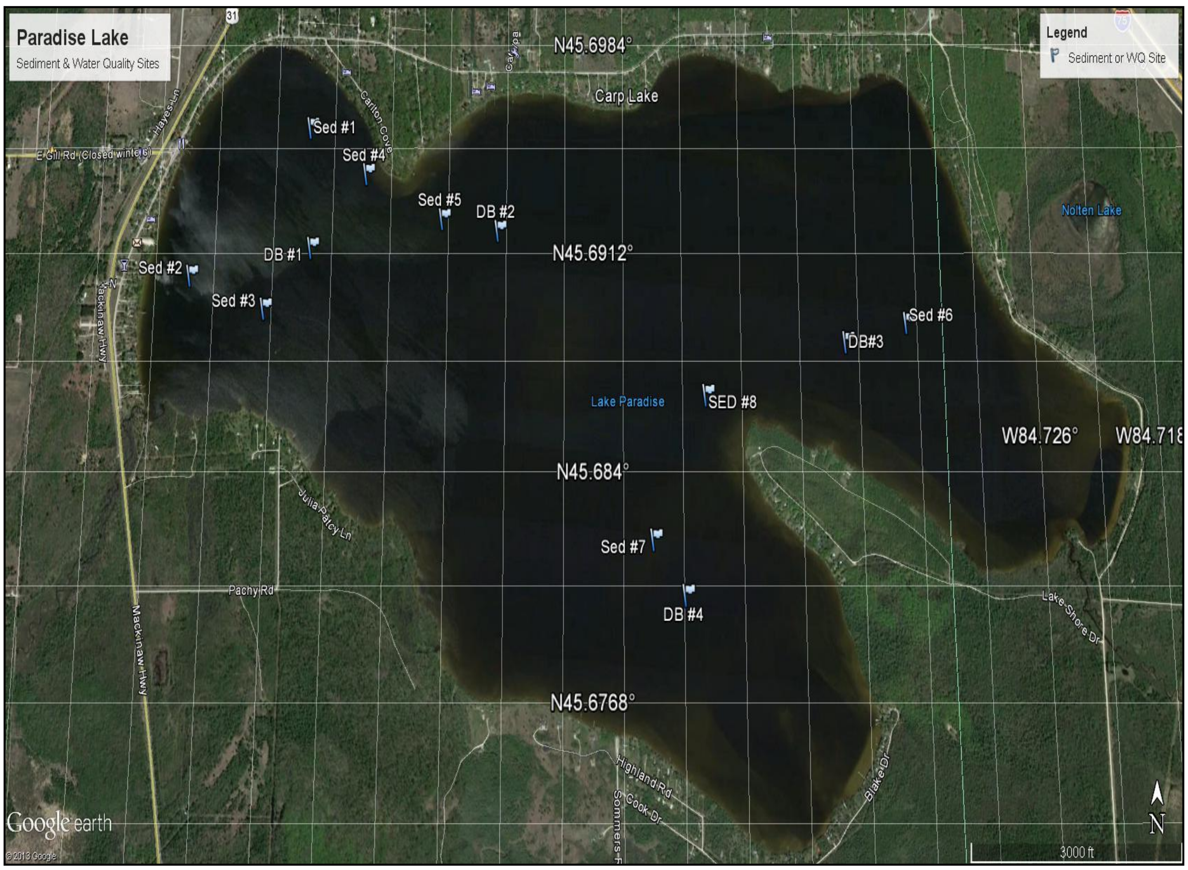

Figure 1. Water quality and sediment sampling locations around Paradise Lake. Note: Sampling sites 1-8 denote sediment sampling locations and DB #1-DB #4 denote deep basin water quality sampling sites.

2.1.1 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 10.1-11.9 mg L^{-1} in October of 2013. The West Basin (DB#1) exhibited higher DO levels than the other basins at the surface and at depth as was observed in 2012. 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 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.

2.1.2 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 45.1-41.9°F from the surface to the bottom. 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.

2.1.3 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 (µS cm^{-1}) with the use of a calibrated conductivity probe (Hanna Model HI 9828).
Conductivity values for Paradise Lake ranged between 207-234 µS cm^{-1}. These values are normal for an inland lake and reflect a moderate concentration of dissolved solids. Additionally, these values are much lower than in 2012, especially in the aerated West Basin.

2.1.4 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 7.8-8.1 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.

2.1.5 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 13.0+ feet (2 feet higher than last year), while the Secchi transparency for Deep Basin 2 was 10+ feet, 3 was 11.0+ feet (to the bottom) and Deep Basin 4 was 7.0+ 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.

2.1.6 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 119.4-188.4 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.

2.1.7 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 mesotrophic range of 0.010-0.020 mg L^{-1}.

2.1.8 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 0.5-0.9 mg L^{-1}, which is lower than in previous years.

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	44.1	11.4	8.1	207	156	119.4	0.7	97	0.010
6.5	42.6	11.9	7.9	210	149	167.9	0.5	97	0.010
13	41.9	12.1	7.9	209	142	156.4	0.5	99	0.010

Table 1. Paradise Lake water quality parameter data collected over Deep Basin 1 on October 28, 2013.

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	45.1	11.0	7.9	231	157	135.7	0.7	99	0.010
5	44.3	10.8	8.1	227	149	167.1	0.8	99	0.010
10	42.9	10.8	8.0	232	151	170.1	0.5	101	0.020

Table 2. Paradise Lake water quality parameter data collected over Deep Basin 2 on October 28, 2013.

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	44.8	10.1	7.8	224	104	156.7	0.7	99	0.010
6	44.1	10.6	7.9	221	109	188.4	0.7	99	0.010
11	43.8	10.9	7.9	220	105	169.1	0.9	98	0.020

Table 3. Paradise Lake water quality parameter data collected over Deep Basin 3 on October 28, 2013.

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	44.1	10.6	8.0	234	110	135.7	0.7	99	0.010
7	44.0	10.9	7.9	231	113	167.6	0.8	98	0.010

Table 4. Paradise Lake water quality parameter data collected over Deep Basin 4 on October 28, 2013.

2.1.9 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 47%, with a high of 60% and a low of 1.6%. 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. In comparison to 2012 values, site #1 declined by 7%, site #4 by 8%, and site #4 by 2%. Site 2 actually increased 3% but this could be due to normal sediment variability.**

Sampling Site	*Sediment* *% Organic Matter*
1	55
2	60
3	39
4	50
5	25
6	3.0
7	49
8	1.6

Table 5. Paradise Lake sediment data collected around the lake on October 28, 2013.

2.2 Phytoplankton Methods, Data, and Discussion

2.2.1 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.

Table 6 below shows the relative number of algae by taxa for a composite water sample collected in each deep basin. In comparison to 2012, the number of diatoms (the most favorable algae type) has increased while the number of green and blue-green algae have decreased in the West Basin. This finding has been observed in many lakes that implement laminar flow aeration systems and the mechanism for this is currently unknown.

Site	Mean # Blue-Green Algae	Mean # Green Algae	Mean # Diatoms
Deep Basin #1	1	32	94
Deep Basin #2	2	44	121
Deep Basin #3	4	51	93
Deep Basin #4	2	49	84

Table 6. October 28, 2013 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.

2.3 Submersed Aquatic Plant Sampling Methods, Data, and Discussion

A total of 220 sampling locations were selected in the West Basin in 2012 and sampled again in 2013 for aquatic vegetation relative abundance (Figure 2). Each waypoint was geo-referenced with a Lowrance HDS 8 GPS unit. A combination of visual, rake tosses, and grab sample methods were used to sample the aquatic vegetation.

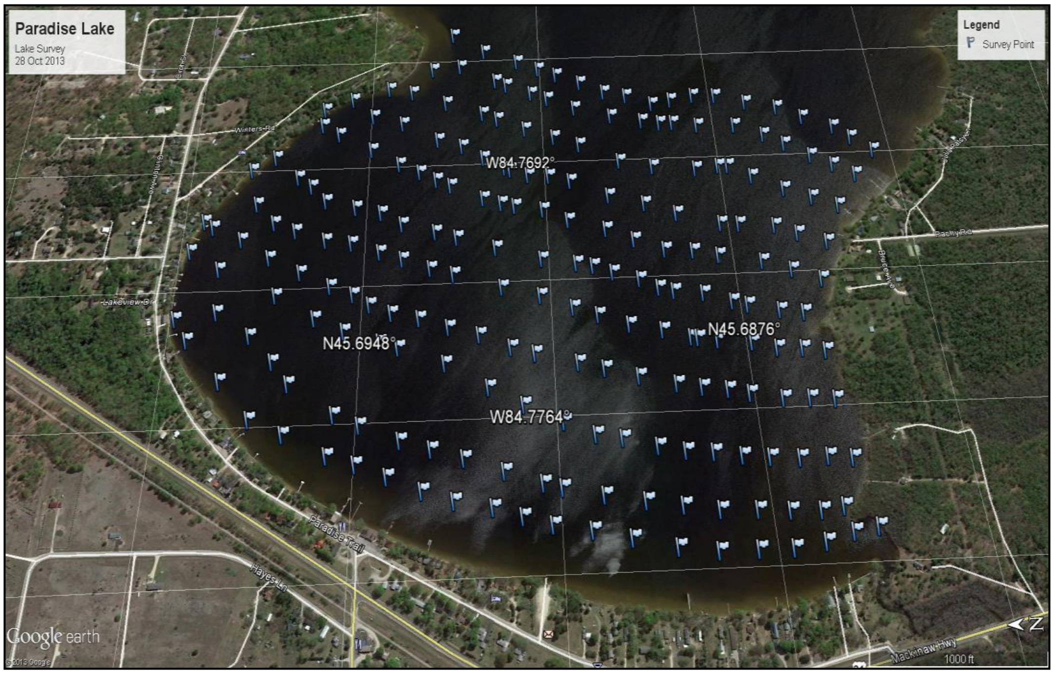

Figure 2. Aquatic vegetation sampling locations (n=220).

2.3.1 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 survey on October 28, 2013 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.

2.3.2 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 and the existing boat-washing station helps to facilitate this.

The only invasive found in Paradise Lake was the exotic, invasive submersed aquatic plant (*Myriophyllum spicatum*), which has been previously treated with weevils and is currently being treated with both aeration and bioaugmentation and sustained weevil populations. 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 chemical-free 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.

2.3.3 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) 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). A map showing the large milfoil bed (76 acres) where weevils were stocked on July 26, 2013 is shown in Figure 3 below.

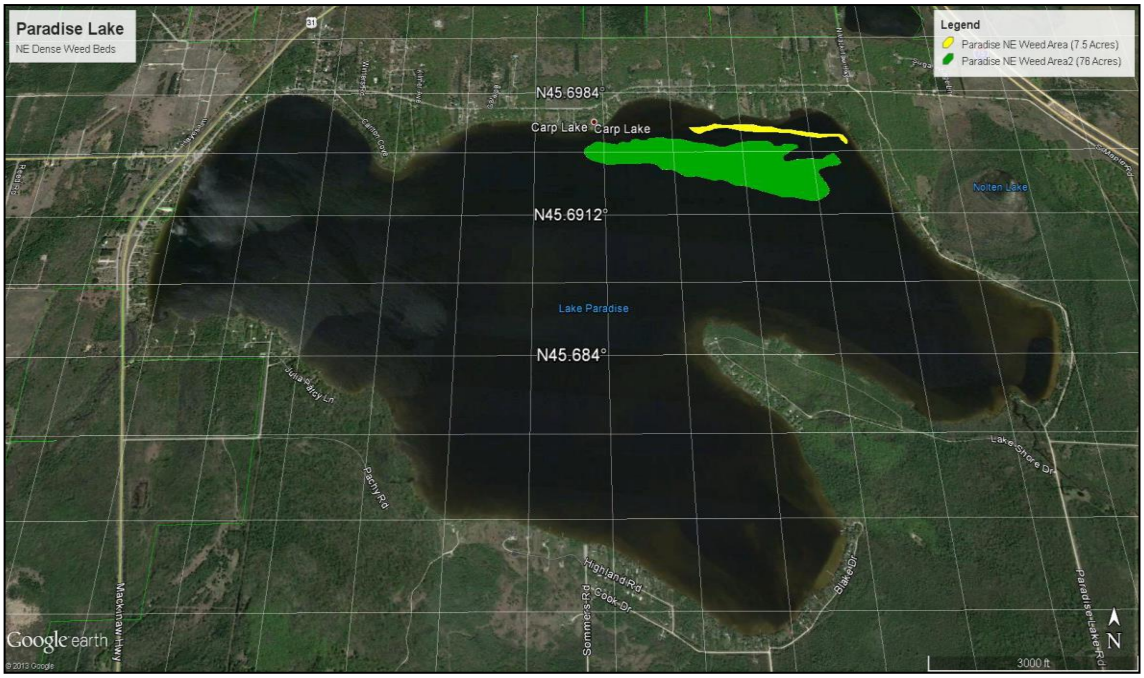

Figure 3. Map showing the large milfoil bed where weevils were stocked in July of 2013.

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.

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 nearly equal damage at the North, South, and West regions of the lake during the 2013 season.

EWM Stem Sampling Location	***October Mean Stem Diameter (mm)***	***October Mean Stem Damage Index (0-5)***
West Basin	1.9±0.2	2.1±1.6
South Basin	2.0±0.3	2.2±1.6
North Basin	2.0±0.3	1.9±1.5

Table 7. Summary data table showing responses of EWM to weevil predation in October of 2013 in the West, South, and North basins of Paradise Lake.

In addition to the weevil damage data on the milfoil plants, the graph below displays the impacts of the laminar flow aeration system on the milfoil relative density for the West Basin in 2013.

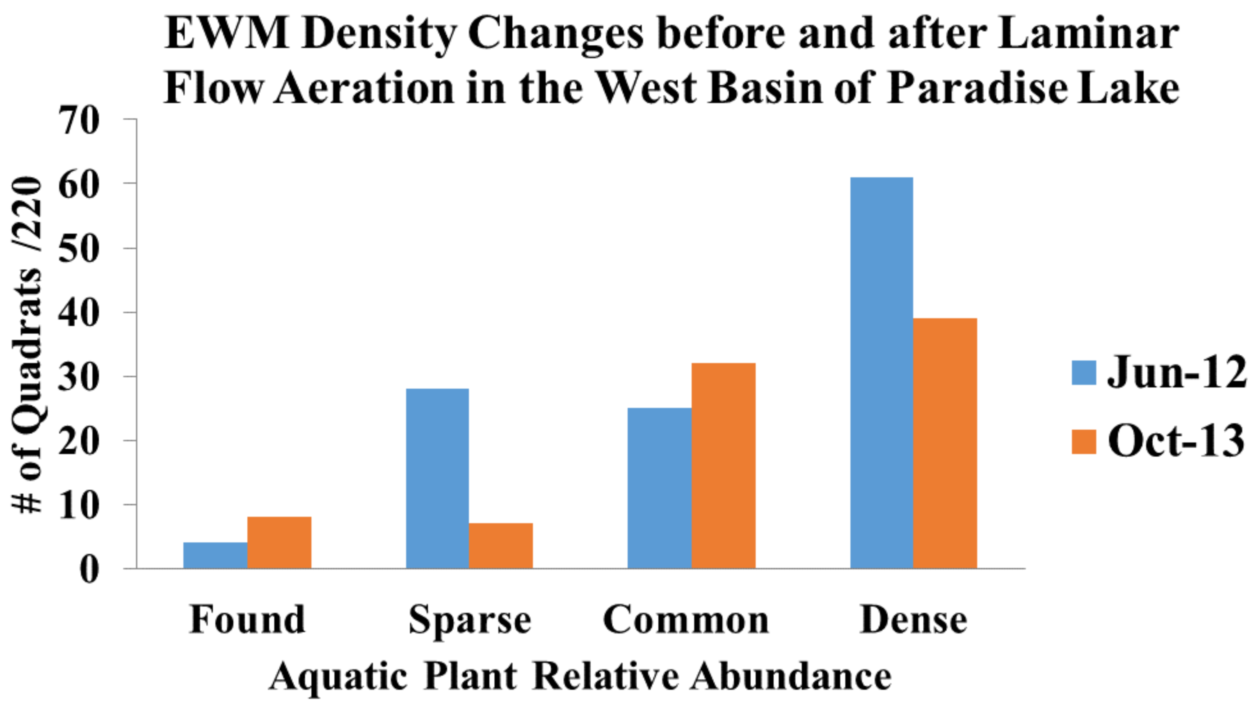

Figure 4. Changes in EWM density at West Basin sampling sites before and after laminar flow aeration.

2.3.4 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 5 shows the relative abundance of all aquatic plant species before and after implementation of the laminar flow aeration system. Additionally, Table 8 shows the changes in native aquatic plants prior to implementation and again in 2013.

The dominant native submersed aquatic plants included Fernleaf Pondweed (*Potamogeton robbinsii*; Figure 6) which occupied over 29% of the West Basin in 2013. The second most abundant submersed plant was Whitestem Pondweed (*Potamogeton praelongus*; Figure 7), which occupied approximately 20% of the West Basin in 2014. The third most abundant aquatic plant was Clasping-leaf Pondweed (*Potamogeton richardsonii;* Figure 8), which has increased dramatically over the past few years and now occupies almost 16% of the West Basin. 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. **Although the relative abundance of some natives has decreased in 2013, the relative abundance of both Bladderwort and Slender Naiad have actually increased.**

Other aquatic plants found in Paradise Lake can be seen in Figures 9-18. 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 June 2012***	***% West Basin Covered October, 2013***
Chara vulgaris, 3	Muskgrass	0.2	2.9
Stuckenia pectinatus, 4	Thin-leaf Pondweed	0.0	0.0
Potamogeton zosteriformis, 5	Flatstem Pondweed	5.1	1.5
Potamogeton robbinsii, 6	Fern-leaf Pondweed	35.2	29.1
Potamogeton gramineus, 7	Variable-leaf Pondweed	4.0	3.5
Potamogeton praelongus, 8	Whitestem Pondweed	21.1	20.1
Potamogeton richardsonii, 9	Clasping-leaf Pondweed	17.3	15.9
Potamogeton illinoensis, 10	Illinois Pondweed	11.5	2.0
Potamogeton amplifolius, 11	Largeleaf Pondweed	16.6	8.7
Vallisneria americana, 15	Wild Celery	8.3	4.7
Myriophyllum verticillatum, 18	Whorled Watermilfoil	4.3	3.6
Elodea canadensis, 21	Common Waterweed	8.4	8.0
Utricularia vulgaris, 22	Bladderwort	2.6	3.7
Najas flexilis, 26	Slender Naiad	4.8	8.6

Table 8. Paradise Lake changes in submersed aquatic plant species and relative abundance prior to and after laminar flow aeration (June, 2012 and October, 2013).

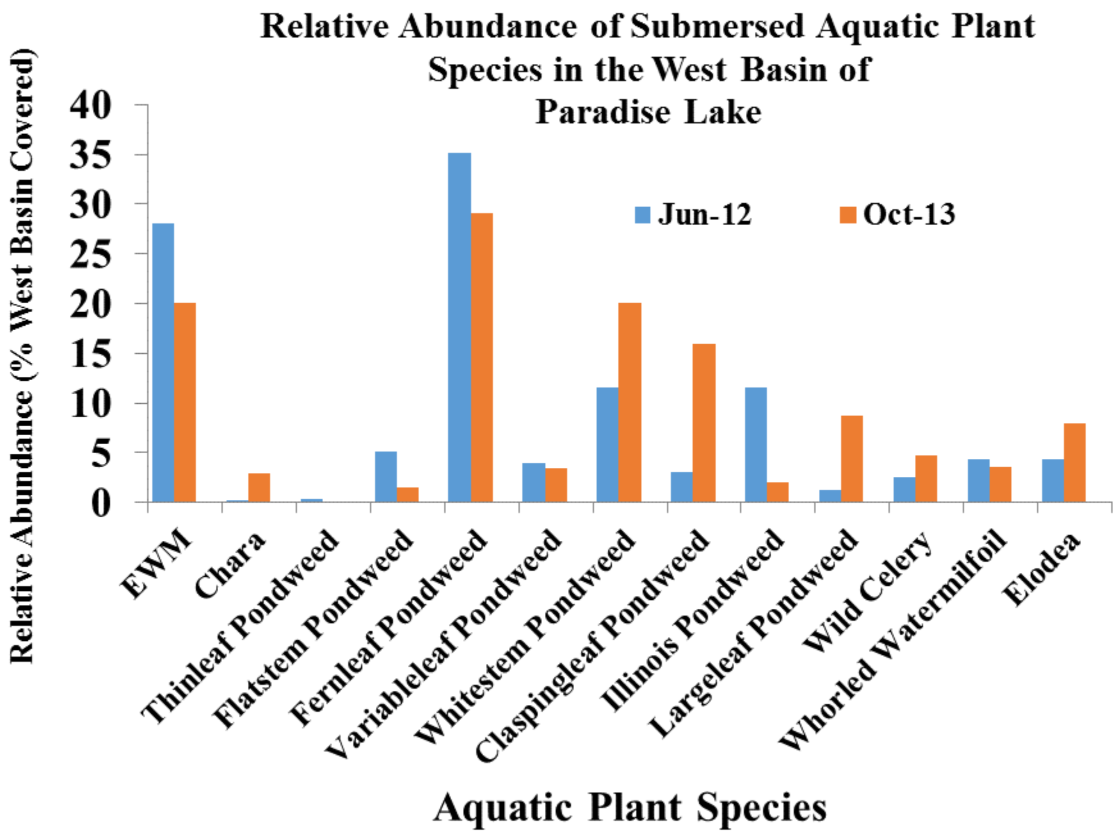

Figure 5. Changes in submersed aquatic plant relative abundance in the West Basin of Paradise Lake before and after laminar flow aeration.

Figure 6. Fern-leaf Pondweed
(*Potamogeton robbinsii*)

Figure 7. Whitestem Pondweed
(*Potamogeton praelongus*)

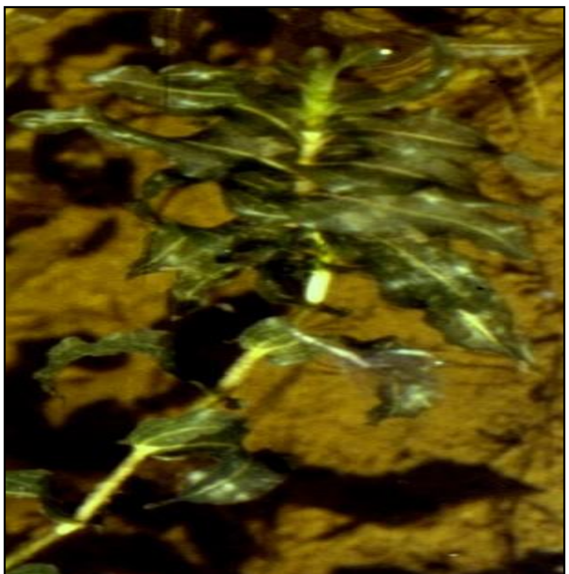

Figure 8. Clasping-leaf Pondweed
(*Potamogeton richardsonii*)

Figure 9. Large-leaf Pondweed
© *Superior Photique, 2008*

Figure 10. Common Waterweed
(*Elodea canadensis*)
© *Superior Photique, 2006*

Figure 11. Wild Celery
(*Vallisneria americana*)
© *Superior Photique, 2006*

Figure 12. Slender Naiad
(*Najas flexilis*)
© *Superior Photique, 2006*

Figure 13. Whorled Watermilfoil
(*Myriophyllum verticillatum*)
© *Superior Photique, 2012*

Figure 14. Variable-leaf Pondweed
(*Potamogeton gramineus*)
© *Superior Photique, 2008*

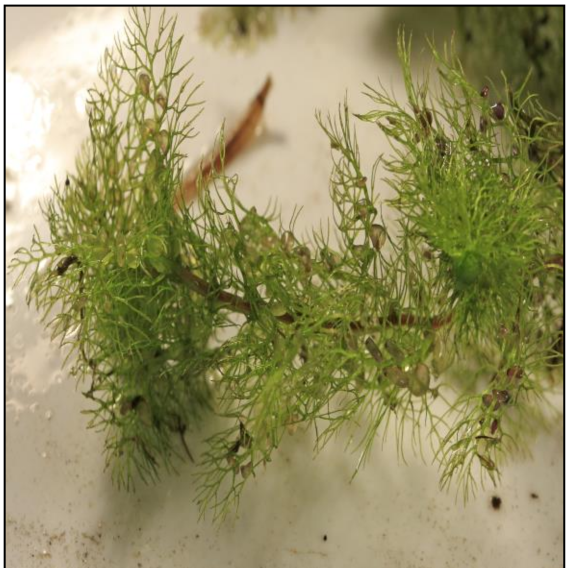

Figure 15. Bladderwort
(*Uricularia vulgaris*)
© *Superior Photique, 2008*

Figure 16. Illinois Pondweed
(*Potamogeton illinoensis*)
© *Superior Photique, 2008*

Figure 17. Muskgrass
(*Chara vulgaris*)

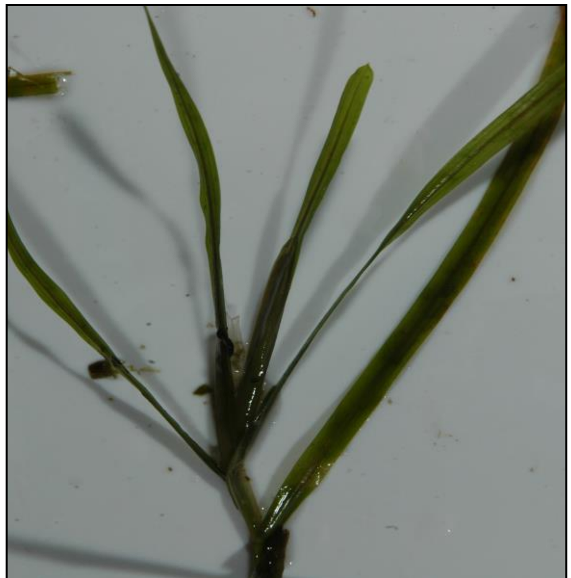

Figure 18. Flatstem Pondweed
(*Potamogeton zosteriformis*)

2.4 Shoreline Plant Sampling Methods, Data, and Discussion

There is great importance of having a vegetative buffer in between the lake and a manicured lawn. The shoreline zone is the last line of defense against forces that may otherwise destroy a healthy lake. A naturally-vegetated shoreline filters runoff generated by surrounding land uses, removing chemicals and nutrients. Shoreline vegetation also protects the lakeshore from the eroding capability of waves and ice. The shoreline zone also provides critical foraging and spawning habitat for aquatic insects, zooplankton, fish, and other animals, as well as unique vegetation that help to maintain a balance in aquatic ecosystems. Unfortunately, as lakeshores are developed, natural shorelines often are damaged or destroyed. Beneficial natural vegetation can be cut, mowed, or replaced with non-native species. In urban and rural environments this can lead to eroded shorelines, degraded water quality and aquatic habitat, impaired aesthetics, and a reduction in property values.

A native vegetative buffer consists of plants that are normally found along the lakeshore. These natural buffers require little maintenance, and use of fertilizers and pesticides is discouraged. Buffer strip characteristics may vary depending on the lake setting and a buffer may include forest, prairie, or wetland vegetation. Natural buffer widths can vary depending on the morphological characteristics of the lake (slope, soil, etc.) Natural buffer strips have many benefits including runoff filtering, shoreline stabilization, plants that can withstand normal water fluctuations and do not need additional watering, fish and wildlife habitat preservation, noise pollution resistance, and a natural aesthetic value. The purpose of this shoreline study was to quantify to what extent the Paradise Lake shoreline has been developed and what percentage of the shoreline had buffers.

2.4.1 Shoreline Plant Sampling Methods

The complete shoreline survey occurred on June 28, 2013 and consisted of viewing shoreline buffer characteristics from a boat within short distance of the shoreline (within 50 feet). GPS points were taken at the beginning and end of each respective stretch of buffer category (Table 9). A number 1 was given for each section of mowed lawn and shoreline vegetation with no buffer. A number 2 denoted an installed seawall with no vegetative buffer. A number 3 was given to delineate a thin buffer of less than 5 meters wide. A number 4 was given for all rip-rap areas that had no vegetative buffer adjacent to the lake. Finally, a value of 5 was given to those areas of the lake shoreline that had buffers greater than 5 meters wide. Photos of each respective shoreline buffer classification type were also taken. Dominant native and non-native vegetation around the entire shoreline were recorded.

Classification	Description
1	Mowed lawn and shoreline vegetation, no buffer considered
2	Installed seawall, no vegetative buffer
3	Thin buffer less than 5 meters wide
4	Rip-rap, no vegetative buffer
5	Natural buffer greater than 5 meters wide

Table 9. Shoreline Buffer Classification for Paradise Lake.

2.4.2 Shoreline Plant Sampling Data

The majority of the Paradise Lake shoreline has a buffer of some sort (Figures 19 and 20; Table 10). The highest occurrence of GPS points had a buffer of less than 5 m; however, 48 occurrences had a large buffer of greater than 5 m. Only a small percentage of occurrences had a lack of a natural buffer. The high occurrence of some sort of natural buffer indicates that Paradise Lake appears to have considerable protection against erosion, sedimentation, and ample fish and wildlife habitat availability, in the buffer areas. However, those areas that do not contain a buffer may suffer from a lack of the aforementioned natural buffer benefits.

A majority of vegetation species were seen and recorded during the shoreline survey (Table 10). The table also depicts whether the species seen is considered native, exotic, or invasive. The majority of the species seen were native species. This list may also serve to be used as a tool for those interested in creating a buffer of various species. Additional information on creating buffers is located in the recommendations section of this report.

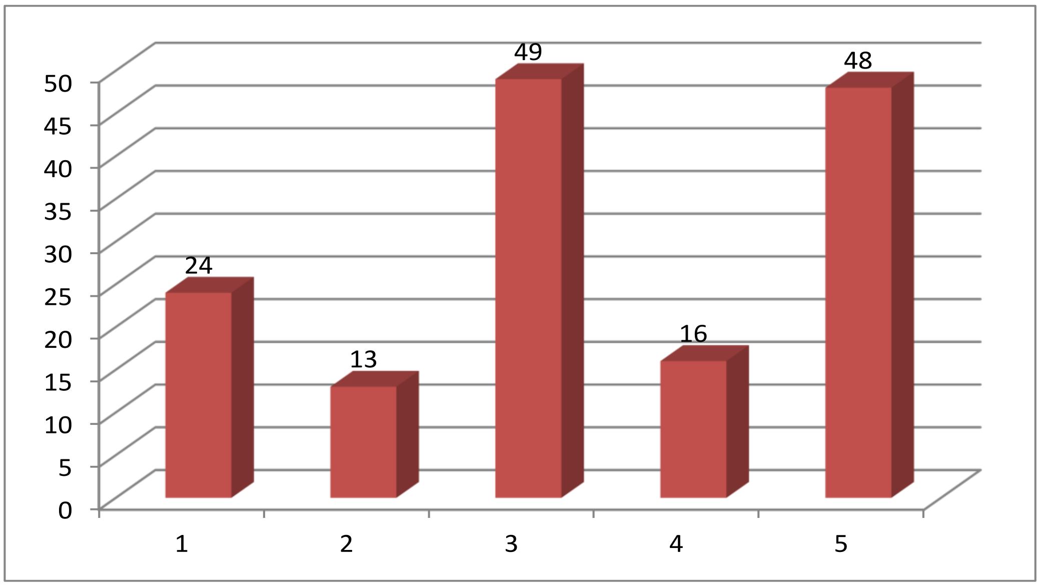

Figure 19. Number of occurrences of each shoreline development type.
1 is mowed lawn and shoreline vegetation, 2 is seawall present, 3 is thin buffer less than 5 m in width, 4 is rip-rap presence, and 5 is natural buffer greater than 5 m in width.

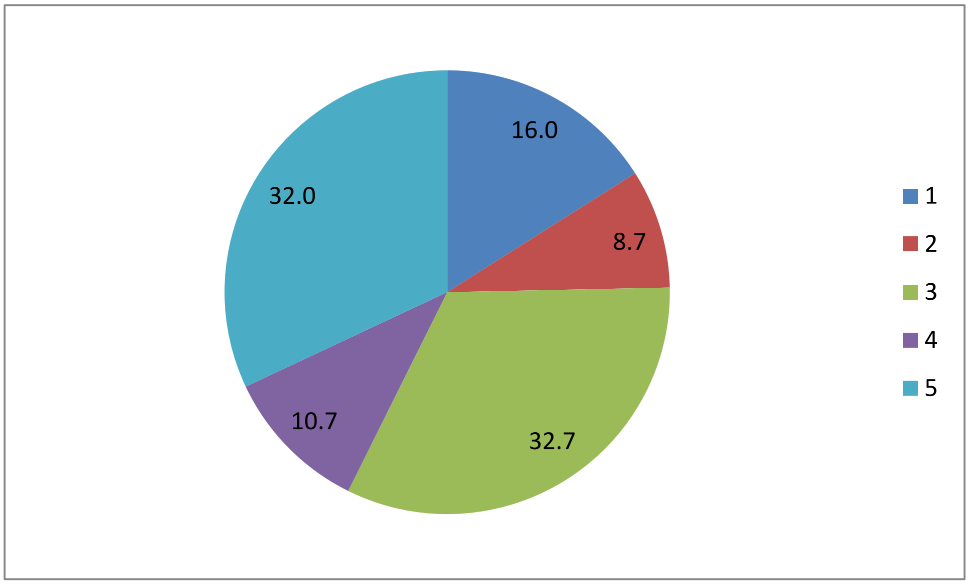

Figure 20. Percentage of shoreline development with respect to buffer type. In the legend, a value of 1 indicates mowed lawn and shoreline vegetation, 2 is seawall present, 3 is thin buffer less than 5 m in width, 4 is rip-rap presence, and 5 is natural buffer greater than 5 m in width.

Scientific Name	Common Name	Native, Exotic, Invasive
Phalaris arundinacea	Reed canary grass	Exotic
Anenome canadensis	Canada anenome	Native
Salix nigra	Black willow	Native
Acer saccharum	Sugar maple	Native
Quercus alba	White oak	Native
Quercus rubra	Red oak	Native
Betula papyrifera	Paper birch	Native
Nymphaea odorata	Fragrant water lily	Native
Acer saccharinum	Silver maple	Native
Acer rubrum	Red maple	Native
Typha angustifolia	Narrow-leaved cattail	Native, Invasive
Typha latifolia	Broad-leaved cattail	Native
Iris versicolor	Blue flag iris	Native
Myrica gale	Sweet gale	Native
Alnus rugosa	Speckled alder	Native
Schoenoplectus tabernaemontani	Softstem bulrush	Native
Nuphar variegata	Yellow pond lily	Native
Scirpus pungens	Three-square bulrush	Native
Carex aquatilus	Water sedge	Native
Fraxinus pennsylvanica	Green ash	Native
Ulmus americana	American elm	Native
Tilia americana	American basswood	Native
Picea glauca	White spruce	Native
Abies balsamea	Balsam fir	Native
Thuja occidentalis	Northern white cedar	Native
Pinus strobus	White pine	Native
Populus tremuloides	Trembling aspen	Native
Populus balsamifera	Balsam poplar	Native
Onoclea sensibilis	Sensitive fern	Native
Osmunda cinammomea	Cinnamon fern	Native
Carex lacustris	Lake sedge	Native
Carex stricta	Tussock sedge	Native
Potamogeton natans	Floating pondweed	Native, invasive
Silene vulgaris	Bladder campion	Exotic
Senecio paupercaulus	Balsam ragwort	Native
Potentilla anserina	Silverweed	Native

Pteridium aquilinum	Bracken fern	Native
Leucanthemum vulgare	Oxeye daisy	Exotic
Carex pensylvanica	Pennsylvania sedge	Native
Spiraea alba	Meadowsweet	Native
Iris pseudoacris	Yellow flag iris	Exotic
Populus deltoides	Eastern cottonwood	Native
Solidago rugosa	Rough-leaved goldenrod	Native
Solidago canadensis	Canada goldenrod	Native, Invasive

Table 10. Shoreline vegetation species observed during the shoreline development survey. Native is native to the area, exotic is non-native to the area, and invasive can be native or exotic, but can outcompete other species to create infestation areas.

2.4.3 Shoreline Plant Protection Recommendations

The importance of using natural vegetative buffers has been well documented and can benefits including runoff filtering, shoreline stabilization, plants that can withstand normal water fluctuations and do not need additional watering, fish and wildlife habitat preservation, noise pollution resistance, and a natural aesthetic value. The width of buffers can vary depending on local shoreline topography, but any width of natural vegetation will provide some benefit. It has also been suggested that a 25 foot minimum width is most often recommended. Wider buffers should be established for larger or more sensitive lakes. **The U.S. Department of Agriculture actually recommends strips of 66 to 99 feet for complete water quality protection along the shoreline.**

While a continuous buffer is preferable for protection of water quality and habitat, some flexibility may be needed to provide beach, pier, and other lake access. Access typically is provided via a mown footpath or a stepping stone trail. The use of a paved buffer access is discouraged as this allows directly flow of nutrients, chemicals, and sediment into the lake, as well as enhancing erosion, sediment build-up and destroying fish and wildlife habitat.

If the need for creating a natural buffer arises, it is recommended that buffers be planted with native species that are indigenous to Paradise Lake. Buffer vegetation also should reflect local needs. For example, a forested buffer is appropriate if noise screening is desired, but it may not be appropriate if local residents desire an unobstructed lake view. Similarly, some property owners may prefer a greater mix of showy wildflowers which may be less functional than other prairie plants but will enhance the aesthetic beauty of the shoreline. Table 10 contains a list of all species recorded while performing the shoreline survey, including a note of whether the species is native or exotic. This list can be used for those interested in creating a natural buffer.

Buffer installation begins with the removal of existing, undesirable vegetation or other unwanted material. Native vegetation can be planted as live plants or seeds. Planting should begin at or below the normal water elevation with wetland species and should proceed up the shoreline slope with water-tolerant and upland species. Normal plantings occur in spring or fall and not during summer when temperatures can reach high temperatures and water and rainfall levels are normally the lowest.

Natural buffer maintenance often requires involve occasional mowing or other means to control weeds and maintain native plant diversity. If certain noxious weeds need additional control, limited use of approved herbicides may be appropriate. Use of fertilizer is not necessary and should be avoided in the buffer strip. The buffer normally takes 1-3 years depending on the species desired.

2.5 Susceptible Soils Data and Discussion

The area delineated in Figure 21 below around the shoreline of Paradise Lake includes 49 different soil types. The north shore is dominated by East lake loamy sands with a slope between 0-6%. The south shore is dominated by Bevort mucky loamy sands and Charlevoix sandy loams with 0-4% slopes. The west shore contains East lake loamy sands with a slope between 6-12% and also with 0-6% slopes. The east shore contains the most diverse soil types with Nadeau extremely gravelly loamy sand with 1-9% slopes, Au Gres-Roscommon complex, 1-4% slopes, Roscommon muck, Tawas Peat, Brevort mucky loamy sand, Ensley sandy loam, and Charlevoix sandy loams with 0-4% slopes. Of these soil types, the loamy sands are most susceptible to septage seepage, while the mucky soils (at the east end of the lake) are the most prone to ponding and runoff. While the constituency of the soils cannot be altered, the land use on the soils can be changed to reduce impacts of the soils on lake water quality. Details are given below relative to septic systems and drain fields relative to the probable nutrient contributions to lake water given soils that are prone to ponding.

2.5.1 Shoreline Soils Locations and Impairments

The areas denoted with yellow circles contain mucky soils that are prone to saturation and ponding and thus are associated with increased runoff during heavy rains. These areas are also the most susceptible for contributing septage that may be backing up onto lawns from full septic systems. The area denoted by a yellow triangle at the west end of the lake indicates an area of high slope where erosion of loamy sand may contribute to sediment loading to the lake.

Figure 21. Map showing the mucky soils (denoted by yellow circles) and high erosion sands (denoted by a yellow triangle) around the shoreline of Paradise Lake. (Data and map collected by the USDA-NRCS).

2.5.2 Shoreline Soils Prioritization Areas

Although the majority of the lake is surrounded by loamy sands, the areas above denoted by yellow circles are mucky soils that are prone to ponding. It is critical that the drain fields in these areas be maintained with low soil compaction to avoid the probability of septage running off from the land during a heavy rainfall event. In addition, the areas around the remainder of the lake that contain loamy sands are susceptible to rapid permeability of septage through sands and eventually to the water table. It is a challenge to determine if septic systems are failing from a shoreline survey. Inspections of each drain field system must be conducted to determine the operational efficiency of the septic system and to determine if leaching of septage has occurred. In addition, placement of seepage meters underwater near shoreline areas would be needed to determine if septage is entering lake water via the water table and contributing to water quality degradation (such as increased bacteria levels or submersed aquatic plant growth).

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