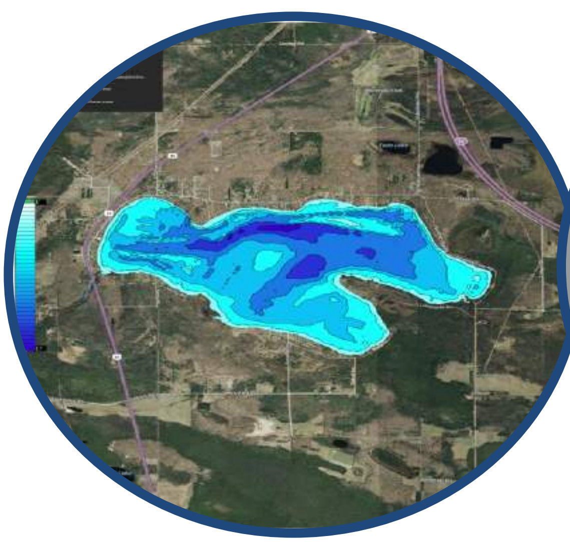
Paradise Lake "State of the Lake" (2016) Report: Evaluation of Laminar Flow Aeration, Bioaugmentation, and Biological Control for Improvements to Paradise Lake, Emmet and Cheboygan Counties, Michigan



Paradise Lake "State of the Lake" (2016) Report: Evaluation of Laminar Flow Aeration, Bioaugmentation, and Biological Control for Improvements to Paradise Lake, Emmet and Cheboygan Counties, Michigan

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Paradise Lake "State of the Lake" (2016) Report: Evaluation of Laminar Flow Aeration, Bioaugmentation, and Biological Control for Improvements to Paradise Lake, Emmet and Cheboygan Counties, Michigan

The overall condition of Paradise Lake is ranked in the top 20% of developed lakes of similar size in the state of Michigan (Restorative Lake Sciences). Paradise Lake is approximately 1,878 acres and has a maximum and average depth of 17 feet and 3.9 feet, respectively. The shoreline length is approximately 14.3 miles and the volume of the lake is approximately 10,358,982 m^3. The watershed is approximately 16,685 acres, which is nearly 8.9 times the lake surface area.

Invasive species such as Eurasian Watermilfoil (EWM) can grow in moderate nutrient waters and thus are a challenge to the Paradise Lake ecosystem. The West Basin of Paradise Lake contained less EWM than in previous years and a basin-wide aeration system has been in operation for three years with good success and reduction of EWM and associated sediment muck. Protection of the 26 native aquatic plant species is paramount for the health of the lake fishery. There is significantly more beneficial native aquatic plant diversity now than in 2009 when milfoil covered numerous areas of the lake bottom. Weevil activity is still present on EWM stems throughout the lake but is strongest in the South region of the lake.

Nutrient loading from external sources into the lake water column is a growing concern for many lakes in Michigan. One area where significant nutrient loads end up in lakes is from water runoff following rain depending on the amount and intensity of rainfall, slope of downhill terrain, soil composition and its ability to absorb rain water, etc. These additional nutrients interfere with all invasive aquatic plant management programs, including herbicide treated lakes, which may require additional herbicide treatments. Many of these nutrients stay in suspension, get distributed to large areas of the lake and are quickly absorbed by aquatic vegetation, resulting in aquatic plant re-germination and/or regrowth. The aeration system is working hard to compensate for these inputs, but cannot process all of the external nutrient load, so we are directing additional future efforts to try to reduce external loading from the land which should ultimately improve the water quality in the future.

This report contains important 2016 data. Most notably was the reduction of soft mucky bottom on Paradise Lake as determined through whole-lake benthic scans using a scientific GPS system with specialized software. These maps show how the aeration system has sigfnicantly and naturally "biodegraded" and reduced the nutrient-rich organic lake-bottom muck in even a single year of operation. Continued use of the aeration system with added natural microbes and enzymes is critical for the future health of Paradise Lake. Additionally, RLS has recommended that a smaller-scale aeration system be installed at the northeast region of the lake to naturally reduce nuisance aquatic vegetation growth in that area.

Section 2

2.0 Paradise Lake Water Quality Data (2016)

2.1 Water Quality Parameters Measured

There are hundreds of water quality parameters one can measure on an inland lake but several are the most critical indicators of lake health. These parameters include dissolved oxygen (measured in mg/L), water temperature (measured in °F), conductivity (measured in micro-Siemens per centimeter-µS/cm) pH (measured in standard units-SU), secchi transparency (in feet), ORP (in mV), total phosphorus and total nitrogen (both in mg/L), total dissolved solids (mg/L), total alkalinity (in mg/L $CaCO_3$), sediment organic matter (%), chlorophyll-*a* (in µg/L), and algal community composition. Water quality is measured in the 4 deep basins of Paradise Lake in October of each year. Table 1 below demonstrates how lakes are classified based on key parameters. **Paradise Lake would be considered mesotrophic (relatively productive) since it does contain ample nitrogen and aquatic vegetation growth but has good water clarity and moderate algal growth as well as low phosphorus concentrations. 2016 water quality data for Paradise Lake are shown below in Tables 2-6. Table 7 shows the relative algal community composition. Sampling sites are shown in Figure 1.**

Did You Know? Paradise Lake has a maximum depth of 17 feet

Table 1. Lake trophic classification (MDNR).

Lake Trophic Status	*Total Phosphorus (µg L⁻¹)*	*Chlorophyll-a (µg L⁻¹)*	*Secchi Transparency (feet)*
Oligotrophic	**< 10.0**	**< 2.2**	**> 15.0**
Mesotrophic	**10.0 – 20.0**	**2.2 – 6.0**	**7.5 – 15.0**
Eutrophic	**> 20.0**	**> 6.0**	**< 7.5**

Figure 1. Paradise Lake water and sediment sampling sites (2016)

Table 2. Paradise Lake water quality parameter data collected over Deep Basin 1 on July 20, 2016.

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	76.8	9.3	8.4	202	90	106.7	0.6	93	0.012
6	76.2	9.0	8.3	201	92	106.4	0.7	93	0.012
12	75.9	9.0	8.3	202	91	101.4	0.6	94	0.016

Table 3. Paradise Lake water quality parameter data collected over Deep Basin 2 on July 20, 2016.

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	76.5	9.7	8.4	201	97	133.5	0.5	94	0.010
5	76.1	9.4	8.4	202	97	114.7	0.5	94	<0.010
10	74.8	9.5	8.3	198	95	99.7	0.8	96	0.010

Table 4. Paradise Lake water quality parameter data collected over Deep Basin 3 on July 20, 2016.

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	76.3	9.5	8.4	198	92	124.5	1.8	96	0.017
6	76.0	9.4	8.4	197	95	102.5	1.2	94	0.014
11	75.2	9.6	8.3	197	95	106.8	1.5	94	0.021

Table 5. Paradise Lake water quality parameter data collected over Deep Basin 4 on July 20, 2016.

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	76.5	9.4	8.4	201	93	136.5	2.2	96	0.019
7	76.2	9.5	8.3	201	91	119.5	3.6	94	0.034

Table 6. Paradise Lake sediment OM data collected around the lake in 2016.

Sampling Site	*Sediment % Organic Matter*
1	36
2	41
3	32
4	40
5	14
6	2
7	21
8	4

Table 7. 2016 phytoplankton data (Paradise Lake, Emmet and Cheboygan counties, MI).

Site	Mean # Blue-Green Algae	Mean # Green Algae	Mean # Diatoms
Deep Basin #1	0	26	88
Deep Basin #2	0	44	106
Deep Basin #3	2	50	122
Deep Basin #4	0	38	106

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 during sampling ranged from 9.0-9.7 mg L^{-1} during the 2016 sampling, which is excellent given the high water temperatures.** 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.

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 during the 2016 sampling ranged between 76.8-75.2°F from the surface to the bottom which indicated high water temperatures throughout the lake.** 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 in a lake increases, and also increases as water temperature increases. **The conductivity values for Paradise Lake during the 2016 sampling were moderate and ranged from 197-202 µS/cm which is sigfnicantly lower than in 2015.** Severe water quality impairments do not occur until values exceed 800 µS/cm and are toxic to aquatic life around 1,000 µS/cm.

2.1.4 pH

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). Paradise Lake is considered "slightly basic" on the pH scale. **The pH of Paradise Lake during the 2016 sampling ranged from 8.3-8.4 S.U. which is ideal for an inland lake and also similar to previous years.**

2.1.5 Water Clarity (Transparency) Data

Elevated Secchi transparency readings allow for more aquatic plant and algae growth. The transparency throughout Paradise Lake is adequate (8-16 feet) to allow abundant growth of algae and aquatic plants in the majority of the littoral zone of the lake. 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 all Deep Basins went beyond the maximum depth at each basin and corresponded with the moderate chlorophyll-a concentrations and low total dissolved solids.**

2.1.6 ORP (Oxidative 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 during the 2016 sampling ranged from 99.7-133.5 mV and were in the oxidative state.** 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 Total Phosphorus and Total Nitrogen

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. 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. **The mean TP concentration measured in all basins was around 0.016 mg L^{-1}, which is higher than in 2015 but still considered low for an inland lake.** Total Kjeldahl Nitrogen (TKN) is the sum of 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 mean TKN concentration among all deep basins during the 2016 sampling was 1.3 mg L^{-1} which is higher than in 2015.**

2.1.8 Total Dissolved Solids

Total dissolved solids (TDS) are the measure of the amount of dissolved organic and inorganic particles in the water column. Particles dissolved in the water column absorb heat from the sun and raise the water temperature and increase conductivity. Total dissolved solids are often measured with the use of a calibrated meter in mg L^{-1}. Spring values are usually higher due to increased watershed inputs from spring runoff and/or increased planktonic algal communities. **The TDS during the 2016 sampling ranged from 90-97 mg L^{-1} for the deep basins which is lower than in 2015.**

2.1.9 Total Alkalinity

Total alkalinity is a measure of the hardness or softness of water. Lakes that have hard water have elevated alkalinity levels whereas lakes that have soft water have lower alkalinity levels. The term also refers to how buffered the water is from acidic inputs. **The total alkalinity of Paradise Lake has ranged from 93-96 mg/L $CaCO_3$ (calcium carbonate) during the 2016 sampling. Paradise is a moderately soft water system which is common for inland lakes in northern Michigan.**

2.1.10 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. Eight sediment samples were collected by hand with a hand-held (Ekman) dredge from eight areas throughout the lake. 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 in 2016 was 24% which is slightly lower than in previous years.**

2.1.11 Chlorophyll-*a* and Algal Community Composition

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).

Chlorophyll-*a* is a measure of the amount of green plant pigment present in the water, often in the form of planktonic algae. High chlorophyll-*a* concentrations are indicative of nutrient-enriched lakes. Chlorophyll-*a* concentrations greater than 6 µg L^{-1} are found in eutrophic or nutrient-enriched aquatic systems, whereas chlorophyll-*a* concentrations less than 2.2 µg/L are found in nutrient-poor or oligotrophic lakes. **The mean chlorophyll-*a* concentrations for all basins in 2016 were around 2.5 µg/L which are moderate for an inland Michigan lake and slightly lower than in 2015. This is surprising given the very warm water temperatures observed in 2016.**

The algal genera were determined from composite water samples collected over the deep basins of Paradise Lake in 2016 were analyzed with a compound bright field microscope. The genera present included the Chlorophyta (green algae): *Haematococcus* sp., *Chlorella* sp., *Scenedesmus* sp., *Ulothrix* sp., *Mougeotia* sp., and *Pediastrum* sp.; the Cyanophyta (blue-green algae): *Gleocapsa* sp.; the Bascillariophyta (diatoms): *Stephanodiscus* sp., *Navicula* sp., *Synedra* sp., *Tabellaria* sp., and *Cymbella* sp. The aforementioned species indicate a favorable algal flora and represent a good diversity of alga with an abundance of diatoms that are indicative of great water quality. Since the aeration program began, blue-green algae and green algae have declined and diatoms have increased.

2.2 Paradise Lake Aquatic Vegetation Data (2016)

The aquatic vegetation communities in Paradise Lake are diverse and have increased in biodiversity since control of the EWM began in the West Basin. Native aquatic plants such as pondweeds and native milfoils have increased and are a benefit to the lake fishery.

2.2.1 Paradise Lake Aquatic Vegetation Sampling Methods

A total of 220 sampling locations were selected in the West Basin in 2012-2016 and sampled again on July 20 of 2016 for aquatic vegetation relative abundance. 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. An additional 600 sampling points were collected throughout the entire lake basin to determine the relative abundance of native aquatic plants. 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.

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.

2.2.2 Paradise Lake Native Aquatic Vegetation (2016)

The native aquatic vegetation present in Paradise Lake is essential for the overall health of the lake and the support of the lake fishery. **Surveys in 2016 determined that there were a total of 26 native aquatic plant species in Paradise Lake. These include 18 submersed species, 4 floating-leaved species, and 4 emergent species. This indicates a high biodiversity of aquatic vegetation in Paradise Lake.** The overall % cover of the lake by native aquatic plants is low relative to the lake size and thus these plants should be protected unless growing near swim areas at nuisance levels.

Table 8 below compares the relative abundance of all native aquatic plants in 2016 where as Table 9 shows the relative abundance of aquatic vegetation in the West Basin which is currently aerated. There were five more species in 2016 relative to 2008-9. This is due to the elimination of many dense milfoil beds that allowed native aquatic plants to germinate. The most notable comparisons include the substantial reduction of most species due to two consecutive harsh winters throughout the lake and the aeration system in the West Basin. The five new species found in 2015-2016 included Variable-leaf Pondweed, Fern-leaf Pondweed, Floating-leaf Pondweed, Water Stargrass, and Duckweed. **The most common native aquatic plant species found in 2016 include: 1) Fern-leaf Pondweed (Figure 2) which is a low-growing green and brown colored fern-like aquatic plant that serves as excellent fish cover; 2) Common Bladderwort (Figure 3) which is a bright green, rootless aquatic plant with clear bladders that trap zooplankton for food; and 3) White-stem Pondweed (Figure 4) which is a bright green aquatic plant that grows tall into the water column and has s prominent seed head that may surface in shallow waters during late spring.**

Table 8. Paradise Lake native aquatic plant species and relative abundance in 2016.

Native Aquatic Plant Species	*Aquatic Plant Common Name*	*2016 Abundance*
Chara vulgaris	Muskgrass	0.9
Potamogeton illinoensis	Illinois Pondweed	2.5
Stuckenia pectinatus	Sago Pondweed	1.3
Potamogeton amplifolius	Large-leaf Pondweed	6.5
Potamogeton gramineus	Variable-leaf Pondweed	3.2
Potamogeton robbinsii	Fern-leaf Pondweed	9.6
Potamogeton pusillus	Small-leaf Pondweed	2.2
Potamogeton zosteriformis	Flat-stem Pondweed	3.6
Potamogeton natans	Floating-leaf Pondweed	2.2
Potamogeton praelongus	White-stem Pondweed	7.2
Potamogeton richardsoni	Clasping-leaf Pondweed	0.4
Zosterella dubia	Water Stargrass	0.1
Vallisneria americana	Wild Celery	6.6
Myriophyllum verticillatum	Whorled Watermilfoil	3.5
Najas guadalupensis	Southern Naiad	4.2
Elodea canadensis	Common Elodea	5.0
Ceratophyllum demersum	Coontail	0.2
Utricularia vulgaris	Common Bladderwort	9.5
Nymphaea odorata	White Water lily	0.6
Nuphar variegata	Yellow Water lily	0.5
Brasenia schreberi	Water shield	0.5
Lemna minor	Duckweed	0.2
Pontedaria cordata	Pickerelweed	0.4
Typha latifolia	Cattails	0.9
Decodon verticillatus	Swamp Loosestrife	1.4
Polygonum amphibium	Water Smartweed	0.6

Table 9. Paradise Lake West Basin native aquatic plant species and relative abundance in 2016.

Native Aquatic Plant Species	*Aquatic Plant Common Name*	*% West Basin Covered June 2016*
Chara vulgaris	Muskgrass	2.5
Stuckenia pectinatus	Thin-leaf Pondweed	0.9
Potamogeton zosteriformis	Flatstem Pondweed	2.2
Potamogeton robbinsii	Fern-leaf Pondweed	5.3
Potamogeton gramineus	Variable-leaf Pondweed	2.6
Potamogeton praelongus	Whitestem Pondweed	6.5
Potamogeton richardsonii	Clasping-leaf Pondweed	2.1
Potamogeton illinoensis	Illinois Pondweed	2.9
Potamogeton amplifolius	Large-leaf Pondweed	4.3
Vallisneria americana	Wild Celery	3.6
Myriophyllum verticillatum	Whorled Watermilfoil	1.8
Elodea canadensis	Common Waterweed	2.3
Utricularia vulgaris	Bladderwort	4.1
Najas flexilis	Slender Naiad	5.2

Figure 2. Fern-leaf Pondweed

Figure 3. Bladderwort

Figure 4. White-stem Pondweed

2.2.3 Paradise Lake Invasive (Exotic) Aquatic Plants

Figure 5. Eurasian Watermilfoil

The amount of Eurasian Watermilfoil (EWM; Figure 5) present in Paradise Lake varies each year and is dependent upon climatic conditions, especially runoff-associated nutrients. 2016 was one of the hottest years on record and many lakes experienced nuisance milfoil and algal outbreaks even given the two consecutive harsh winters. The July 20, 2016 survey revealed that approximately 15.5% of the littoral zone was covered with milfoil. This is a slight increase in 2016 and may be attributed to unprecedented warm water temperatures that resulted in more re-growth of milfoil. Paradise Lake did not contain any other invasive aquatic plant species in 2016.

2.2.4 Assessment of Weevil Damage on EWM Stems in Paradise Lake

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). Weevils were last stocked in Paradise Lake on July 26, 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 in Table 10 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 2016 season. The damage is holding consistent to previous years and indicates that there is still weevil predation on EWM stems in Paradise Lake.

Figure 6 below shows the aquatic vegetation biovolume which corresponds to milfoil in all of the basins. Table 11 below demonstrates the changes in aquatic vegetation biovolume since 2014. As is evident, there has been an increase in low-growing favorable aquatic plants and a decline in the dense vegetation over time.

Table 10. Summary data table showing responses of EWM to weevil predation in July of 2016 in the West, South, and North basins of Paradise Lake.

EWM Stem Sampling Location	***2016 Mean Stem Diameter (mm)***	***2016 Mean Stem Damage Index (0-5)***
West Basin	2.0±0.1	1.8±0.3
South Basin	2.2±0.5	2.0±0.6
North Basin	2.1±0.2	1.4±1.0

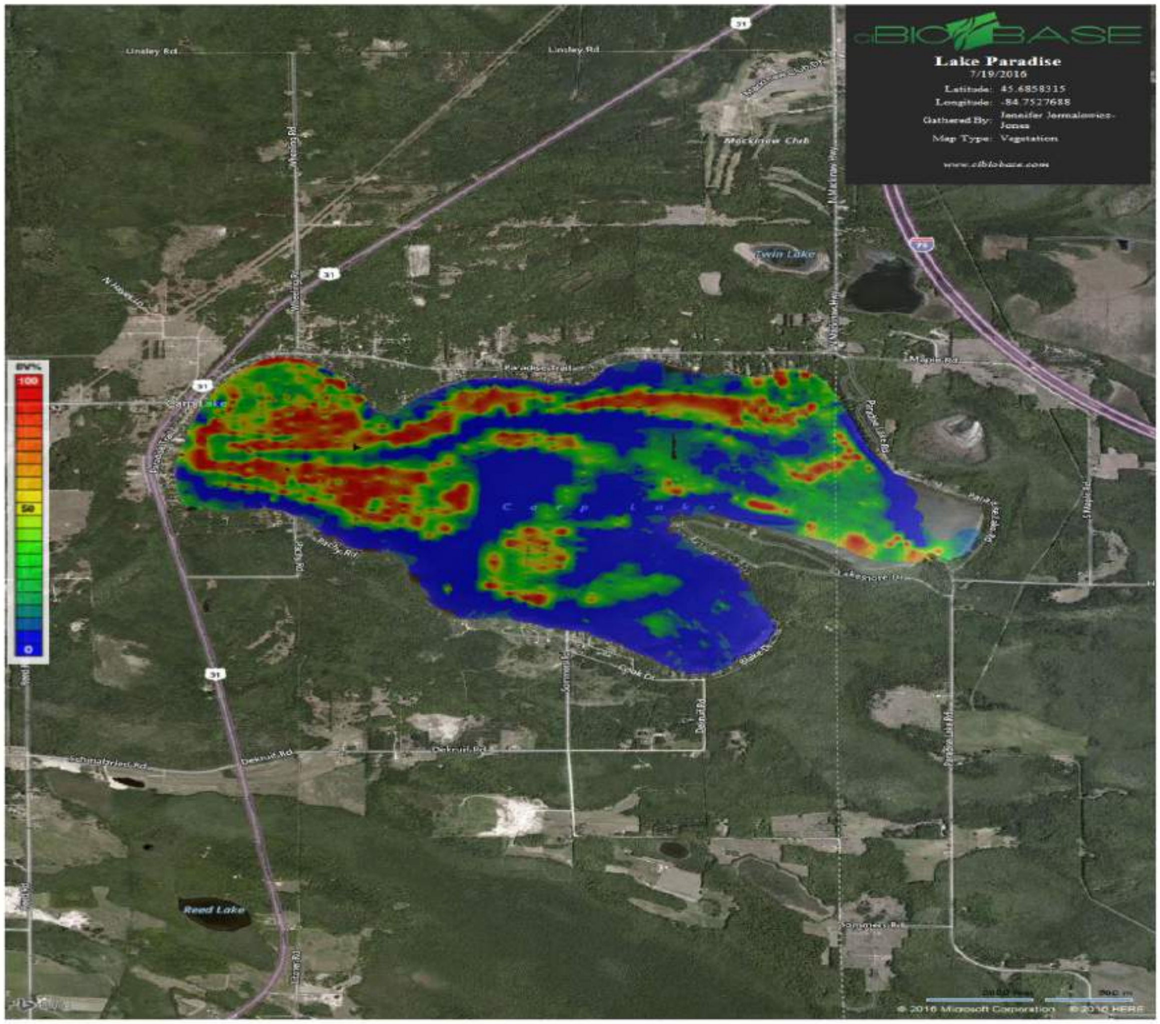

Figure 6. Paradise Lake 2016 aquatic vegetation biovolume map. Note: Red denotes high-growing aquatic vegetation and/or lily pads. Green denotes low-growing aquatic vegetation. Blue denotes a lack of aquatic vegetation.

Table 11. Aquatic Vegetation Biovolume Changes with Time in Paradise Lake.

% Cover Category	2014	2015	2016
0-5%	25.43	30.49	31.04
5-20%	21.19	19.91	17.64
20-40%	19.67	14.36	18.76
40-60%	10.78	7.15	8.30
60-80%	7.48	6.46	6.71
>80%	15.64	21.63	17.56

2.3 Paradise Lake Sediment Muck Reduction Data

Restorative Lake Sciences conducted another whole-lake scan of the sediments in Paradise Lake. Figure 7 below shows the overall sediment bottom hardness categories and Table 12 shows the changes in sediment bottom hardness over the past few years. There has been a significant reduction in soft organic bottom and an increase in firm bottom substrate.

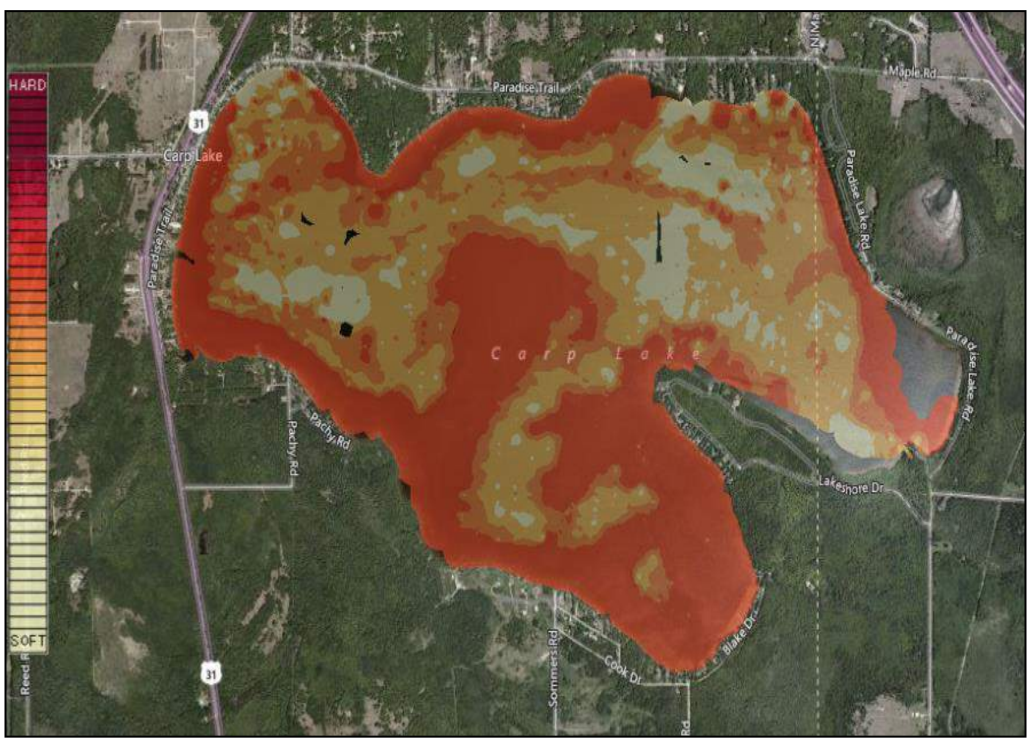

Figure 7. Sediment bottom hardness map of Paradise Lake (2016).

Table 12. Sediment Bottom Hardness Changes with Time in Paradise Lake.

Value	2014 %	2015 %	2016 %
<0.1 (softest)	0.04	0.19	0.12
0.1-0.2	1.17	1.50	39.44
0.2-0.3	52.70	38.34	38.20
0.3-0.4	26.90	41.83	35.85
>0.4 (hardest)	19.16	18.13	24.59

Section

3

3.0 MANAGEMENT RECOMMENDATIONS FOR 2017 AND BEYOND

Continuous aquatic vegetation surveys are needed to determine the precise locations of EWM or other problematic invasives in Paradise Lake. These surveys should occur in late-June to early-October in 2017.

The aeration system has sigfnicantly reduced the overall growth and distribution of EWM present in the West Basin and the weevil activity is still apparent on EWM stems throughout the lake. RLS recommended an additional aeration system at the northeast region of the lake to reduce nuisance aquatic vegetation growth in that area. RLS will be carefully monitoring the efficacy of that system by collecting many additional sampling point data sets in that region.

The nutrient concentrations in the lake are moderate and the majority of the aquatic plants obtain nutrition from the lake sediments. Fortunately, the soft bottom muck is declining and thus the sediments will not supply as much nutrient to vegetation in future years which should further reduce EWM and other nuisance growth. The 2016 weather (unprecedented air and water temperatures) created a perfect medium for enhanced growth of all aquatic plants. Hopefully, 2017 will yield more favorable weather and more stable water levels.

In conclusion, Paradise Lake is a healthy lake with high aquatic plant biodiversity, good water clarity, moderate nutrients, and a healthy lake fishery. Management of the EWM and protection of the water quality are paramount for the long-term health of the lake. Continued operation and monitoring of the West Basin aeration system is recommended along with dosing of microbes and enzymes.

4.0 GLOSSARY OF SCIENTIFIC TERMS

1) Biodiversity- The relative abundance or amount of unique and different biological life forms found in a given aquatic ecosystem. A more diverse ecosystem will have many different life forms such as species.

2) $CaCO_3$- The molecular acronym for calcium carbonate; also referred to as "marl" or mineral sediment content.

3) Eutrophic- Meaning "nutrient-rich" refers to a lake condition that consists of high nutrients in the water column, low water clarity, and an over-abundance of algae and aquatic plants.

4) Mesotrophic- Meaning "moderate nutrients" refers to a lake with a moderate quantity of nutrients that allows the lake to have some eutrophic qualities while still having some nutrient-poor characteristics

5) Oligotrophic- Meaning "low in nutrients or nutrient-poor" refers to a lake with minimal nutrients to allow for only scarce growth of aquatic plant and algae life. Also associated with very clear waters.

6) Sedimentary Deposits- refers to the type of lake bottom sediments that are present. In some lakes, gravel and sand are prevalent. In others, organic muck, peat, and silt are more common.

5.0 SCIENTIFIC LITERATURE CITED

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