Picture 1. Columbia Lake, 5 August 2014

A LIMNOLOGICAL AND FISHERIES SURVEY OF

COLUMBIA LAKE

WITH RECOMMENDATIONS AND A MANAGEMENT PLAN

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Table of Contents

LIST OF PICTURES

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIXES

INTRODUCTION

We were asked to perform a fishery investigation of Columbia Lake located near Brookyln, MI in Jackson County, and to develop short-term and long-term management plans for the lake. Columbia Lake is a eutrophic lake with mostly shallow littoral zone with a 26 - ft deep hole in the north basin of the lake. The lake was formed by damming Goose Creek which enters from the south. It is ringed with many houses located around the lake. There is a considerable amount of sand and gravel in and along the shores along with extensive beds of aquatic plants, including the exotic Eurasian milfoil, which is being actively controlled. Native plants can act as good habitat for insect prey and good spawning sites for minnows. There is one inlet and several small bays and indentations in the lake, which can act as good sites for spawning, migrating species, such as white suckers and northern pike.

The lake is 840-acres. The dissolved oxygen measurements we took showed that at the deep spot, there was an unusual stratification pattern, since there was no thermocline and the water temperature was similar from surface to bottom, unlike most eutrophic lakes, which have a warm surface area, a thermocline area, and a bottom layer called the hypolimnion where there is usually dissolved oxygen depletions. We suspect boat traffic destratifies the lake during summer activities. There are at least 25 fish species in the lake, including some unusual species, such as white bass, walleye, redear sunfish, and smallmouth bass. The lake has zebra mussels, Asiatic clams, Eurasian milfoil, and common carp. It also has *Hexagenia*, the large mayfly.

HISTORY

There is a dam on Columbia Lake, which dammed Goose Creek which enters from the south end. Originally, the lake was a mill pond in 1836, then after damming (28 ft head with 12 ft spillway) it expanded to 840 acres in 1961. There are 16 parks on Columbia Lake. A considerable amount of water thus enters the lake from Goose Creek, depending on season. There is also Eurasian milfoil in the lake which can expand and cover large areas of the substrate if conditions are optimal. Columbia Lake is a eutrophic lake with two major basins and a maximum depth of 26 ft. It has a number of small bays and inlets, and is highly developed around the entire lake. The lake has had sewers for 6-7 years now. The limnological conditions in the lake are not typical, since we think the lake is being destratified with excessive boat traffic or by prevailing winds (Kevern et al. 1994). This had led to similar warm temperatures from the surface to the bottom and a lack of dissolved oxygen (anoxia or a dead zone) near bottom on occasion during summer. Initially northern pike were common in the lake, but recently few have been seen or collected. A number of fish have been stocked into Columbia Lake including walleyes, smallmouth bass, redear sunfish, white bass, rainbow trout and aquatic plants have been controlled chemically for years.

METHODS

Our study involves physical, chemical, and biological measurements and observations by professional aquatic biologists who have conducted lake management studies since 1972; we incorporated in 1974. We use specialized samplers and equipment designed to thoroughly examine all components of an aquatic ecosystem. Shallow water, deep water, sediments, animal and plant life as well as inlet and outlet streams are intensively sampled and analyzed at several key stations (sites on the lake). Some samples are analyzed in the field, while the balance is transported to our laboratory for measurements and/or identification of organisms found in samples.

After the field study, we compile, analyze, summarize, and interpret data. We utilize a comprehensive library of limnological studies, and review all the latest management practices in constructing a management plan. All methods used are standard limnological procedures, and most chemical analyses are according to Standard Methods for the Examination of Water and Wastewater. Water analyses were performed by Grand Valley State University.

STATION LOCATIONS

During any study we choose a number of places (stations) where we do our sampling for each of the desired parameters. We strive to have a station in any unusual or important place, such as inlet and outlet streams, as well as in representative areas in the lake proper. One of these areas is always the deepest part of the lake. Here we check on the degree of thermal and chemical stratification, which is extremely important in characterizing the stage of eutrophication (nutrient enrichment), invertebrates present, and possible threats to fish due to production of toxic substances due to decomposition of bottom sediments. The number and location of these stations for this study are noted in that section.

PHYSICAL PARAMETERS

Depth

Depth is measured in several areas with a sonic depth finder or a marked sounding line. We sometimes run transects across a lake and record the depths if there are no data about the depths of the lakes as we did in this study. These soundings were then superimposed on a map of the lake and a contour map constructed to provide some information on the current depths of the lake.

Acreage

Acreage figures, when desired, are derived from maps, by triangulation, and/or estimation. The percentage of lake surface area in shallow water (less than 10 feet) is an important factor. This zone (known as the littoral zone) is where light can penetrate with enough intensity to support rooted aquatic plants. Natural lakes usually have littoral zones around their perimeters. Man-made lakes and some reservoirs often have extensive areas of littoral zone.

Hydrographic Map

A map of the depth contours of the lake was prepared for Columbia Lake, since there was no prior one and because the depths changed due to dredging. We secured starting and ending GPS values for transects across the lake and then ran the pontoon boat at a consistent speed and measured the depth every 5 sec until the opposite shore was reached. These depth data were recorded and later entered on each of the transect lines drawn across a copy of the lake map showing the lake shoreline outline. The distance of the transect line (in mm) was divided by the number of observations for each transect so that the depths could be assigned accurately to the line at equal intervals. Next we interpolated contour lines based on the depth contour of interest, including lines for 5, 10, 15, 20, and 30 ft. This map will assist us in making assessments of the lake and hopefully fishers who want to fish in specific depths on the lake.

Sediments

Bottom accumulations give good histories of the lake. The depth, degree of compaction, and actual makeup of the sediments reveal much about the past. An Ekman grab or dredge sampler is used to sample bottom sediments for examination. It is lowered to the bottom, tripped with a weight, and it "grabs" a 1 square foot sample of the bottom. Artificial lakes often fill in more rapidly than natural lakes because disruption of natural drainage systems occurs when these lakes are built. Sediments are either organic (remains of plants and animals produced in the lake or washed in) or inorganic (non-living materials from wave erosion or erosion and run-off from the watershed).

Light Penetration

The clarity of the water in a lake determines how far sunlight can penetrate. This in turn has a basic relationship to the production of living phytoplankton (minute plants called algae), which are basic producers in the lake, and the foundation of the food chain. We measure light penetration with a small circular black and white Secchi disc attached to a calibrated line. The depth at which this disc just disappears (amount of water transparency) will vary between lakes and in the same lake during different seasons, depending on degree of water clarity. This reference depth can be checked periodically and can reflect the presence of plankton blooms and turbidity caused by urban run-off, etc. A regular monitoring program can provide an annual documentation of water clarity changes and also a historical record of changes in the algal productivity in the lake that may be related to development, nutrient inputs, or other insults to the lake.

Temperature

This is a physical parameter but will be discussed in the chemistry section with dissolved oxygen. Thermal stratification is a critical process in lakes which helps control the production of algae, generation of various substances from the bottom, and dissolved oxygen depletion rates.

Stream Flows from Inlets and Outlets

Estimation of flows in and out of a lake gives us information about ground water inputs, inputs of nutrients and toxic substances, and amount of water moving through the ecosystem. When tied to the chemical analyses described earlier, nutrient inputs and outputs can be calculated and amount of impact of these inputs evaluated.

CHEMICAL PARAMETERS

Water chemistry parameters are extremely useful measurements and can reveal considerable information about the type of lake and how nutrients are fluxing through the system. They are important in classifying lakes and can give valuable information about the kind of organisms that can be expected to exist under a certain chemical regime. All chemical parameters are a measure of a certain ion or ion complex in water. The most important elements--carbon (C), hydrogen (H), and oxygen (O) are the basic units that comprise all life, so their importance is readily obvious. Other elements like phosphorus (P) and nitrogen (N) are extremely important because they are significant links in proteins and RNA/DNA chains. Since the latter two (P and N) are very important plant nutrients, and since phosphorus has been shown to be critical and often times a limiting nutrient in some systems, great attention is given to these two variables. Other micronutrients such as boron, silicon, sulfur, and vitamins can also be limiting under special circumstances. However, in most cases, phosphorus turns out to be the most important nutrient.

Temperature Stratification

Temperature governs the rate of biological processes. A series of temperature measurements from the surface to the bottom in a lake (temperature profile) is very useful in detecting stratification patterns. Stratification in early summer develops because the warm sun heats the surface layers of a lake. This water becomes less dense due to its heating, and "floats" on the colder, denser waters below. Three layers of water are thus set up. The surface warm waters are called the epilimnion, the middle zone of rapid transition in temperatures is called the thermocline, and the cold bottom waters, usually around 39 F (temperature of maximum density), are termed the hypolimnion. As summer progresses, the lowest cold layer of water (hypolimnion) becomes more and more isolated from the upper layers because it is colder and denser than surface waters (see Fig. 1 for documentation of this process over the seasons).

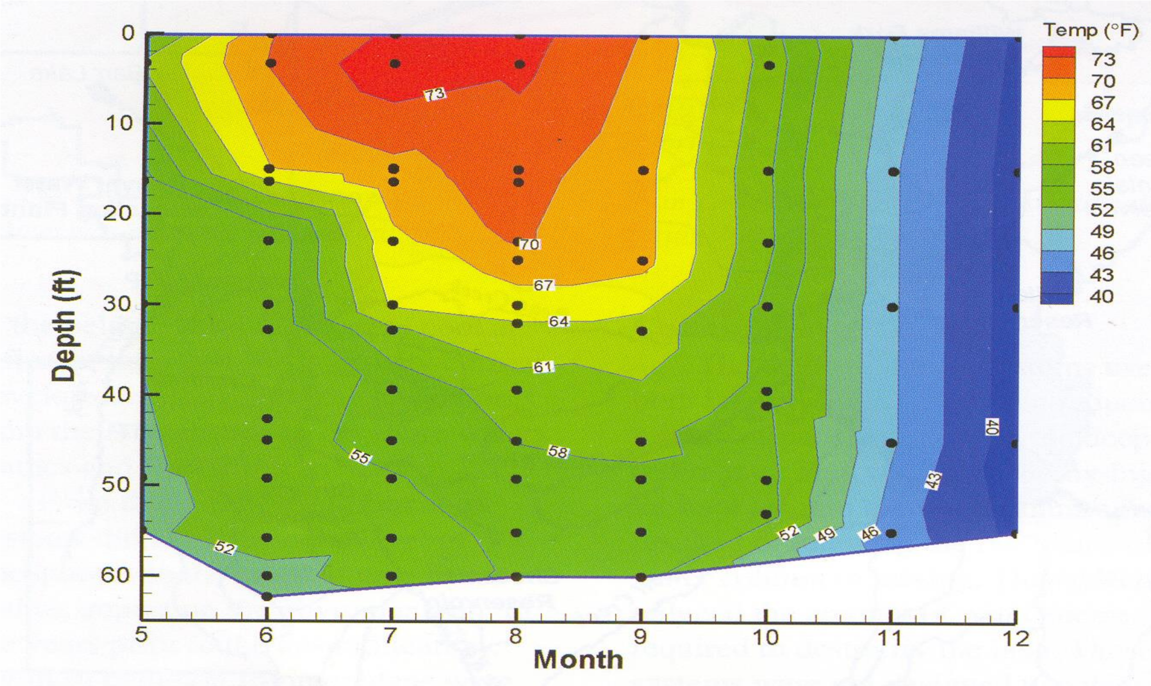

Figure 1. Depiction of the water temperature relationships in a typical 60-ft deep lake over the seasons. Note the blue from top to bottom during the fall turnover (this also occurs in the spring) and the red yellow and green (epilimnion, thermocline, and hypolimnion) that forms (stratification) during summer months. Adapted from NALMS.

When cooler weather returns in the fall, the warm upper waters (epilimnion) cool to about 39 F, and because water at this temperature is densest (heaviest), it begins to sink slowly to the bottom. This causes the lake to "turnover" or mix (blue part on right of Fig. 1), and the temperature becomes a uniform 39 F top to bottom. Other chemical variables, such as dissolved oxygen, ammonia, etc. are also uniformly distributed throughout the lake.

As winter approaches, surface water cools even more. Because water is most dense at 39 F, the deep portions of the lake "fill" with this "heavy water". Water colder than 39 F is actually lighter and floats on the more dense water below, until it freezes at 32 F and seals the lake. During winter decomposition on the bottom can warm bottom temperatures slightly.

In spring when the ice melts and surface water warms from 32 to 39 F, seasonal winds will mix the lake again (spring overturn), thus completing the yearly cycle. This represents a typical cycle, and many variations can exist, depending on the lake shape, size, depth, and location. Summer stratification is usually the most critical period in the cycle, since the hypolimnion may go anoxic (without oxygen--discussed next). We always try to schedule our sampling during this period of the year. Another critical time exists during late winter as oxygen can be depleted from the entire water column in certain lakes under conditions of prolonged snow cover.

Dissolved Oxygen

This dissolved gas is one of the most significant chemical substances in natural waters. It regulates the activity of the living aquatic community and serves as an indicator of lake conditions. Dissolved oxygen is measured using an YSI, dissolved oxygen-temperature meter or the Winkler method with the azide modification. Fixed samples are titrated with PAO (phenol arsene oxide) and results are expressed in mg/L (ppm) of oxygen, which can range normally from 0 to about 14 mg/L. Water samples for this and all other chemical determinations are collected using a device called a Kemmerer water sampler, which can be lowered to any desired depth and like the Ekman grab sampler, tripped using a messenger (weight) on a calibrated line. The messenger causes the cylinder to seal and the desired water sample is then removed after the Kemmerer is brought to the surface. Most oxygen in water is the result of the photosynthetic activities of plants, the algae and aquatic macrophytes. Some enters water through diffusion from air. Animals use this oxygen while giving off carbon dioxide during respiration. The interrelationships between these two communities determine the amount of productivity that occurs and the degree of eutrophication (lake aging) that exists.

A series of dissolved oxygen determinations can tell us a great deal about a lake, especially in summer. In many lakes in this area of Michigan, a summer stratification or stagnation period occurs (See previous thermal stratification discussion). This layering causes isolation of three water masses because of temperature-density relationships already discussed (see Fig. 2 for demonstration of this process).

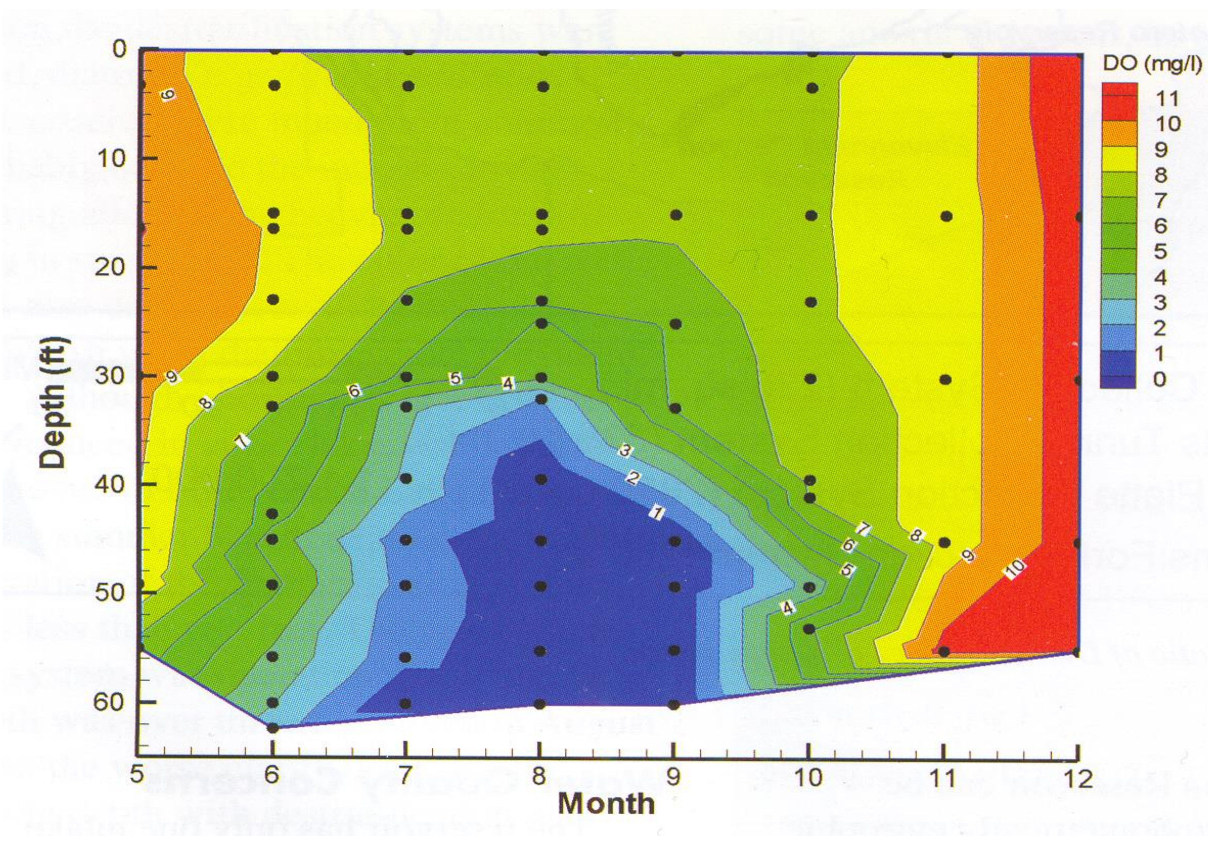

Figure 2. Dissolved oxygen stratification pattern over a season in a typical, eutrophic, 60-ft deep lake. Note the blue area on the bottom of the lake which depicts anoxia (no dissolved oxygen present) during summer and the red section in the fall turnover period (there is another in the spring) when the dissolved oxygen is the same from top to bottom. Adapted from NALMS.

In the spring turnover period dissolved oxygen concentrations are at saturation values from top to bottom (see red area which is the same in the spring – Fig. 2). However, in these lakes by July or August some or all of the dissolved oxygen in the bottom layer is lost (used up by bacteria) to the decomposition process occurring in the bottom sediments (blue area in Fig. 2). The richer the lake, the more sediment produced and the more oxygen consumed. Since there is no way for oxygen to get down to these layers (there is not enough light for algae to photosynthesize), the hypolimnion becomes devoid of oxygen in rich lakes. In non-fertile (Oligotrophic) lakes there is very little decomposition, and therefore little or no dissolved oxygen depletion. Lack of oxygen in the lower waters (hypolimnion) prevents fish from living here and also changes basic chemical reactions in and near the sediment layer (from aerobic to anaerobic).

Stratification does not occur in all lakes. Shallow lakes are often well mixed throughout the year because of wind action. Some lakes or reservoirs have large flow-through so stratification never gets established.

Stratified lakes will mix in the fall because of cooler weather, and the dissolved oxygen content in the entire water column will be replenished. During winter the oxygen may again be depleted near the bottom by decomposition processes. As noted previously, winterkill of fish results when this condition is caused by early snows and a long period of ice cover when little sunlight can penetrate into the lake water. Thus no oxygen can be produced, and if the lake is severely eutrophic, so much decomposition occurs that all the dissolved oxygen in the lake is depleted.

In spring, with the melting of ice, oxygen is again injected into the hypolimnion during this mixing or "turnover" period. Summer again repeats the process of stratification and bottom depletion of dissolved oxygen.

One other aspect of dissolved oxygen (DO) cycles concerns the diel or 24-hour cycle. During the day in summer, plants photosynthesize and produce oxygen, while at night they join the animals in respiring (creating CO2) and using up oxygen. This creates a diel cycle of high dissolved oxygen levels during the day and low levels at night. These dissolved oxygen sags have resulted in fish kills in lakes, particularly near large aquatic macrophyte beds on some of the hottest days of the year.

pH

The pH of most lakes in this area ranges from about 6 to 9. The pH value (measure of the acid or alkaline nature of water) is governed by the concentration of H (hydrogen) ions which are affected by the carbonate-bicarbonate buffer system, and the dissociation of carbonic acid (H2CO3) into H + ions and bicarbonate. During a daily cycle, pH varies as aquatic plants and algae utilize CO2 from the carbonate-bicarbonate system. The pH will rise as a result. During evening hours, the pH will drop due to respiratory demands (production of carbon dioxide, which is acidic). This cycle is similar to the dissolved oxygen cycle already discussed and is caused by the same processes. Carbon dioxide causes a rise in pH so that as plants use CO2 during the day in photosynthesis there is a drop in CO2 concentration and a rise in pH values, sometimes far above the normal 7.4 to values approaching 9. During the night, as noted, both plants and animals respire (give off CO2), thus causing a rise in CO2 concentration and a concomitant decrease in pH toward a more acidic condition. We use pH as an indicator of plant activity as discussed above and for detecting any possible input of pollution, which would cause deviations from expected values. In the field, pH is measured with color comparators or a portable pH/conductivity meter and in the laboratory with a pH meter.

Alkalinity

The amount of acid (hydrogen ion) that needs to be added to a water sample to get a sample to a pH of 4.5 (the endpoint of a methyl-orange indicator) is a measure of the buffering capacity of the water and can be quantitatively determined as mg/L or ppm as calcium carbonate (CaCO3). This measurement is termed total alkalinity and serves as an indicator of basic productivity and as an estimate of the total carbon source available to plants. Alkalinity is a measure of hydroxides (OH-), carbonates (CO3=) and bicarbonates present. Plants utilize carbon dioxide from the water until that is exhausted and then begin to extract CO2 from the carbonate-bicarbonate buffer system through chemical shifts. As discussed before, this decrease in CO2 concentrations causes great pH increases during the day and a pH drop during the night. There are two kinds of alkalinity measured, both based on the indicators, which are used to detect the end-point of the titration. The first is called phenolthalein alkalinity (phth) and is that amount of alkalinity obtained when the sample is titrated to a pH of 8.3. This measurement is often 0, but can be found during the conditions previously discussed; that is, during summer days and intense photosynthesis. Total alkalinity was noted above and includes phenolthalein alkalinity.

Hardness

Like alkalinity, hardness is also a measure of an ion, though these are divalent cations, positive double charged ions like calcium (Ca++) and magnesium (Mg/L++). Again, the units of hardness are mg/L as CaCO3. A sample of water is buffered and then an indicator is added. Titration to the indicator endpoint using EDTA completes the analysis. As with all our analyses, for more detail, consult Standard Methods. Alkalinity and hardness are complementary, so that comparing the two readings can give information about what ions are present in the system and confirm trends seen in other data. Alkalinity and hardness are complementary because every calcium ion must have a bicarbonate ion or other such divalent negative ion and vice versa; each carbonate or hydroxide ion must have a divalent or monovalent anion associated with it. For example, we might find high chlorides from street run-off in a particular sample. Since chlorides are probably applied as calcium chloride (CaCl2), we would confirm our suspicions when hardness (a measure of Ca++ ions) was considerably higher than alkalinity. If alkalinity were higher than hardness it would indicate that some positive anion like potassium (K+) was present in the lake, which was associated with the bicarbonate and carbonate ions but was not measured by hardness. Generally speaking, high alkalinity and hardness values are associated with a greater degree of eutrophication; lakes are classified as soft, medium, or hard-water lakes based on these values.

Chlorides

Chlorides are unique in that they are not affected by physical or biological processes and accumulate in a lake, giving a history of past inputs of this substance. Chlorides (Cl-) are transported into lakes from septic tank effluents and urban run-off from road salting and other sources. Chlorides are detected by titration using mercuric nitrate and an indicator. Results are expressed as mg/L as chloride. The effluent from septic tanks is high in chlorides. Dwellings around a lake having septic tanks contribute to the chloride content of the lake. Depending upon flow-through, chlorides may accumulate in concentrations considerably higher than in natural ground water. Likewise, urban run-off can transport chlorides from road salting operations and also bring in nutrients. The chloride "tag" is a simple way to detect possible nutrient additions and septic tank contamination. Ground water in this area averages 10-20 mg/L chlorides. Values above this are indicative of possible pollution.

Phosphorus

This element, as noted, is an important plant nutrient, which in most aquatic situations is the limiting factor in plant growth. Thus if this nutrient can be controlled, many of the undesirable side effects of eutrophication (dense macrophyte growth and algae blooms) can be avoided. The addition of small amounts of phosphorus (P) can trigger these massive plant growths. Usually the other necessary elements (carbon, nitrogen, light, trace elements, etc.) are present in quantities sufficient to allow these excessive growths. Phosphorus usually is limiting (occasionally carbon or nitrogen may be limiting). Two forms of phosphorus are usually measured. Total phosphorus is the total amount of P in the sample expressed as mg/L or ppm as P, and soluble P or Ortho P is that phosphorus which is dissolved in the water and "available" to plants for uptake and growth. Both are valuable parameters useful in judging eutrophication problems.

Nitrogen

There are various forms of the plant nutrient nitrogen, which are measured in the laboratory using complicated methods. The most reduced form of nitrogen, ammonia (NH_3), is usually formed in the sediments in the absence of dissolved oxygen and from the breakdown of proteins (organic matter). Thus high concentrations are sometimes found on or near the bottom under stratified anoxic conditions. Ammonia is reported as mg/L as N and is toxic in high concentrations to fish and other sensitive invertebrates, particularly under high pHs. With turnover in the spring most ammonia is converted to nitrates ($NO_3=$) when exposed to the oxidizing effects of oxygen. Nitrite (NO_2-) is a brief form intermediate between ammonia and nitrates, which is sometimes measured. Nitrites are rapidly converted to nitrates when adequate dissolved oxygen is present. Nitrate is the commonly measured nutrient in limnological studies and gives a good indication of the amount of this element available for plant growth. Nitrates, with Total P, are useful parameters to measure in streams entering lakes to get an idea of the amount of nutrient input. Profiles in the deepest part of the lake can give important information about succession of algae species, which usually proceeds from diatoms, to green algae to blue-green algae. Blue-green algae (an undesirable species) can fix their own nitrogen (some members) and thus out-compete more desirable forms, when phosphorus becomes scarce in late summer.

BIOLOGICAL PARAMETERS

Algae

The algae are a heterogeneous group of plants, which possess chlorophyll by which photosynthesis, the production of organic matter and oxygen using sunlight and carbon dioxide, occurs. They are the fundamental part of the food chain leading to fish in most aquatic environments.

There are a number of different phyla, including the undesirable blue-green algae, which contain many of the forms, which cause serious problems in highly eutrophic lakes. These algae can fix their own nitrogen (a few forms cannot) and they usually have gas-filled vacuoles which allow them to float on the surface of the water. There is usually a seasonal succession of species, which occurs depending on the dominant members of the algal population and the environmental changes, which occur.

This usual seasonal succession starts with diatoms (brown algae) in the spring and after the supply of silica, used to construct their outside shells (frustules), is exhausted, green algae take over. When nitrogen is depleted, blue-green algae are able to fix their own and become dominant in late summer.

The types of algae found in a lake serve as good indicators of the water quality of the lake. The algae are usually microscopic, free-floating single and multicellular organisms, which are responsible many times for the green or brownish color of water in which they are blooming. The filamentous forms, such as *Spirogyra* and *Cladophora* are usually associated with aquatic macrophytes, but often occur in huge mats by themselves. The last type, *Chara*, a green alga, looks like an aquatic macrophyte and grows on the bottom in the littoral zone, sometimes in massive beds. It is important to understand the different plant forms and how they interact, since plants and algae compete for nutrients present and can shade one another out depending on which has the competitive advantage. This knowledge is important in controlling them and formulating sensible management plans. Samples are collected using a No. 20 plankton net (63-micron mesh), preserved with 10% formaldehyde and examined microscopically in the laboratory.

Macrophytes

The aquatic plants (emergent and submersed), which are common in most aquatic environments, are the other type of primary producer in the aquatic ecosystem. They only grow in the euphotic zone, which is usually the inshore littoral zone up to 6 ft., but in some lakes with good water clarity and with the introduced Eurasian water-milfoil (*Myriophyllum spicatum)*, milfoil has been observed in much deeper water. Plants are very important as habitat for insects, zooplankton, and fish, as well as their ability to produce oxygen. Plants have a seasonal growth pattern wherein over wintering roots or seeds germinate in the spring. Most growth occurs during early summer. Again plants respond to high levels of nutrients by growing in huge beds. They can extract required nutrients both from the water and the sediment. Phosphorus is a critical nutrient for them. The aquatic plants and algae are closely related, so that any control of one must be examined in light of what the other forms will do in response to the newly released nutrients and lack of competition. For example, killing all macrophytes may result in massive algae blooms, which are even more difficult to control.

Zooplankton

This group of organisms is common in most bodies of water, particularly in lakes and ponds. They are very small creatures, usually less than 1/8 inch, and usually live in the water column where they eat detritus and algae. Some prey on other forms. This group is seldom seen in ponds or lakes by the casual observer of wildlife but is a very important link in the food web leading from the algae to fish. They are usually partially transparent organisms, which have limited ability to move against currents and wave action, but are sometimes considered part of the 'plankton' because they have such little control over their movements, being dependent on wind-induced or other currents for transport.

Zooplankton is important indicators for biologists for three reasons. First, the kind and number present can be used to predict what type of lake they live in as well as information about its stage of eutrophication. Second, they are very important food sources for fish (especially newly hatched and young of the year fish), and third, they can be used to detect the effects of pollution or chemical insult if certain forms expected to be present are not. These data can be added to other such data on a lake and the total picture can then lead to the correct conclusions about what has occurred in a body of water.

Zooplankton is collected by towing a No. 10 plankton net through the water and the resulting sample is preserved with 10% formaldehyde and then examined microscopically in the laboratory. Qualitative estimates of abundance are usually given.

Benthos

The group of organisms in the bottom sediments or associated with the bottom is termed benthos. These organisms are invertebrates (lacking a backbone) and are composed of such animals as aquatic insect larvae and adults, amphipods (fairy shrimp), oligochaetes (aquatic worms), snails, and clams. The importance of this group for fish food and as intermediates in the food chain should be emphasized. Because of the tremendous variety of animals in each group and their respective tolerances for different environmental conditions, this group is a very important indicator of environmental quality. One of those organisms is called *Hexagenia*, the large mayfly that hatches in late July and precipitates much trout fishing in our local trout streams. This organism has a 2-yr life cycle; the larval form (naiad) lives in thick organic muds making a U-shaped burrow, so it can take in algae and detritus on which it feeds. It requires high dissolved oxygen at all times and good water quality to survive, so when present it indicates excellent water quality is present. We examine samples from deep water stations for the presence of organisms, as certain types live in low to no dissolved oxygen conditions, whereas other kinds can only exist when their high dissolved oxygen needs are satisfied.

These benthic organisms are collected using a special sampler called an Ekman dredge or Ekman grab sampler. It is lowered to the bottom in the open position, a messenger sent down the line and tripped. This results in about an l square foot section of bottom being sampled. The sample is washed through a series of screens to remove the fine mud and detritus, leaving only the larger organisms and plant material behind. The sample is then picked in the field or lab and the organisms found identified.

Fish

The top carnivores in most aquatic ecosystems, excluding man, are the fish. They are integrators of a vast number and variety of ever-changing conditions in a body of water. They, unlike the zooplankton and benthos, which can reflect short-term changes, are indicative of the long-range, cumulative influences of the lake or stream on their behavior and growth. The kind of fish, salmon or sunfish, can tell us much about how oligotrophic (low productivity) or eutrophic (high productivity) a lake is. We collect fish with seines, gill nets and from lucky fishermen on the lake. Most fish are weighed, measured, sexed, and their stomach contents removed and identified. Fish are aged using scales, and breeding condition is observed and recorded. The catches from our nets and age information on the fish will tell us how your length-at-age data compare with state averages and whether or not fish growth is good. Another problem, "stunting", can be detected using these sources of information.

Stomach contents of fish document whether or not good sources of food are present and help confirm age and growth conclusions. Imbalances in predator-prey relationships are a closely related problem, which we can usually ascertain by examining the data and through discussions with local fishermen. From studying the water chemistry data and supportive biological data, we can make recommendations, such as habitat improvement, stocking of more predators, and chemical renovation. We can also predict for example, the effects of destroying macrophytes through chemical control. All elements of the ecosystem are intimately interrelated and must be examined to predict or solve problems in a lake.

RESULTS

WATERSHED

Columbia Lake is located in Jackson County and is in the Grand River watershed. The local watershed is composed of the land surrounding the lake which has many roads and houses located on it (see Google Map Fig. 3). There are lawns and large areas of grasses and shrubs and some forested areas. The houses have been put on sewers about 6-7 years ago, so old septic tank effluent, which depending on soil type, should have passed through the system by now.

The local riparian zone is very important also, especially that band right at the lake, which can be the gateway for nutrient entry to the lake proper. Thus riparians can substantially reduce nutrient input into Columbia Lake. Things that can be done to inhibit entry of undesirable and deleterious substances into the lake are: planting greenbelts (thick plants that can absorb nutrients and retard direct runoff into the lake) along the lake edge, reducing erosion where ever it occurs, reducing or eliminating use of fertilizers for lawns, cutting down on road salting operations, not feeding the geese or ducks, no leaf burning near the lake, prevention of leaves and other organic matter from entering the lake, and care in household use of such substances as fertilizers, detergents to wash cars and boats, pesticides, cleaners like ammonia, and vehicle fluids, such as oil, gas, and antifreeze (summarized in Appendix 1).

STATION LOCATION

Columbia Lake is an 840-acre lake located near Brooklyn, MI. We established two types of stations on Columbia Lake for sampling various parameters in this study (Fig. 3-4, and Table

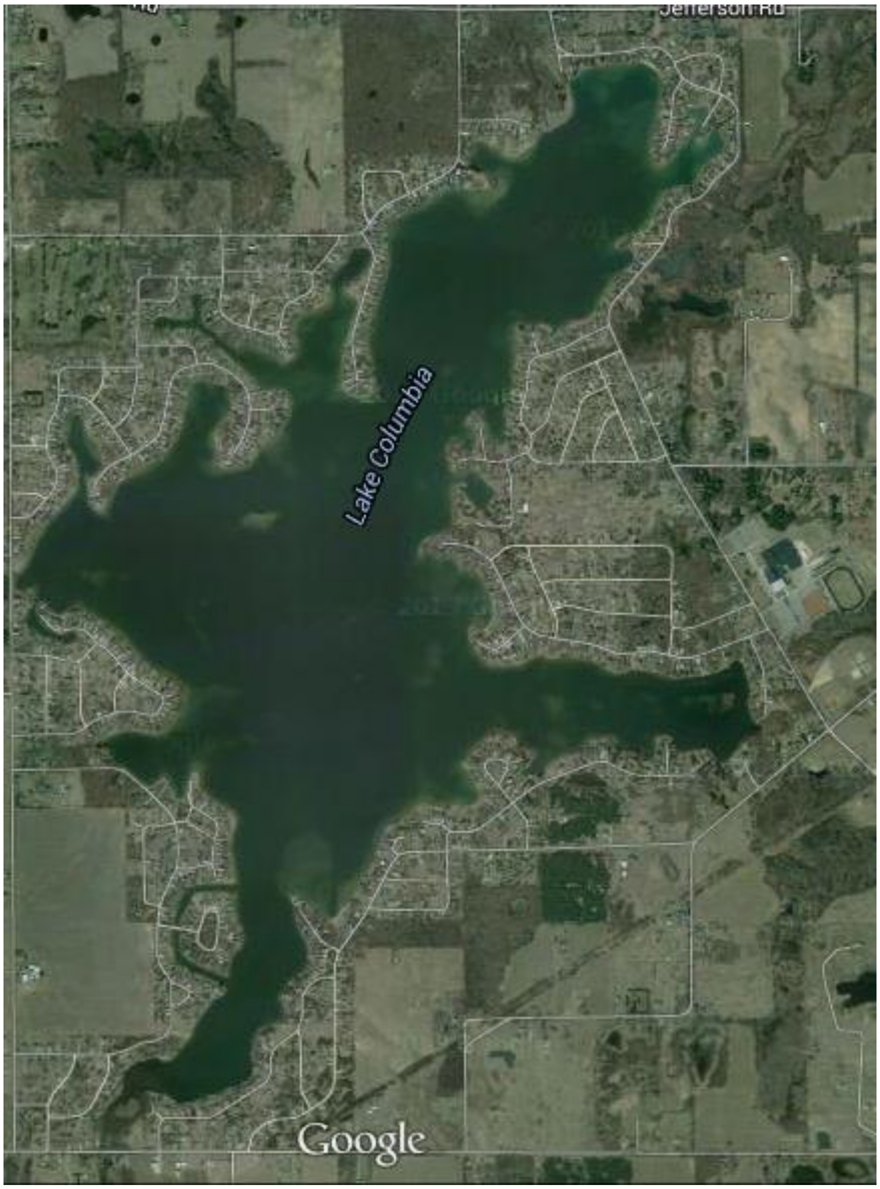

Figure 3. Google map of Columbia Lake showing the extensive development all around the lake.

2). Water chemistry, a dissolved oxygen profile, and zooplankton were sampled at the deepest site (station A) and water quality samples were collected at Goose Creek to ascertain nutrient inputs from this stream (Fig. 4, Table 2). Places and times for sampling fish were set up in various locations around the lake to maximize catch of fishes (Fig. 4, Table 1, 2). Fishes were collected using seines at stations S1, S2, S3, and S4, gill nets at stations G1 and G2, and trap nets at stations TN1, TN2, and TN3 (Fig. 4). The GPS readings for the gill net and trap net stations are as follows:

GN1 – N42 06.277 W84 17.476
GN2 – N42 05.386 W84 17.854

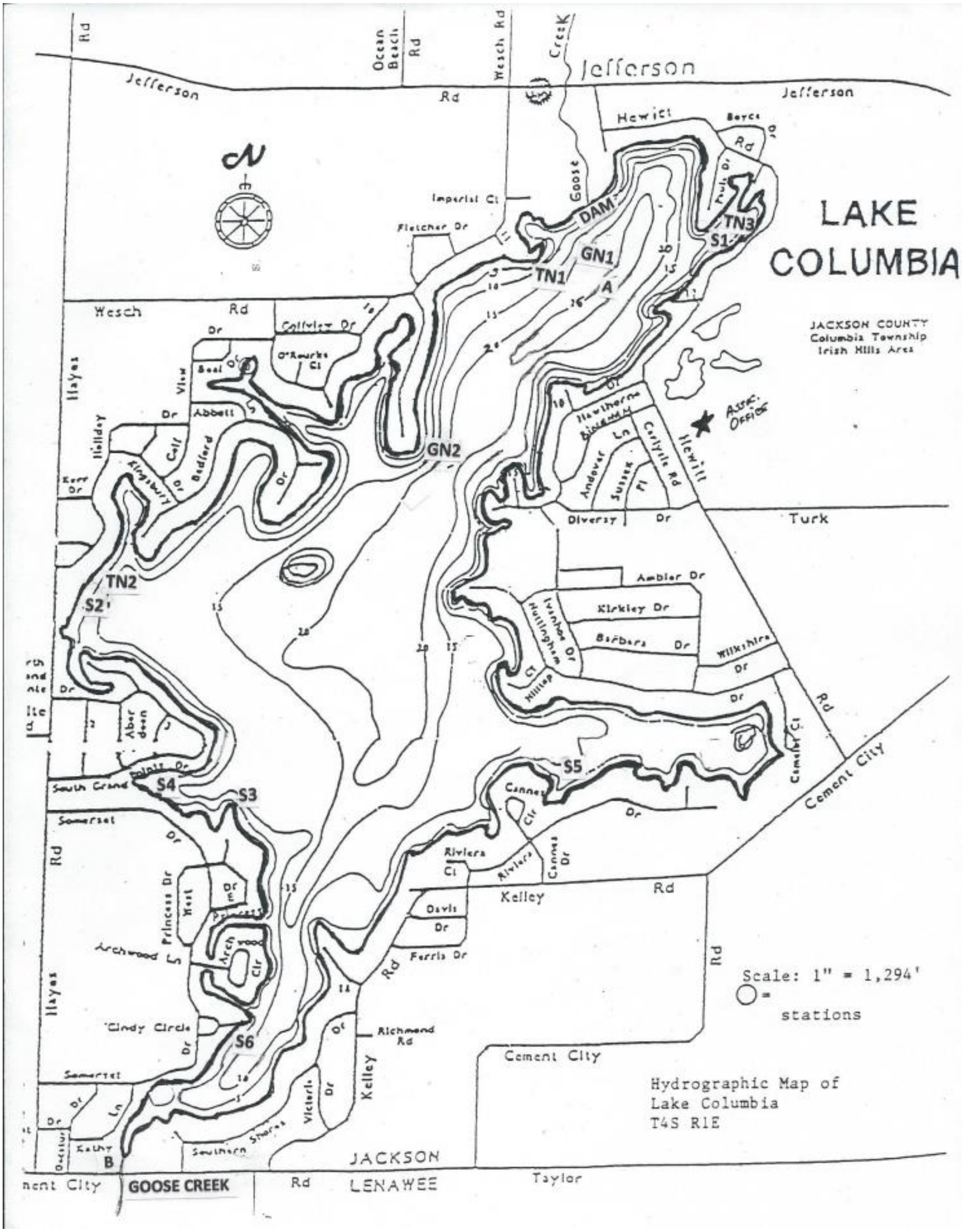

Figure 4. Map of Columbia Lake showing the water quality and zooplankton sampling station A, Goose Creek, and fish sampling sites for seining (S), gill netting (GN), and trap netting (TN).

TN1 - N42 05.275 W84 17.540
TN2 - N42 05.150 W 84 18.616
TN3 - N42 05.507 W 84 18.910

Table 1. Place and time during which various gear were deployed at Columbia Lake, 5- 6 August 2014. GN = gill net, TN = trap net, S = seine.

Fishing Gear	Site Name	Time Start	Finish	Time Start	Finish
		DAY 1		DAY 2	
GN1	N deep	1200	1710	1720	920
GN2	NW mid lake	1208	1635	1650	855
TN1	NW near shore	1220	1015		
TN2	W side, mid lake	1250	1000		
TN3	NE corner, near shore	1215	945		
S1	N east side	1300	1310		
S2	W side, mid lake	1345	1410		
S3	S end, W shore, point	1430	1510		
S4	S end, W shore, bay	1530	1550		
S5	Mid lake, east bay shore	1600	1620		
S6	S end, W shore, launch	1625	1650		

Table 2. Location and description of sampling stations where various water quality and biological samples were collected in Columbia Lake, Jackson Co., Michigan, 5-6 August 2014. See Fig. 4 for map of locations.

Station Letter	Description/Location
A	In the northern basin, depth = 26 ft
S1	Seining station, north end, east shore, near huge culvert, 2-4 ft.
S2	Seining station mid lake, west shore in small bay
S3	Seining station south end, west shore, off point
S4	Seining station south basin, west shore, small bay
S5	Seining station, south end, east large bay, by park

S6	Seining station, south end, west shore, near park launch site
GN1	Gill netting in north, near station A, deep 9-24 ft.
GN2	Gill netting in north end, off point near west shore, 12-17 ft.
TN1	Trap net set in north basin along the west shore, 5-8 ft
TN2	Trap net set in mid lake, west side, 2.5-6 ft
TN3	Trap net set in north end, east bay near large culvert

PHYSICAL PARAMETERS

Depth

Columbia Lake is fairly shallow throughout the basins with a deep hole (station A – Fig. 4) of about 26 ft in the north part of the lake near the dam. The littoral zone is extensive and highly vegetated.

Acreage

Columbia Lake is 840 acres and is extensively developed all around the lake.

Light Penetration

The Secchi disc (measure of water transparency) readings during 5 August 2014 at station A was 1.2 m (3.9 ft) (Fig. 4, Table 2), which is not a particularly good reading, since it indicates high productivity in the lake (any value <7.5 ft indicates a eutrophic lake). This is a reflection of the high input of nutrients that enter the lake, which results in growth of algae and plants.

On 15 August 1994 the Secchi disk reading was 1.4 m (4.6 ft) (Kevern et al. 1994), which is slightly better than what we measured on 5 August 2014. During 1976 (Freshwater Physicians 1977), the Secchi disk readings were also low and ranged from 1 (3.3 ft) to 2.2 m (7.3 ft) on 21 August, while monitoring Secchi Disk data by Columbia Lake staff ranged from 4.3 to 8.5 ft from weekly measurements from 10 May through 20 September, 1976. It appears that there has been a degradation of water clarity over the years from 1976 to 2014, but we would need a larger dataset to confirm this finding.

Temperature/Dissolved Oxygen

Water temperature is intimately associated with the dissolved oxygen profiles in a lake. The summer profile is the one that most characterizes a lake and the stratification impacts are very important. A lake goes through a series of changes (see introductory material- Temperature) in water temperature, from spring overturn, to summer stratification, to fall over turn, to winter conditions. During both summer and winter rapid decomposition of sediments and detritus occurs when bottom waters are fertile and can cause degraded chemical conditions on the bottom (to be discussed). Because the lake is essentially sealed off from the surface when it is stratified during summer, no dissolved oxygen can penetrate to the bottom and anoxia (no dissolved oxygen conditions- a dead zone) can result. This has implications for the aquatic organisms (fish will not go there; sanctuary for some zooplankton and insects, such as the phantom midge *Chaoborus*) and chemical parameters (phosphorus is released from the sediments under anoxic conditions, which then contribute these nutrients to the lake during the fall overturn).

During early summer (5 August 2014), when we measured the temperature/oxygen profile, water temperatures were warm at the surface (25.1 C) and on the bottom (22.3 C) (Fig. 5, Table 3). We measured this profile prior to maximum stratification, so we expect conditions will get much worse before summer ends. Usually we find a lake like Columbia stratifies with distinct layers. There is some stratification (not temperature) since the dissolved oxygen is very low (0.1-0.4 mg/L) below 6 m or 20 ft. Since warm-water fish require at least 3 mg/L this zone would be off limits to fish. This finding confirms two conditions: first, the lake has some fertile mud or other organic material, such as rotted leaves, on the bottom of the lake, which degraded the oxygen levels through decomposition. Second, it appears that the lake is destratified, either by boat traffic or wind fetch or both. This results in the circulation and mixing of water from the bottom to the surface and the near uniform water temperature data and a non-typical dissolved oxygen pattern. Most warm water fishes require at least 3 mg/L while cool water fish, such as northern pike and walleye require 5 mg/L. Hence these fish will be subject to a part of the squeeze noted in Fig. 9: warm temperatures in surface water and all the way to the bottom forces them downward to seek cooler temperatures, while low dissolved oxygen (hypoxia) in the bottom waters of the lake forces them up into too warm surface waters. This point is important for fish management considerations for the cool water species, walleye and northern pike in Columbia Lake: fish will be severely stressed during summer and not grow well. It should also be noted that Columbia Lake is unusual among eutrophic lakes, in that it was not thermally stratified during 2014 nor during earlier studies done (see Fig. 6, 7, and 8 for the data for 2000, 1994, and 1976 (Freshwater Physicians 2001, Kevern 1994, Freshwater Physicians 1976). There are two possibilities one can hypothesize: 1. The boat traffic in Columbia Lake is so intense and common that it essentially destratifies the lake. We have seen this phenomenon in other lakes that were shallow and had too much boat traffic. 2. Wind may destratify the lake (this is less likely since the lake has a south - north fetch, not an east – west one, which would promote more intense wind effects. Lastly, Goose Creek oxygenated input water may be cooler than Columbia Lake water and sink to the bottom improving water quality in bottom waters. However, this water flows through a shallow part of Columbia Lake at the south end of the lake and would be expected to be warmed to higher temperatures from initial cooler Goose Creek temperatures or at least attain similar temperatures than found on the lake bottom. We need to know how much water comes in through this creek and whether there is any possibility of this being true.

There also seems to be a change in the degradation of bottom waters in Columbia Lake over time, since the dissolved oxygen concentrations in former studies during 1976 and 1994 showed at least >3 mg/L dissolved oxygen on the bottom, while studies in 2000 and 2014 showed decreasing concentrations on the bottom. These concentrations were not zero but very close and in the case of 2014 would prevent fish from utilizing that zone of the lake. This could just be a reflection of when we did the sampling and some change in the mechanism (boat traffic) that may have caused it, but we doubt this. In addition, in examining the water quality conditions on the bottom of Columbia Lake from 1976, 1994, 2000, and 2014 (Freshwater Physicians 1977, Kevern et al. 1994, and Freshwater Physicians 2001; Table 4), there has NOT been a buildup of either ammonia or phosphorus on the bottom, which almost always occurs in other stratified, eutrophic lakes in Michigan. So even though we have seen degraded dissolved oxygen conditions on the bottom, we have not seen buildup of deleterious nutrients over the same time period. Over time material will accumulate on the bottom of the lake and this process only increases, especially if riparians are careless about their treatment of the lake. This would include lawn fertilization practices; riparians should strive to use no fertilizer or at most only nitrogen-based fertilizer. There are other practices that should be used (see Appendix 1) to reduce nutrient input to Columbia Lake and improve water quality and reduce algal and plant growth.

Table 3. Dissolved oxygen (mg/L) and water temperature (F) profile for station A (7.5 m - 26 ft) 5 August 2014 on Columbia Lake, Jackson County (see Fig. 4 for station location).

Depth (m)	Temp-C	DO - mg/L
0	25.1	10.6
1	25.1	10.5
2	25	10.5
3	24.3	9.2
4	23.2	5.2
5	23.1	4.1
6	22.3	0.4
7	22.6	0.1
8	22.3	0.1

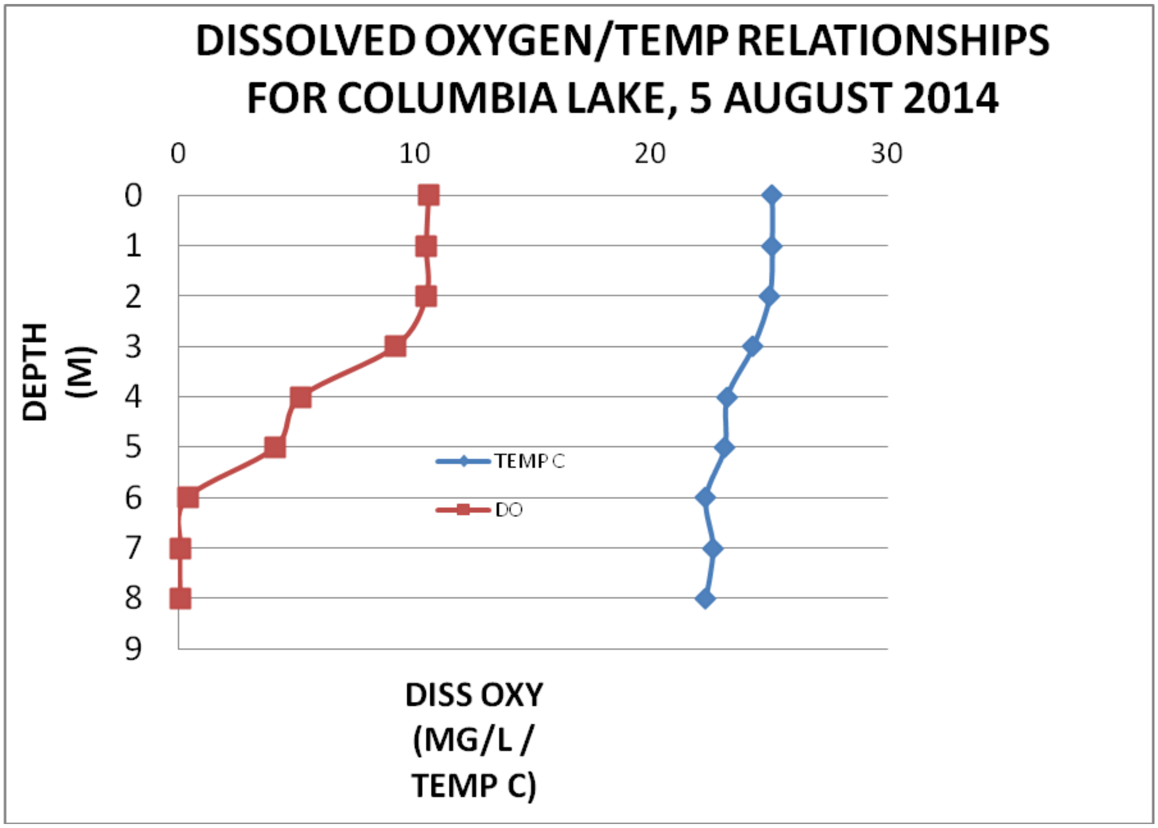

Figure 5. Dissolved oxygen (mg/L) and water temperature (F) profile for station A Columbia Lake, 5 August 2014.

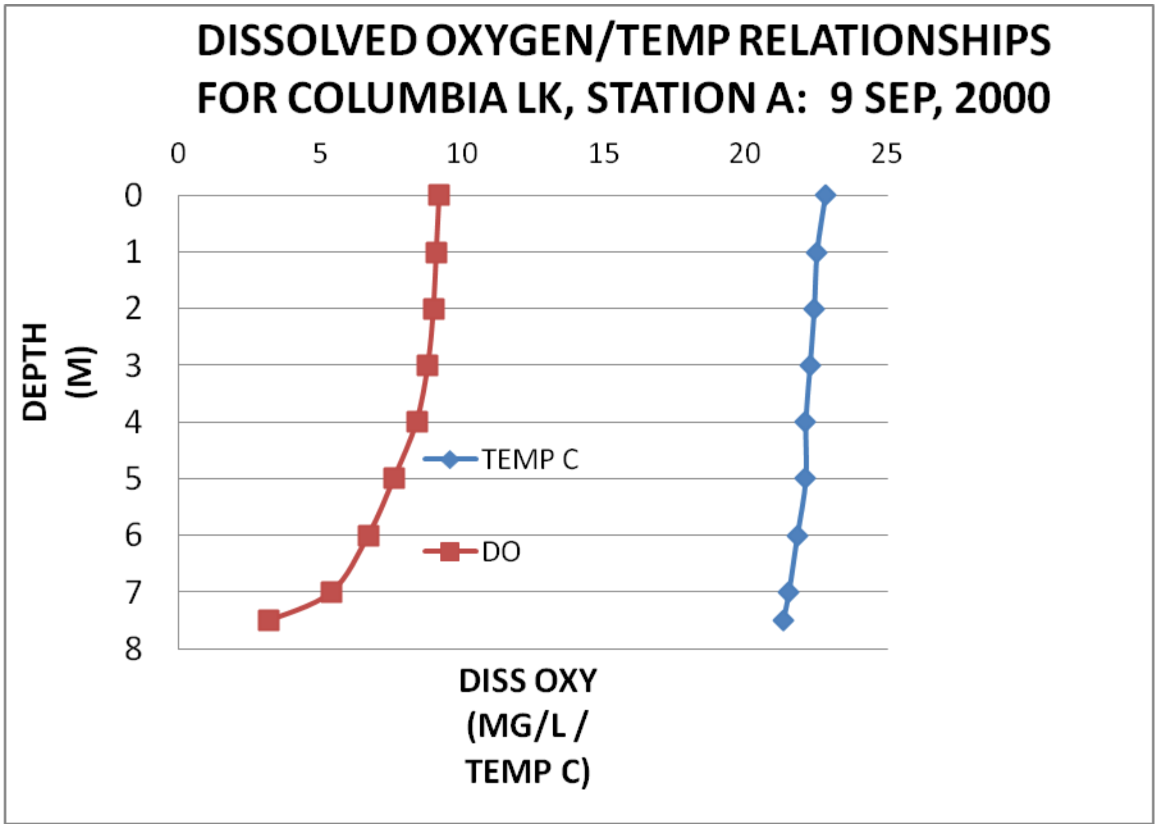

Figure 6. Dissolved oxygen (mg/L) and water temperature (F) profile for station A Columbia Lake, 9 September 2000. Data from Freshwater Physicians (2001).

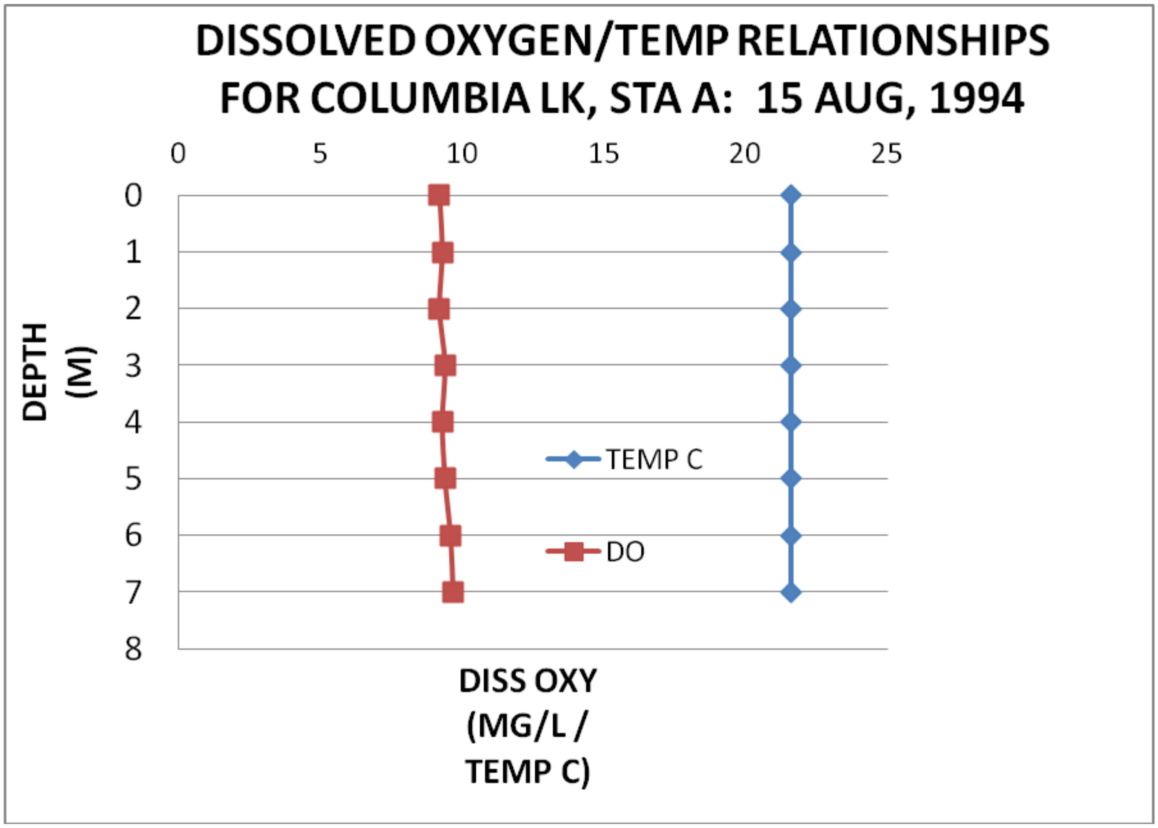

Figure 7. Dissolved oxygen (mg/L) and water temperature (F) profile for station A Columbia Lake, 15 August 1994 (from Kevern et al. 1994).

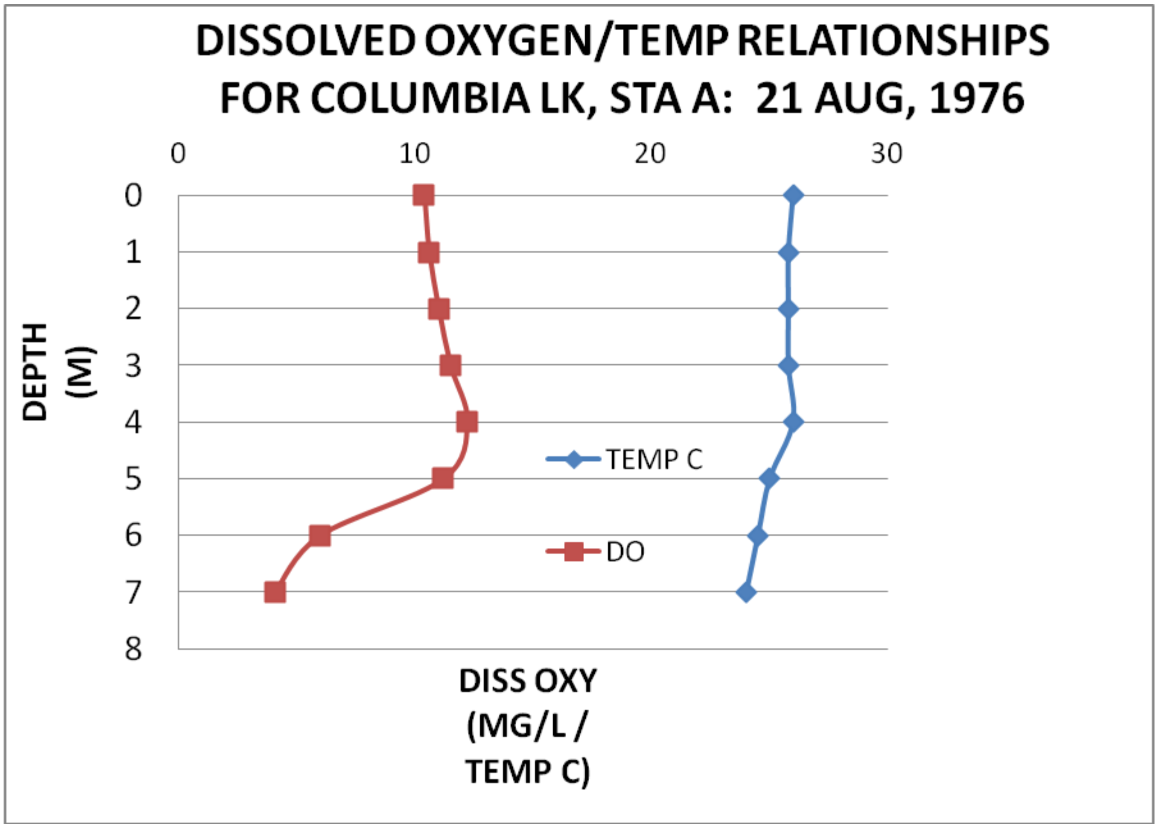

Figure 8. Dissolved oxygen (mg/L) and water temperature (F) profile for station A Columbia Lake, 21 August 1976 (from Freshwater Physicians 1977).

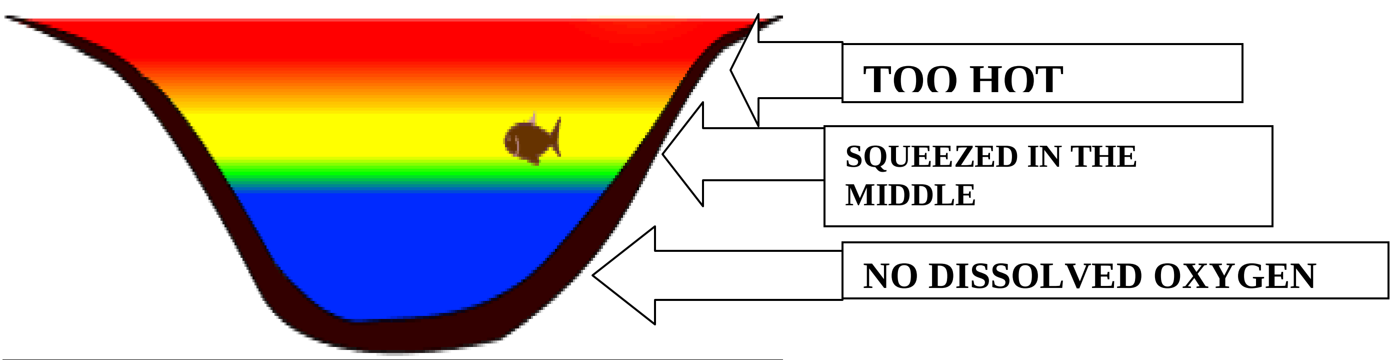

Figure 9. Depiction of the dissolved oxygen concentrations in a stratified lake, showing the surface layer (epilimnion) where warmest temperatures exist, the thermocline area where water temperatures and dissolved oxygen undergo rapid changes, and the bottom layer, where the coolest water exists, but has no or very low dissolved oxygen present. Cool water fishes, such as northern pike and walleyes are "squeezed" between these two layers and undergo thermal stress

during long periods of summer stratification. Columbia Lake shows no such configuration, but is destratified.

CHEMICAL PARAMETERS

pH

The pH (how acid or alkaline water is) for Columbia Lake during 5 August 2014 at station A showed a typical pattern matching the expected situation. The pH was highest at the surface (8.3) where algal and aquatic plant growth remove carbon dioxide and increase pH, while it is lowest on the bottom (7.91) where decomposition of bottom sediments increases the CO2 produced and reduces pH (Table 4). Here there are differences between the pH at the surface and bottom, but they are not large. It does confirm that the lake is not completely mixed, since there is a dissolved oxygen pattern of high concentrations at the surface and low concentrations on the bottom. All the other parameters suggest good mixing between bottom and surface, while pH and dissolved oxygen levels confirm there are still differences ongoing with decomposition on the bottom removing dissolved oxygen and pH differences reflecting this situation.

Table 4. Conductivity (uSiemens), pH, chlorides (CL), nitrates (NO3), ammonia (NH3), and soluble reactive phosphorus (SRP) for Columbia Lake, 5 August 2014. See Table 2, Fig. 5 for location of station A. All concentrations are in mg/L.

Station	Depth	pH	Cond	Cl	NO3	NH3	SRP
A	SURF	8.3	485	29	<0.01	<0.02	<0.005
A	3.5 M	8.19	499	28	<0.01	<0.02	<0.005
A	7 M	7.91	539	28	<0.01	<0.02	<0.005
GOOSE CR	SURF	8.21	585	28	0.54	0.02	<0.005

Chlorides

Chloride concentrations in Columbia Lake were surprisingly low ranging from 28 to 29 mg/L (Table 4). Interestingly, Goose Creek was the same concentration, indicating that there are not high chlorides coming in from this source. It also indicates that the water quality of Columbia Lake is good, with low inputs apparently of chlorides from either road salting operations or septic tanks. Chloride ions are conservative ions, which mean they are not altered by biological or chemical activity; they can only change with evaporation or input of water of differing concentrations of chlorides. They can derive from septic tank effluent, road salt runoff, or can be naturally occurring. Therefore they accumulate in a lake and give a good impression of the past history of inputs of that ion, as well as co-occurring substances from runoff, such as nutrients, toxic substances, and sediment. Part of the reason for these low values may be input from Goose Creek, which originates around Somerset Lake and goes a short distance through many wetlands and few areas that are urbanized or with roads.

Lastly, the vertical distribution of chlorides was not stratified, which often happens because of differing water temperature in varying water layers. This supports our contention that Columbia Lake has been destratified, probably because of excessive boat traffic.

Data from 2000 (Freshwater Physicians 2001) show that chlorides have not changed much in 14 years, since concentrations were 31 mg/L in May 2000, which compares favorably with values of 28-29 mg/L during 2014. However, during 1994 studies (Kevern et al. 1994) chlorides were lower than found in 2000-2014, ranging from 18.5 to 23 mg/L with one high value in Beal Drive bay where a value of 33.5 mg/L was measured. During 1976, Freshwater Physicians (1977) found that the earliest measurements were even lower, ranging from 10.5 to 15 mg/L. So the chlorides have increased about 0.4 mg/L per year from 1976 (mean around 15 mg/L) to 2014 (30 mg/L), ca. 40 years. This indicates a small but consistent input of chlorides, either from residual septic tank effluent seeping into the lake, natural inputs, or road salting operations. Along with those chlorides, we expect there are increased levels of contaminants and nutrients that are also entering the lake.

Phosphorus

We are interested in phosphorus (P) because P is generally the limiting nutrient for plant growth and the level of concentrations can indicate the trophic state or amount of enrichment in the lake. Soluble reactive phosphorus (SRP) measures only that P which is dissolved in the water, which is the form that is readily available for algal and plant growth. Total P would be all the P in the water, dissolved and that tied up in algae or other detritus. During summer, SRP values were at trace levels (<0.005 mg/L) throughout the water column from surface to bottom (Table 4). Algae and aquatic plants usually take up all the phosphorus for growth during summer, which is what happened in Columbia; however, usually SRP builds up on the bottom due to decompositional processes. This did not happen in Columbia Lake (Table 4) during 2014. Phosphorus is probably limiting in surface waters at this time in Columbia Lake. It should be pointed out that buildup of total phosphorus on the bottom was noted during 1994 (Kevern et al. 1994), indicating that at least during one year, destratification was not complete during sampling.

Second, the SRP in Goose Creek was also at trace concentrations (Table 4), indicating that there is not a lot of nutrients coming into Columbia Lake during this time on 5 August 2014. This is a good sign since we thought there might be some agricultural influence (high nutrients) coming in from the creek. However, the Goose Creek that enters Columbia Lake is known to run through many wetlands and forests, which apparently took up most of the phosphorus before it entered Columbia Lake.

We concluded three things from these data: first, P is limiting in Columbia Lake throughout the water column during summer. Second, it confirms our view that boat traffic on the lake has destratified the lake, since there should be buildup of SRP on the bottom and there was not in 2014. Third, input of SRP from Goose Creek was low, which is a good sign, even though more data would be required to validate this conclusion. Residents need to do all they can to prevent nutrients from entering the lake so as to preserve the current water quality they do enjoy. See Appendix 1 for suggestions.

Nitrates

Nitrate is very important since it too is a critical plant nutrient as well as P; however, blue-green algae can generate their own nitrogen, favoring them when nitrate concentrations are depleted. Nitrates in Columbia Lake during 5 August 2014 were uniformly <0.01 mg/L, which is unusually low (Table 4). It indicates that algae and aquatic plants have removed most of the P and N from the entire water volume of Columbia Lake in summer. It also supports the findings observed for chlorides and SRP, that the lake is de-stratified, since we expected to see buildup on the bottom due to decomposition of organic matter. The Goose Creek data, unlike the findings for SRP, showed that there were some level of nitrates (0.54 mg/L) coming in from the watershed (Table 4). This is a rather high concentration and unlike SRP, does indicate some input from agricultural sources. It also documents that probably high amounts of nitrate enter Columbia Lake, but apparently it is taken up by the shallow, macrophyte-dominated, bay into which the creek water first flows, since it is at trace levels in the deep area of the lake where we measured it.

Ammonia

Ammonia is also a plant nutrient, but it can be toxic to fish in high concentrations. Ammonia is formed by the decomposition of bottom sediments under low or no oxygen present. Concentrations of ammonia were uniformly low (0.02 mg/L or less) in the water column of Columbia Lake on 5 August 2014 (Table 4). First, this is unusual, since in most eutrophic lakes in Michigan, ammonia builds up on the bottom in high levels along with the lack of dissolved oxygen also usually noted in these lakes. The lack of ammonia again confirms the lake has been destratified and ammonia is mixed throughout the water column and taken up by algae and plants. Concentrations in Goose Creek were also at trace concentrations, which would be expected since ammonia gets converted to nitrates in the presence of dissolved oxygen.

Hydrogen Sulfide

Hydrogen sulfide is a toxic substance produced under conditions of no dissolved oxygen (anoxia) from the decomposition of organic matter on the bottom. It is the rotten-egg smelling chemical; it was zero on the bottom on 5 August 2014. This too is evidence of destratification and subsequent mixing into the water column, since usually the dissolved oxygen is zero on the bottom and high concentrations of hydrogen sulfide are often produced. These processes are active in Columbia Lake, since the dissolved oxygen on the bottom was very near zero and the mixing was inadequate to restore dissolved oxygen to higher levels. This is a deviation from prior data from 1976, 1994, and 2000, where dissolved oxygen was lower, but still high enough (>3 mg/L) to support fish movement on the bottom in the deep areas of Columbia Lake (see Figs. 6, 7, 8).

Conductivity

Conductivity is a measure of the ability of water to conduct current and is proportional to the dissolved solutes present. During our early summer survey, conductivity ranged from 485 at the surface to 539 uS on the bottom (Table 4). These are moderately low values, compared with other lakes, partially explained by the low chlorides (a negative ion that carries electricity). However, like pH and dissolved oxygen, conductivity was stratified slightly by depth. This was not unexpected. The 2014 conductivity values were comparable to values measured during 1994 (Kevern et al. 1994), since they measured conductivity from 393 to 464 uS.

BIOLOGICAL PARAMETERS

Algae

We did not sample algae in Columbia Lake but we think there was an algal bloom ongoing during 5 August because of the low Secchi disk reading (3.9 ft) that we measured and the presence of *Oscillatoria*, a blue-green alga, in the zooplankton samples. Previous work that was done suggest blue-green algal blooms are common during summer at Columbia Lake. During summer 1976, blue-green algae such as *Anabaena*, *Lyngbya*, and even *Microcystis* (the one responsible for polluting the water supply in Lake Erie with toxins) were common to abundant (Freshwater Physicians 1977). Blue-green algae blooms are another indicator of eutrophic conditions in Columbia Lake. During 1994, Kevern et al. (1994) found few blue-green algae, but booms of green algae and dinoflagellates (*Ceratium)* were abundant. More importantly, we wanted to ensure that residents be on the lookout for an exotic species, called starry stonewort (Picture 2), which has been observed in many Michigan lakes in the past few years. Note this species is an alga, and is a very destructive plant. It looks a lot like *Chara*, another green alga but is somewhat different. If seen, it should be reported to the board and follow up studies done to confirm identification and begin treatment before it reaches nuisance levels.

Picture 2. Starry stonewort

Aquatic Macrophytes

Columbia Lake was populated with many species of macrophytes based on observations during the 2014 study. They were abundant in the near shore zone all around the lake and are a very important component of the lake ecosystem serving several functions. They are shelter and nurseries for young fish, they are spawning substrates for some species (e.g., minnows), they produce many insects which are important food for fishes, and help to retard wave action from producing and re-suspending sediments from wave action. Those aquatic plants (not an exclusive list) include one invasive species: Eurasian milfoil *(Myriophyllum spicatum)* and several native species including: eel grass *Valliseneria*, largeleaf pondweed *Potomogeton amphlifolius*, and thin-leafed naiads N*aijas* spp. We also found the alga *Chara*, which looks a lot like an aquatic macrophyte.

Zooplankton

Zooplankters are small invertebrates present in most lakes and ponds (See Picture 3 for an example of a copepod). They are critical connectors between plants (they eat algae) and fish, since they are important as food for larval fish and other small fishes in the lake and are indicators of the amount of predation that fish exert on these organisms. Zooplankton we collected (Table 5) was comprised of very few species (five), indicating that there was not a diverse group of these organisms in Columbia Lake. These species included: *Daphnia* (see Picture 4), *Mesocyclops*, *Sida crysalina*, *Skistodiaptomus oregonensis*, and *Chydorus*. The dominant group was *Skistodiaptomus oregonensis* (50%), while *Daphnia* composed around 15%, which has two implications. First, one of the things we look for is the presence of the large species of zooplankton: *Daphnia* especially. *Daphnia* is slow, energy-rich, large, and an easy target for fishes during their summer occurrence. Therefore, since we did find some of these large zooplankters present in the lake it indicates that at least during summer fish predation is not intense, as *Daphnia* is often severely depleted in lakes dominated with planktivores (zooplankton eaters), such as small bluegills, yellow perch, and black crappies. Our fish sampling confirmed that there were moderate numbers of small bluegills, small and largemouth bass, yellow perch, and black crappies present, but they were confined to the near shore zone in the aquatic plants, and apparently did not go offshore into the open water during our sampling in August, or if they did, they were not abundant enough to severely impact or eliminate *Daphnia*.

Second, *Daphnia* is more efficient than copepods (a smaller, faster group of zooplankton – *Skistodiaptomus orgegonensis* is an example and was abundant) at filtering algae from the water column. Since *Daphnia* were so abundant, they are helping to control algae in the surface waters (increasing water clarity), although the Secchi disk readings were still low. Copepods are also not fed on as often by fish since they are faster, unless other large zooplankters are rare.

In addition, we recorded the presence of zebra mussel larvae in the water, called veligers. They are microscopic and point out the dangers of moving water with bait in it for example from lake to lake. This is probably how zebra mussels first entered Columbia Lake and should be highlighted for the lake residents, since if bait and a bait bucket full of Columbia Lake water from this date and probably from May through August (reproduction season for zebra mussels) is moved from Columbia Lake to another uninfected lake, that lake would most likely become replete with this invasive species, with dangerous consequences. Fortunately, some fish species were feeding on the juveniles and adult zebra mussels, but they are unlikely to have much effect on controlling the population. We should also point out that quagga mussels is another species of invasive mussel which could be introduced from other lakes into Columbia Lake, highlighting how important it is to not bring bait from other lakes or other gear/boats that have not been dried or bleached before putting into Columbia Lake.

Ostracods were also found in the sample, which is unexpected, since these are small creatures that inhabit the bottom of water bodies and are termed benthos. They are sometimes eaten by fish and it is strange that they would be found that far off the bottom. Our zooplankton sample was collected using a net towed vertically from about 10-15 ft to the surface at the 26 ft deep station.

Table 5. A listing of the abundance (% composition based on counting a random sample of 100 organisms) of zooplankton species (see Picture 3-4) collected from station A in Columbia Lake, 5 August 2014 (see Fig. 4 for station locations). *Oscillatoria* is a blue-green alga. Ostracods are small bottom-oriented invertebrates.

Organism	% composition
Daphnia spp. *	15%
Chydorus spp.	Rare
Sida chrysallina	5%
Mesocyclops edax	20%
Skistodiaptomus oregonensis	50%

*some *retrocurva*

Note: Algae bloom (*Oscillatoria*), zebra mussel veligers common.

Ostracods present.

Picture 3. A copepod (zooplankter).

Picture 4. *Daphnia*, a large zooplankter, adept at eating algae.

Fish

Fish Species Diversity

We collected fish using three trap nets (stations TN1, TN2, TN3) (Fig. 4, see Picture 5, Table 1, 2). A 50-ft seine (stations S1, S2, S3, S4 – Fig. 4, Picture 6), and two gill nets (shown as stations GN1 and GN2 – Fig. 4, Picture 7) were also deployed in the lake (see Tables 1, 2 for set times and station descriptions). Some fish are very susceptible to gill nets, especially white bass (Picture 8, 12), walleye, and yellow perch. The nets were used during the daytime on 5 August 2014 (see Table 1 for times); the gill nets were picked up and reset, while the trap nets were left overnight. Seining with a 50-ft seine was done at four sites on the lake in different habitats. Most fish were released; we kept enough for an adequate sample for ageing and diet analyses. We never want to kill too many fish, especially top predators, as they are so important to fish community balance in a lake. We could have used a few more large fish (especially largemouth bass), but the ones we did catch and those that were donated by fishers provided a fairly good sample for some basic information on the fish community.

Picture 5. Trap net showing pot.

Picture 6. Deployment of the 50-ft seine in the near shore zone of Columbia Lake, 5 August 2014.

Picture 7. Experimental gill net with fish being brought into the boat.

The lake has a high diversity of fish species; if we combine those collected in 2000 (Freshwater Physicians 2001) with those we collected during this study, there were 24 species collected (Table 6). We also understand there are bullheads (species unknown) in the lake, which would bring the total to 25 species. During 2014, we collected 19 species with nets and were informed of a 20^{th}, bullheads, and northern pike (21^{st}), which was reported caught by sport fishers in one of the shallow bays. Some of these species were stocked (walleye, redear sunfish, white bass, and probably smallmouth bass); most were native, one was invasive (common carp). There are nine important top predators in the lake: largemouth bass, northern pike, white bass, walleye, smallmouth bass, and others that become important at large sizes: black crappie, yellow perch, rock bass, and warmouth. Longnose gar are presumed present in the lake which would make the total ten. In addition, we suspect there are also bullheads in the lake (confirmed by Todd Wanty, personal communication), but we did not collect any during 2000 or 2014. It appears from what we know about white bass, northern pike, and walleyes and our diet information, that these predators (mostly white bass) are having a depressing effect on yellow perch in your lake, since they are a preferred prey item by northern pike and walleye (after soft-rayed fishes, like minnows) and apparently by white bass too, since many were found in their stomachs (Picture 12). Interestingly, we also found yellow perch YOY in largemouth bass (Picture 10). Our sampling also reflected a dearth of larger yellow perch, although we did get some up to 9.4 inches, which would also be expected. There are not many large predators with gape width large enough to eat big yellow perch, except big northern pike and there are very few northern pike in the lake. Hence, once yellow perch make it through the small predator gauntlet, they should grow to larger sizes. It was surprising to us that walleyes can even survive in the lake, with the degraded water quality environment in which they are forced to live during summer (see fish squeeze, Fig. 9), but since they are present during the whole year, and because the lake is so productive, they probably will grow well during the cooler periods of the year.

Picture 8. White bass captured in Columbia Lake, 5 August 2014.

In addition to a good suite of top predators, the lake also contains a good population of bluegills and black crappies; pumpkinseeds seem less common and warmouth is usually rare when found at all. As noted, yellow perch sizes appear to be truncated; there were many young of the year (YOY) indicating excellent reproduction (same for largemouth and smallmouth bass), but few yellow perch appear to be making it to larger sizes, undoubtedly due to white bass, northern pike, and walleye predation with some contribution by largemouth bass as well. There are a few rock bass. There were also four species of minnows captured: common, golden (Picture 13), bluntnose, and spotfin shiners. We also discovered Johnny darters, diminutive members of the Perch Family, in the stomachs of some fishes (see Table 7), establishing their presence, albeit rare, in the lake. Lastly, there is the brook silversides, a small smelt-like fish that jumps out of the water during attempted predation events. These fish are also excellent prey and provide more fish diversity. Overall this is an excellent diversity of predators and prey.

It appears that there is adequate spawning substrate for yellow perch and largemouth/smallmouth bass (sandy gravel areas) and a diversity of habitats that support the high number of other species of minnows which also seem to have adequate populations. The northern pike situation is interesting. We caught none, but there are a few in the lake; they were caught during the 2000 study but listed as rare (Freshwater Physicians 2001). Most likely the northern pike are running up Goose Creek and the connected wetlands, but are having limited success. Some research needs to be done to figure out if they are running and spawning in this stream and if there are any impediments to their doing this successfully. We had reports that white suckers run up Goose Creek to spawn in the spring.

Lastly, we noted two groups (families) of larval mayflies called naiads (*Hexagenia* and Baetidae) and caddisflies in the diet items eaten by pumpkinseeds (Picture 14). This is a good indication of the high water quality of the lake, since these aquatic insects can only survive in areas with high dissolved oxygen over at least 1 year as well as appropriate substrate and water temperatures.

Table 6. List of the code, common name, and scientific names of the fishes collected during a 5 August 2014 survey of Columbia Lake. Status referred to species collected during an earlier study in 2000 (Freshwater Physicians 2001) and during this study (2014). A=abundant, C=common, R-C=rare to common, R=rare. *=not collected by our gear set during 2014 but verified as present from two that were caught by sports fishers (Wanty, T., personal communication). Bullheads (unknown species) are also reported to be present in the lake.

Fish Code	**Taxon**	**Scientific Name**	**Status**	**ABUNDANCE**
BC	BLACK CRAPPIE	*Pomoxis nigromaculata*	*2014*	R-C
BG	BLUEGILL	*Lepomis macrochirus*	*2014*	A
BM	BLUNTNOSE MINNOW	*Pimphalus notatus*	*2014*	C
BF	BOWFIN	*Amia calva*	*2000*	R
SV	BROOK SILVERSIDES	*Labidesthes sicculus*	*2014*	R-C
CP	COMMON CARP	*Cyprinus carpio*	*2014*	C
CS	COMMON SHINER	*Luxilus cornutus*	*2014*	R
GL	GOLDEN SHINER	*Notemigonus crysoleucas*	*2014*	R
GN	GREEN SUNFISH	*Lepomis cyanellus*	*2000*	R
JD	JOHNNY DARTER	*Etheostoma nigrum*	*2014*	R
LC	LAKE CHUBSUCKER	*Erimyson sucetta*	*2000*	R
LB	LARGEMOUTH BASS	*Micropterus salmoides*	*2014*	C
LG	LONGNOSE GAR	*Lepisosteus osseus*	*2000*	R
NP	NORTHERN PIKE	*Esox lucius*	*2014*	R*
PS	PUMPKINSEED	*Lepomis gibbosus*	*2014*	R-C
RE	REDEAR SUNFISH	*Lepomis microlophus*	*2014*	R
RB	ROCK BASS	*Ambloplites ruprestis*	*2014*	R
SB	SMALLMOUTH BASS	*Micropterus dolumieu*	*2014*	R-C
SF	SPOTFIN SHINER	*Cyprinella spiloptera*	*2014*	C
WL	WALLEYE	*Sander vitreus*	*2014*	R
WM	WARMOUTH	*Lepomis gulosus*	*2014*	R
WB	WHITE BASS	*Morone chrysops*	*2014*	C-A

WS	WHITE SUCKER	*Catostomous commersonii*	*2014*	R
YP	YELLOW PERCH	*Perca flavescens*	*2014*	R-C

Fish Diets

The diet of the 2-7.9-inch bluegills we examined was diverse and almost exclusively insects with the addition of some algae, eel grass *Vallisneria*, zebra mussels, terrestrial insects, zooplankton, amphipods, and snails (Table 7). The insects eaten included mayflies, caddisflies, phantom midges *Chaoborus*, and chironomids. The presence of mayflies and caddisflies in Columbia Lake is an indicator of high water quality as well as very high energy fish food. In many other lakes I work on, at this time of the year, the bluegills are struggling to find food and often I see these fish eating only algae and aquatic plants, which does not get them much energy. Hence, I expect their populations are doing well in the lake, based on the large numbers, range of sizes in our catch and a diverse diet. Interestingly, some bluegills were eating zebra mussels, which are also present in the lake, adding pressure on this invasive species.

Table 7. Listing of the species collected, length, weight, sex, and diet information for fishes from Columbia Lake, Jackson County, MI 5 August 2014. NA = not available, ZOOP = zooplankton, M = male, F= female, 1= poorly developed gonads, 2= moderately developed, while 3= fully developed gonads. I = immature, MT = empty stomach, CHIR = Chironomidae, MT = empty stomach, XX = unknown, Z=zebra. See Table 6 for a definition of fish species codes. G = gill net with G1 being the first net and G2 the second net; G1-1 indicates the first set, while G1-2 indicates the second set (see Table 1 for times of net sets). TN= trap net, and S = seine. For seine designations, S1= site 1, etc. as defined in Table 2. TL = total length in inches, while WT=weight in ounces.

Species	Gear	TL (IN)	WT (Oz)	Sex	Diet
BLACK CRAPPIE					
BC	S1	1.9	0.04	II	ZOOPLANKTON
BC	TN3	8.4	4.95	M1	XX FISH
BC	TN2	8.7	5.21	M1	XX FISH
BC	TN2	8.8	5.90	M1	XX FISH
BC	TN2	8.9	5.45	M1	XX FISH
BC	G 2-1	9.6	7.80	F2	XX FISH
BC	G1-2	10.0		NA	CHEWED UP
BC	TN2	10.1	8.30	M1	XX FISH
BC	TN2	10.8	10.30	F2	BG 35,36,42,44 MM
BC	G 2-1	11.2	11.70	F2	XX FISH

BLUEGILL

BG	S1	2.0	0.06	II	ZOOPLANKTON - CHYDORUS,CHIRONOMID
BG	S1	2.0	0.06	II	TERRESTRIAL INSECTS, ZEBRA MUSSELS
BG	S1	2.2	0.09	II	CHIRONOMIDS, AMPHIPODS
BG	S1	2.2	0.11	II	WATER MITES, AMPHIPODS,SNAIL, ZOOPLANKTON
BG	S1	2.6	0.15	II	8 CHIRONOMIDS
BG	S5	2.7	0.16	II	10 CHIRONOMIDS
BG	S5	2.7	0.14	II	9 CHIRONOMIDS
BG	S5	3.0	0.22	F1	ZOOPLANKTON
BG	S5	3.3	0.27	F1	ZOOPLANKTON
BG	S5	3.3	0.30	II	ZEBRA MUSSELS, CADDISFLIES
BG	S5	3.5	0.39	II	TERRESTRIAL INSECTS, CHIRONOMIDS
BG	S5	3.5	0.34	F1	MAYFLIES, Z MUSSELS, AMPHIPODS, CHIRONOMIDS
BG	S5	3.9	0.46	F1	MT
BG	G 2-2	4.1	0.70	F1	8 CHIRONOMIDS, 1 CHIRONOMID PUPAE
BG	S3	4.1	0.63	F1	FILAMENTOUS ALGAE, CHIRONOMIDS, ZEBRA MUSSELS
BG	TN1	4.3	0.63	II	ANT
BG	S3	4.4	0.80	II	ZEBRA MUSSELS, CHIRONOMIDS
BG	S3	4.6	0.95	II	TERRESTRIAL INSECTS
BG	S3	4.8	0.95	F1	MT
BG	S3	4.9	1.10	F1	ZEBRA MUSSELS, CHIRONOMIDS
BG	S1	6.2	2.31	M1	MT
BG	S3	6.2	2.44	F5	AMPHIPODS,Z MUSSELS, CHIRONOMIDS, MAYFLIES
BG	S1	6.5	2.62	F2	40 CHIRONOMIDS, CADDISFLIES
BG	G1-2	6.5	2.76	M1	ZOOPLANKTON:DAPHNIA, BOSMINA
BG	G1-2	6.5	2.80	F1	ZOOPLANKTON: DAPHNIA
BG	S1	6.5	2.78	F2	TERRESTRIAL INSECTS, Z MUSSELS, CADDISFLIES
BG	S1	6.6	2.64	F2	CHIRO,Z MUSSELS,AMPHIPODS,MAYFLIES,CADDISFLIES
BG	S1	6.8	3.28	M1	BAETIDAE, CHIRONOMIDS, CADDISFLY,AMPHIPODS, MAYFLIES
BG	S1	6.9	3.21	M2	SPIDER, PLANTS
BG	G1-1	6.9	3.50	F2	PLANTS: CHARA
BG	G1-2	7.1	3.83	F2	ZOOPLANKTON- COPEPIDITES, CHAOBORUS, SNAIL, AMPHIPODS
BG	S6	7.1	3.90	M3	CADDISFLIES, SAND, CHIRONOMIDS
BG	S6	7.2	4.34	M3	MT
BG	G1-2	7.3	NA	F1	CHEWED UP
BG	G 2-1	7.4	3.96	M1	VALLISENERIA
BG	G 2-2	7.7	4.86	F2	PLANTS
BG	G1-2	7.7	NA	F2	CHEWED UP
BG	G1-2	7.7	4.28	M1	VALLISENERIA
BG	TN2	7.8	4.84	F2	VALLISENERIA
BG	G1-1	7.8	4.91	F3	CHIRONOMIDS, PLANTS,CADDISFLIES,AMPHIPODS (MANY)
BG	S5	7.9	5.53	M2	MANY CADDISFLIES

BLUNTNOSE

MINNOW					
BM	S4	1.9	0.03		
COMMON CARP					
CP	G 2-2	25.5	ND		
COMMON SHINER					
CS	S6	6.1	1.66		
CS	S6	6.8	2.01		
CS	S6	6.1	1.60		
GOLDEN SHINER					
GL	S4	4.4	0.44		NA
LARGEMOUTH BASS					
LB	S1	1.7	0.04	II	MAYFLIES, ZOOPLANKTON
LB	S2	1.8	0.04	II	8 CHIRONOMIDS LARVAE, 1 PUPAE
LB	TN1	2.3	0.10	II	XX FISH
LB	S2	2.3	0.08	II	10 AMPHIPODS
LB	S2	2.4	0.09	II	11 AMPHIPODS
LB	S2	2.4	0.09	II	MT
LB	S2	2.6	0.10	II	PLANTS
LB	S1	2.8	0.15	M1	MT
LB	S1	3.0	0.19	II	UNKNOWN FISH
LB	S1	3.2	0.21	II	MT
LB	S1	6.0	1.78	CC	UNKNOWN FISH
LB	S1	8.3	4.33	F1	1 LB65 MM, 1 JD43 MM
LB	S6	9.6	7.50		MT
LB	G1-2	10.0	9.80	M1	YP58,55,52 MM
LB	G1-2	12.0	11.80	F1	MT
LB	G 2-1	12.2	14.00	M1	MT
LB	G1-2	12.3	14.60	F1	MT
PUMPKINSEED					
PS	S4	3.1	0.37	F1	MANY ZEBRA MUSSELS, CHIRONOMIDS
PS	S4	3.5	0.56	II	MANY ZEBRA MUSSELS, CHIRONOMIDS
PS	S4	5.5	2.19	F1	FINGERNAIL CLAMS, CADDISFLIES
PS	S4	5.7	2.08	F1	MAYFLIES, CHIRONOMIDS, ZEBRA MUSSELS,CADDISFLIES
PS	S4	5.7	2.16	II	4 HEXAGENIA, FINGERNAIL CLAMS, CHIRONOMIDS
PS	S4	6.3	3.56	F3	7 CHIRONOMIDS, FINGERNAIL CLAMS
PS	S4	6.4	3.37	F2	HEXAGENIA, FINGERNAIL CLAMS, CADDISFLIES
PS	G 2-1	6.5	3.81	M1	MT
PS	G 2-1	7.6	6.35	M1	MT
ROCK BASS					
RB	TN2	5.0	1.39	F1	YP
RB	TN2	5.1	1.36	F1	MT
RB	G1-2	5.7	NA	F1	CHEWED UP; ATE CADDISFLIES, 4 CHIRONOMIDS
REDEAR SUNFISH					

RE	TN1	9.1	9.40	M1	MT
SMALLMOUTH BASS					
SB	S3	2.0	0.06	II	AMPHIPODS, MAYFLIES
SB	S2	2.2	0.07	II	AMPHIPODS, MAYFLIES
SB	S3	2.4	0.10	II	MT
SB	S1	2.8	0.18	II	50 AMPHIPODS, CERTAPOGONIDAE
SB	S1	3.0	0.17	II	8 BAETIDAE, 25 AMPHIPODS, 5 CHIRONOMIDS
SB	S2	3.0	0.17	II	UNKNOWN FISH
SB	S2	5.1	0.82	II	MT
SB	S4	5.5	1.20	F1	UNKNOWN FISH
SB	S2	6.1	1.55	II	DRAGONFLY
SB	S4	6.3	1.73	F1	1 SV 35 MM
SB	S3	8.7	4.50	F1	2 UNKNOWN MINNOWS
SB	S5	8.8	4.55	F1	MT
SB	G1-2	10.6	8.80	CC	MT
SB	G1-2	11.5	11.60	M1	UNKNOWN FISH
SB	G1-2	11.7	12.40	F5	UNKNOWN FISH
SB	G1-2	13.2	13.90	F5	MT (BLACK FISH)
WHITE BASS					
WB	G 2-2	3.3	5.6	II	MT
WB	G1-2	3.4	0.25	II	ZOOPLANKTON
WB	G 2-2	3.5	6.8	II	CHARA, CADDISFLY CASES
WB	G1-2	3.5	0.24	II	MT
WB	G1-2	3.7	0.34	II	UNKNOWN FISH
WB	G2-1	9.6	7	F2	BG 42 MM
WB	G 2-2	12.0	12	M1	YP 60 MM
WB	G1-2	12.2	12.40	F1	MT
WB	G1-2	13.1	17.00	M1	MT
WB	G2-1	13.4	17	F2	YP 54 MM
WB	G 2-2	13.5	18	F1	MT
WB	G 2-2	13.6	19.1	F2	YP 52, XX 26
WB	G2-1	13.8	18	M1	YP 42,45 MM; CRAYFISH
WB	G2-1	13.8	19.2	F2	YP 52,46;BG 42 MM, BG30,XX48,SV40,JD36,XX35
WB	G1-2	13.9	19.00	F2	MT
WB	G1-1	14.0	20.60	F2	UNKNOWN FISH
WB	G1-2	14.0	19.00	F2	MT
WB	G1-2	14.4	19.50	M1	MT
WB	G1-2	15.2	13.70	F1	MT
WALLEYE					
WL	G 2-2	18.4	29.5	F1	MT
WARMOUTH					
WM	G1-2	5.1	NA	NA	CHEWED UP
WHITE SUCKER					

WS	S4	3.8	0.30		NA
YELLOW PERCH					
YP	S4	2.2	0.05	II	AMPHIPODS, CHIRONOMIDS
YP	S4	2.2	0.06	II	MT
YP	S4	2.2	0.06	II	CHIRONOMIDS, CADDISFLIES
YP	S4	2.4	0.07	II	MT
YP	S4	2.4	0.07	F1	CHIRONOMIDS, CADDISFLIES
YP	G 2-1	3.9	0.34	F1	ZOOPLANKTON - BOSMINA; I CHIRONOMID
YP	S1	4.1	0.37	F1	CHIRONOMIDS, AMPHIPODS
YP	S4	4.1	0.34	F1	AMPHIPODS, CHIRONOMIDS, CADDISFLIES
YP	G1-2	4.1	10.80	II	4 CHIRONOMIDS
YP	S1	4.2	0.39	F1	Z MUSSELS, BAETIDAE, CADDISFLIES, CHIRONOMIDS
YP	S1	4.2	0.45	F1	CADDISFLIES, CHIRONOMIDS
YP	G 2-1	4.3	0.44	F1	MT
YP	G 2-1	4.4	0.44	F1	MT
YP	S1	4.5	0.50	F1	MT
YP	S1	5.6	0.98	F1	CHIRONOMIDS, AMPHIPODS
YP*	S1	5.6	1.00	F1	ZEBRA MUSSELS, SNAILS. *BLACK GRUBS
YP	G1-1	6.1	1.41	F1	10 CHIRONOMIDS,I CHIRONOMID PUPAE
YP	G 2-1	7.2	2.48	F1	MT
YP	G 2-1	7.6	2.75	F1	MT
YP	G1-2	8.1	3.59	F1	MT
YP	G1-1	8.6	3.84	F1	MT
YP	G1-1	8.6	3.99	F1	MT
YP	G 2-2	9.4	4.80	F1	MT

Table 8. List of selected species and their total lengths (mm) from seine hauls. Fish were collected from Columbia Lake, 5 August 2014. 1 mm = 0.039 inch; 50 mm = 2 inches.

Common shiner
134,186,120,120,174

Yellow perch
56,63,58,48,56,56,55,53,94,99,104,85,54,54,96,95,53,62,53,48,54,52,103,52

Brook silversides
87,51,54,49,53,53,45,76,54

Bluntnose minnow
60,74,74,72,78,57,59,45,70,43,75

Spotfin shiner
78,82,65,60,65,54,82,72,73,73,72,72,81,65,69,64,81,68,
55,68,78,50,75,60,51,51,60,68,62,92,57,55,72,71,78,72,
60,58,44,76,78,45,62,65,58,52,64,60,90,55,89,50,51,60,79,70

Bluegill
33,28,32,29

Smallmouth bass 78,68,69,68,77,52,61,68,65,53,64,72,67,66,44,54,51,76,62,68,62,69
56,54,51,57,50,48,46,53,50,71,70

Largemouth bass
71,43,47,53,53,47,61,43

Four other species of sunfish we collected included the warmouth, pumpkinseed, redear sunfish (Picture 9), and rock bass. Green sunfish were reported from earlier studies. We only caught one warmouth, but it was eaten mostly by a turtle so yielded no data (Table 7). Pumpkinseeds were much more abundant, although not as common as bluegills. We collected pumpkinseeds from 3.1 to 7.6 inches (Table 7). Pumpkinseeds are ecologically adapted to eat mollusks and we did observe some fingernail clams and zebra mussels in their stomachs. They mostly ate insects and mollusks as noted. The insects included: chironomids, mayflies (including *Hexagenia*, the large mayfly), and caddisflies. The fact that two pumpkinseeds ate the larval form of the large mayfly *Hexagenia*, is further confirmation that this large food item is present in Columbia Lake, an important finding (Picture 14). Rock bass appear to be uncommon in Columbia Lake, but they are an important predator at large sizes. We collected three fish from 5 to 5.7 inches (Table 7). One was eating a YOY yellow perch, while the other one ate chironomids and caddisflies. We collected one large redear sunfish (Picture 9), which apparently was a stocked fish. It had an empty stomach, but redears are known for eating mollusks, so we would expect them to eat fingernail clams and zebra mussels as well as aquatic insects.

Picture 9. Redear sunfish captured in Columbia Lake, 5 August 2014.

Largemouth bass appear to be quite common in the lake and we collected fish ranging from 1.7 to 12.3 inches (Table 7). We always have difficulty catching larger individuals, since they do not appear in trap nets and do not gill very well. There seems to be great spawning substrate (gravel and sand) both for bluegills, smallmouth and largemouth bass, which build and guard nests during spring-early summer. There was ample evidence of many young-of-the-year (YOY) largemouth bass, since they were common to abundant in the seine hauls (Table 7, 8; Picture 11). YOY bass from 1.7 to 3.2 inches were eating insects, amphipods (*Hyalella* – sometimes called skuds), zooplankton, and unknown fish (Table 7). Insects included chironomids and mayflies. Like bluegills, there is an excellent and diverse benthic fauna present for bass (and bluegills as we have already seen) in the littoral zone, available to promote good growth of the small sizes of largemouth bass.

Largemouth bass from 6 to 12.3 inches switched from eating zooplankton and insects to being predators on fish as they grew older; some of them were cannibalistic as well, consuming some of the abundant YOY bass present in the environment (Table 7). Others ate Johnny darters, YOY yellow perch, and some unknown fishes. Usually largemouth bass do not eat many yellow perch, but there are many in the near shore zone where largemouth bass co occur. This is excellent information, since it indicates that largemouth bass are consuming prey fish and that these prey items are apparently plentiful enough in the lake to sustain the intense predation largemouth bass can exert on prey populations in a lake, which also includes their own young.

Smallmouth bass, which is another probable stocked fish in Columbia Lake, appeared to to be quite common; we collected many YOY in our seine hauls (Table 8, Picture 11). The fish we collected ranged from 2 to 13.2 inches (Table 7). YOY smallmouth bass (2-3 inches) were eating lots of amphipods, mayflies (Baetidae), biting midges (Ceratopogonidae), chironomids, and unknown fish. The larger individuals (5-13.2 inches) were eating dragonflies and fish, including a brook silversides, unknown minnows, and other unknown fish.

Picture 10. Largemouth bass eating a yellow perch. The fish was captured in Columbia Lake, 5 August 2014.

Picture 11. Smallmouth and largemouth bass captured in seine hauls in Columbia Lake, 5 August 2014.

White bass is another apparently stocked fish which is common to abundant in Columbia Lake (Picture 8, 12). We observed them swimming around underwater lights that residents placed in the lake and we collected many in both our gill nets and trap nets as well as small YOY individuals in our seines. Fish we sampled ranged from 3.3 to 15.2 inches. White bass are not members of the sunfish family like largemouth bass, but are members of the Moronidae or true bass and are related to striped bass. They are voracious predators and place a stress on prey fish. YOY white bass (3.3-3.7 inches) ate zooplankton, *Chara*, and caddisflies (Table 7). Larger individuals 9.6-15.2 inches were almost exclusively piscivorous; one ate a crayfish. Among the fishes eaten were: one brook silversides, three bluegills, seven yellow perch, one Johnny darter, and three unknown fish. It is obvious these fish are having a severe impact on the YOY of many species in Columbia Lake, especially yellow perch. This species may be having the most impact on prey fish among the top predators in Columbia Lake.

Picture 12. White bass eating yellow perch and other fish. Fish was captured in Columbia Lake, 5 August 2014.

Walleye is another top predator and some have been apparently stocked into Columbia Lake in the past. We collected only one walleye that was 18.4 inches (Table 7, Picture 15). This fish had an empty stomach. Walleyes are known predators on bottom-dwelling fishes, especially yellow perch, and with their specialized eyes do most of their feeding at night or under low-light conditions. They would be another predator that would target yellow perch, contributing to their low abundance in the lake. The fact that we caught only one in the gill nets we set is an indication that there are not very many residing in the lake. They will contribute to the reduction in yellow perch survival. They apparently survived in Columbia Lake, despite the considerable stresses experienced during summer stratification (fish squeeze (Fig. 9): no dissolved oxygen in bottom waters, while too warm temperatures throughout the water column). Northern pike are also cool-water species like walleyes and also grow poorly and suffer stress during the warmer periods of the year. We have observed them sitting in cool groundwater vents in lakes on the bottom where groundwater enters a lake.

Black crappies 1.9 to 11.2 inches were collected in modest numbers (10) in our sampling efforts. The 1.9-inch young-of-the-year (YOY) fish was eating zooplankton, which is typical for this size of fish (Table 7). In fact sometimes even large black crappies eat zooplankton. Those from 8.4 to 11.2 inches were eating exclusively fish, including YOY bluegill and unknown fish species. This is an important predator in the lake and will help to control the abundant bluegill populations.

Yellow perch YOY were common in two of our four seine hauls in Columbia Lake (Table 7, 8). We kept 23 fish for analyses and of these, 7 large ones came from our gill nets, which are very selective for yellow perch because of their bony opercles. The seven large ones caught in the gill nets ranged from 6 to 9.4 inches. The yellow perch we obtained ranged from 2 to 9.4 inches and the YOY and juveniles (2-4.5 inches) were eating zooplankton, amphipods (fairy shrimp – *Hyallela*), zebra mussels, and insects (mayflies, chironomids, mayflies (Baetidae), and caddisflies) (Table 7). This is a very diverse diet, indicates good supplies of nutritious prey for these young fish, and bodes well for survival of the young. The larger yellow perch (5.6-9.4 inches) had mostly empty stomachs. Those that were eating were consuming many chironomids, amphipods, zebra mussels, and snails. Usually these large fish eat fish, but their residence in the gill net may have compromised diet information. However, it appears that there are not very many large yellow perch. Yellow perch usually are common in the presence of largemouth bass, since their habitats do not overlap precisely; largemouth tend to be shallow, while yellow perch adults anyway, tend to be out deeper. However, one largemouth bass had eaten three YOY yellow perch, which were common in some of the places we seined near shore in Columbia Lake, indicating that there is substantial predation on yellow perch by largemouth bass. We were unable to confirm predation by smallmouth bass (most fish they ate were unable to be identified, suggesting they were minnows, since yellow perch are usually easy to tell in advanced stages of digestion), but expect they too eat some yellow perch. Northern pike, however, are voracious predators on yellow perch, and we see a similar pattern (low abundance) as was observed in Columbia Lake of large adults, in lakes where northern pike are common. However, there appear to be few northern pike in Columbia Lake. Presence of moderate numbers of walleyes also contributes to the diminution of yellow perch as well. The low abundance of large yellow perch is unfortunate, since they are great fish to catch and provide outstanding table fare. There is not much we can do to enhance the survival of yellow perch; stocking them will probably not enhance their chances of survival because of the high mortality rate of young fish due to predators, especially white bass, unless large individuals are stocked. It does suggest that any white perch caught should be removed from the lake to reduce their predation rate.

The panfish community in the lake is comprised of bluegills, warmouth, pumpkinseeds, rock bass, and largemouth bass, all members of the sunfish family. As noted, green sunfish were collected in the past. This complex is the backbone of any warm-water lake fish community and is usually self-sustaining, since the largemouth bass have adequate spawning substrate (gravel and sandy shores) and can usually control the panfish and prevent stunting. However, in Columbia Lake this top predator is accompanied by three other top predators that apparently were stocked into the lake: white bass, walleye, and smallmouth bass. The white bass and smallmouth bass are integral members now of the fish community and naturally reproduce in Columbia Lake. We do not believe walleyes spawn successfully in Columbia Lake. There is a high diversity of prey in the lake including four minnow species, brook silversides, young of bluegill, and yellow perch. Large black crappies, rock bass, and yellow perch, as well as bullheads also eat a considerable amount of your prey resources, so there is an efficient transfer of energy in the food chain leading to these top predators, which are important sport fish in the lake (fishable biomass). There does not seem to be any problems with stunting of bluegills (a problem in some systems) or over exploitation of prey by top predators, with the exception of yellow perch young. In some lakes, we have observed largemouth bass decimating all the minnows, brook silversides, and other prey species. We base this on our seine collections which showed a considerable presence of minnows, bluegill and yellow perch YOY, as well as an abundance of young of large and smallmouth bass.

We also collected four species of cyprinids (minnow family) in our nets. These included the following species: bluntnose minnow, common shiner, spotfin shiner, and the golden shiner. The golden shiner (Picture 13) is a particularly important minnow, since they are omnivorous eating zooplankton, insects, detritus, and algae and grow to large sizes providing excellent prey for the larger predators in the lake, which can often have a limitation on the number of large prey they require as they grow bigger. Common shiners are usually not common in inland lakes and they too are a welcome addition to the fish fauna. They are, like golden shiners, important prey for top predators, since they too grow to large sizes. They can also act as buffer species for yellow perch, since a northern pike would prefer a golden shiner or common shiner to a yellow perch. Minnow species are an excellent addition to the fish fauna, since they utilize resources that none of the other fish consume (algae and detritus and probably some insects) and they add an important forage fish for top predators, such as yellow perch, northern pike, and largemouth bass. These species contribute to the high species diversity we noted in the fish community, which is important for maintaining stability under the different stressors of the environment and varying population swings of the predators in the lake. The analogy to a diverse stock portfolio is apt here.

Naiads of the large mayfly *Hexagenia* (Picture 14) were found in stomachs of pumpkinseed in Columbia Lake during 2014. We also found smaller mayflies from the family Baetidae and caddisflies, which also require high dissolved oxygen conditions to survive. The water quality in the near shore zone must be adequate to support them (high dissolved oxygen), despite the lack of dissolved oxygen in the deep, bottom area during summer stratification. The other requirement that apparently is satisfied for *Hexagenia* is to have soft, thick organic substrate where they can make U-shaped burrows and filter the water of detritus and algae.

There is another common species that is probably confused with minnows in the lake called the brook silversides. They have a 2-year life cycle, grow up to 2-3 inches, and can be seen feeding at the surface, sometimes jumping out of the water when they are chased by predators. Again this is another good member of the fish community adding another prey species to the wide diversity in the lake. We observed them in our seine collections at two of the four sites where we seined.

We also found a few Johnny darters in the diets of largemouth and white bass. We did not capture any in our seine hauls at four stations, so they must be rare in the lake. Darters are miniature members of the perch family (Percidae) and again add to the diversity of fish species in the lake.

Common carp was also present in the lake and appeared to be common, based on our capture of one fish (25.5 in), observations of some during sampling, and reports from fishers and residents (Picture 15). This is a destructive species and should be killed or removed if caught or shot by archers. The predators we documented will probably eat large numbers of their young when they reproduce, but adults should be targeted by humans by any legal means possible to reduce their numbers.

Picture 13. Large golden shiner seined from Columbia Lake, 5 August 2014.

Picture 14. *Hexagenia* (large mayfly) found in the stomachs of fishes collected from Columbia Lake, 5 August 2014.

Mercury in fish

As noted, mercury is a problem in most of Michigan's inland lakes. Most mercury comes to the watersheds of lakes through deposition from the air with most coming from power plants burning coal. The elemental mercury is converted to methyl mercury through bacterial action or in the guts of invertebrates and animals that ingest it. It becomes rapidly bioaccumulated in the food chain, especially in top predators. The older fishes, those that are less fatty, or those high on the food chain will carry the highest levels. Studies we have done in Michigan lakes and studies by the MDNR have shown that large bluegills, largemouth bass, black crappies, northern pike, and walleyes all contain high levels of mercury. The larger the fish the more mercury it contains. This suggests that fishers should consult the Michigan fishing guide for recommendations on consumption, limit their consumption of large individuals, and try to eat the smaller ones. It also suggests that a trophy fishery be established for largemouth bass, and some of the larger individual bluegills in the lake.

Picture 15. Some of the fish species we collected from Columbia Lake, 5 August 2014. Shown are common carp, white bass, yellow perch, and largemouth bass.

Fish Growth

Growth of the fishes we collected was determined by ageing a sample of fish of various sizes using multiple scales and comparing the age of fish from Columbia Lake with Michigan DNR standards (Latta 1958, DNR pamphlet no. 56). We had to use other data for white bass (Phelps et al. 2011) and redear sunfish, since they were not in the MDNR records (Latta 1958). Bluegills are common in Columbia Lake and those we aged (n=28) were growing at or slightly above state mean lengths (Table 9, Fig. 10). The fish we aged ranged from 1.1 to 8.5 inches, so there is a good size range of fish present, suggesting a well balanced population in control by the large numbers of predators in the lake. The scattered aquatic plant beds present in the lake, the good diversity and abundance of benthos, and abundance of large zooplankton are apparently providing food and good habitat for bluegill shelter and sufficient food for adequate growth.

Table 9. Growth of selected fishes collected from Columbia Lake, Newaygo Co., 5 August 2014. Fishes were collected in seines, gill nets, and trap nets, scales removed, aged, and total lengths at various ages compared with Michigan state mean lengths for various fishes at those same ages (see Latta 1958). Shown is the age (years) of the fish, its total length (inches) based on MDNR state of Michigan mean lengths for all species (except redear sunfish and white bass), and the mean length-at-age of Columbia Lake fishes along with sample size (N) in parentheses. Redear sunfish data for comparison came from Arkansas, while white bass data are from Minnesota and South Dakota (Phelps et al. 2011). See Figs. 9-18 for graphical display of these same data. Total number fish aged given above common name.

Age (yr) **Species**	**Len (in)**	**Len (in)**	**Len (in)**	**Len (in)**	**Len (in)**
	MDNR	COLUMBIA	ARKANSAS	S. DAKOTA	MINN
N=1					
REDEAR SUNFISH					
0			2.1		
1			2.8		
2			4.0		
3			4.5		
4			6.3		
5			8.1		
6		9.1(1)	9.2		
7			9.9		
8			10.2		
9			10.2		
10			10.2		
N=14					
WHITE BASS					
0		3.5(5)			5.7
1				3.7	9.6
2				6.6	11.7
3		12.1(2)		9.2	13.3
4		13.3(2)		11.0	14.1
5		14.1(4)		12.3	15.1
6		15.2(1)			
N=12					
BLACK CRAPPIE					
0		1.9(1)			
1					
2	5.9				
3	8				
4	9	8.7(4)			

5	9.9	9.9(3)
5	9.9	10(2)
6	10.7	10.8(1)
7	11.3	11.2(1)
8	11.6	

N=28

BLUEGILL

0	2.1	2.3(7)
1	2.9	3.4(4)
2	4.3	4.5(4)
3	5.5	
4	6.5	6.7(6)
5	7.3	7.3(4)
6	7.8	7.6(3)
7	8	
8	8.5	
9	8.5	
10	9.2	

N=17

LARGEMOUTH BASS

0	3.3	2.5(10)
1	6.1	6(1)
2	8.7	8.3(1)
3	10	9.8(2)
4	12.1	12.2(3)
5	13.7	
6	15.1	
7	16.1	
8	17.7	
9	17.9	

N=18

SMALLMOUTH BASS

0	3.3	2.6(6)
1	5.9	5.8(4)
2	9	9.2(3)
3	11.2	11.4(4)
4	13.3	
5	15	
6	15.3	
7	16.4	
8	16.8	19(1)

N=8

PUMPKINSEED

0	2	
1	2.9	3.3(2)
2	4.1	
3	4.9	
4	5.7	5.5(2)
5	6.2	6.4(3)
6	6.8	7.6(1)
7	7.3	
8	7.8	

N=3

ROCK BASS

0	1.5	
1	3.2	
2	4.3	
3	5.2	5.3(3)
4	6.2	
5	7.3	
6	7.9	
7	8.8	
8	9	
9	9.9	
10	10.5	

N=1

WALLEYE

0	6.6	
1	9.1	
2	12	
3	15.9	
4	17.8	18.4(1)
5	18.9	
6	18.8	
7	18.8	
8	21.4	
9	19.7	
10	22.6	

N=16

YELLOW PERCH

0	3.3	2.3(5)
1	4	4.1(4)
2	5.7	5.6(2)
3	6.8	7.4(2)

4	7.8	8.4(2)
5	8.7	9.4(1)
6	9.7	
7	10.5	
8	11.3	
9	11.7	

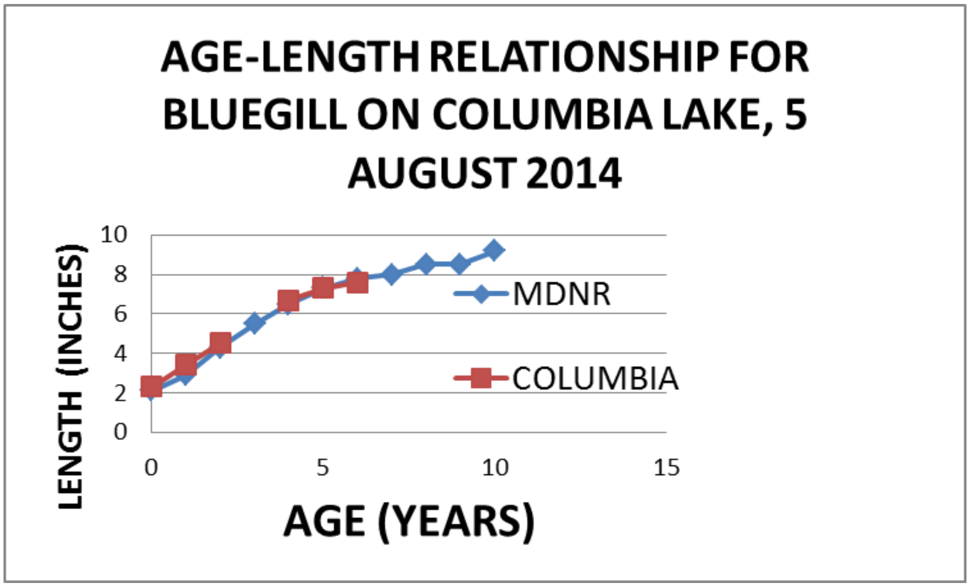

Figure 10. Growth of bluegill in Columbia Lake (red squares) compared with the Michigan state averages (blue diamonds) (see Latta 1958), 5 August 2014. See Table 9 for raw data.

Largemouth bass were also common in Columbia Lake, especially YOY, but we never saw very many very large fish. Fish collected ranged from 1.3 to 18 inches (Table 7); sample size was 17 fish. The age-length relationship for Columbia Lake largemouth bass (Fig. 11, Table 9) was almost identical to the growth rates of Michigan DNR's fish, so there do not appear to be any growth issues with your fish. This species is one of the keystone predators in your lake and responsible for keeping the bluegills in check (but note they also ate yellow perch – Picture 10), so the big fish should be left in the lake to the degree possible to control bluegill stunting. Those foul hooked that will die should of course be kept. The other reason to practice catch and release on large bass, as noted elsewhere, is that large individuals are probably contaminated with mercury and should not be eaten anyway. We concluded the following: first, largemouth bass are generally growing at state averages, and second, based on our findings of large numbers of young-of-the-year fish caught (personal observations; Table 8, Picture 11), we think that largemouth bass are reproducing adequately in the lakes. We explored the near shore zone in the lake, and there definitely was considerable gravel/sand bottom along shore that is good spawning substrate for the sunfish family members, including largemouth bass. In addition, an abundance of small, stunted sunfish can sometimes wreak havoc with bass nests, but this does not seem to be a problem in Columbia Lake.

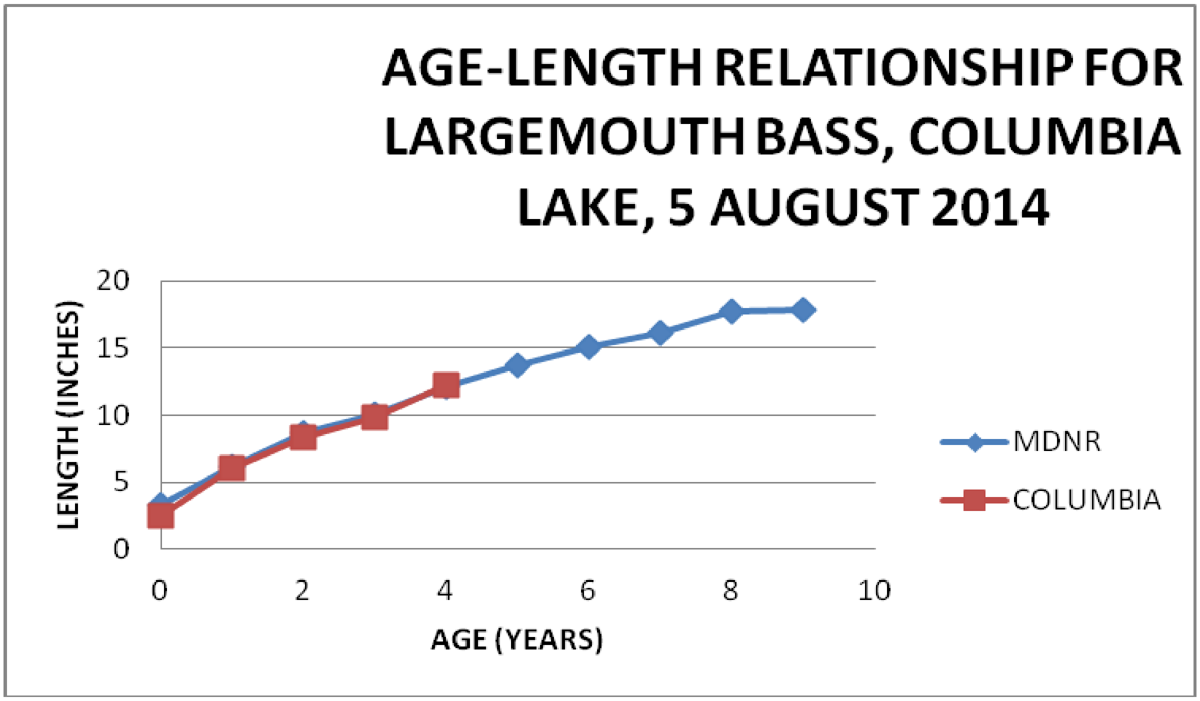

Figure 11. Growth of largemouth bass in Columbia Lake (red squares) compared with Michigan state averages (blue diamonds) (see Latta 1958), 5 August 2014. See Table 9 for raw data.

Large yellow perch seem to be scarce in the lake based on our collections and fishers' reports. Those we did catch ranged from 2 to 6.7 inches (N=16) and seemed to be growing at or above Michigan DNR averages (Table 9, Fig. 12). Yellow perch are important prey fish that are usually not too susceptible to bass predation, and are outstanding table fare for people. Hence, we would like to have seen more of them in the lake. White bass were eating large numbers and along with some largemouth, smallmouth, and rock bass predation and northern pike and walleye predation, could have reduced juvenile yellow perch numbers in the lake. Decreased intra-specific completion can lead to increased growth of remaining individuals, which could account for the increased growth of larger individuals. We do not think stocking yellow perch would contribute much to increasing the population with the abundance of predators currently inhabiting the lake.

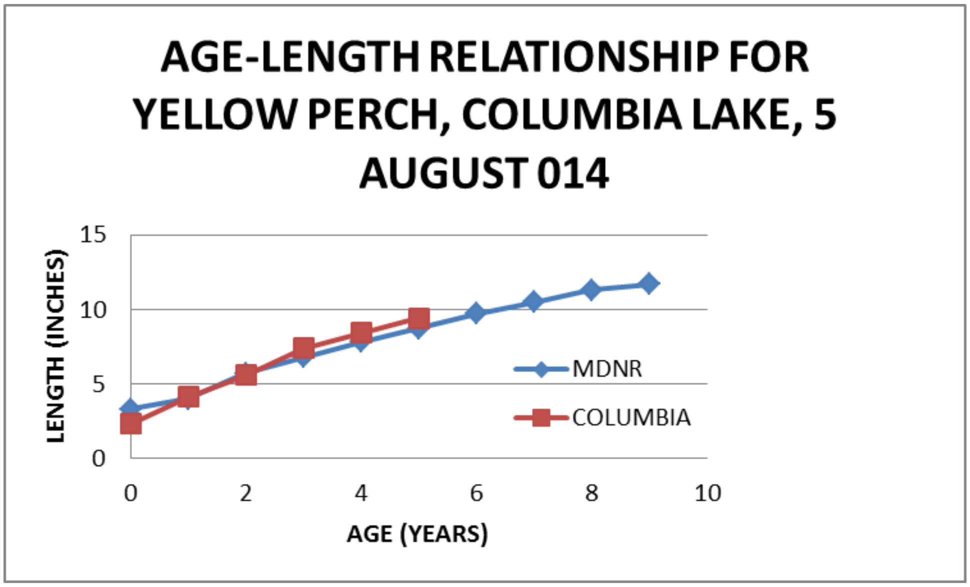

Figure 12. Growth of yellow perch in Columbia Lake (red squares) compared with the Michigan state averages (blue diamonds) (see Latta 1958), 5 August 2014. See Table 9 for raw data.

White bass (see Picture 8, 12) were apparently stocked into Coumbia Lake sometime between 1976 when we found none (Freshwater Physicians 1977) and 2000 when one was collected (Freshwater Physicians 2001). During 2014, they were caught in all our gear (most in gill nets), observed at the lights on the lake at night, and we observed some people catching them. We deduced they might be the most abundant top predator in the lake. Unfortunately, since every lake has a limit to production of fish termed carrying capacity, these fish are supplanting other top predators, such as largemouth bass and northern pike, and probably depressing their survival. In addition, they appear to be having fairly serious predation pressure on prey species, especially yellow perch, decreasing their numbers in Columbia Lake. We examined the scales of 14 white bass from Columbia Lake and since white bass were not in MDNR records we obtained some length-age data from South Dakota and Minnesota for comparison. White bass from Columbia Lake were growing almost exactly the same as fish from Minnesota, but considerably higher than South Dakota fish (Fig. 13, Table 9). We found a few YOY fish, indicating that reproduction has occurred during 2014. Interestingly, we found no 1 or 2 year olds, indicating year class failures for those years or we just did not catch them. We found 6-yr old fish were around 15 inches, while YOY were around 3.5 inches. White bass are well known for their fighting ability, but from what we have heard, they are not very good to eat, unless smoked. They certainly never should have been stocked into the lake. It appears they are currently firmly established in the fish community of the lake and are successfully spawning most years.

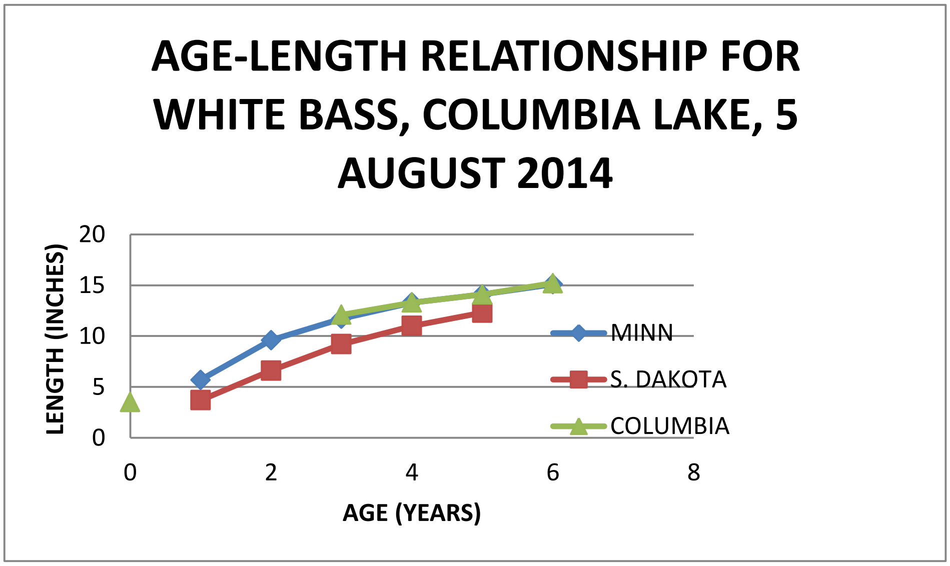

Figure 13. Growth of white bass in Columbia Lake (green triangles) compared with data from Minnesota state averages (blue diamonds), and South Dakota (red squares), 5 August 2014. See Table 9 for raw data.

We analyzed eight pumpkinseeds from collections; these fish ranged from 3.1 to 7.6 inches (Table 9, Fig. 14). They also grew approximately at MDNR state averages for this species.

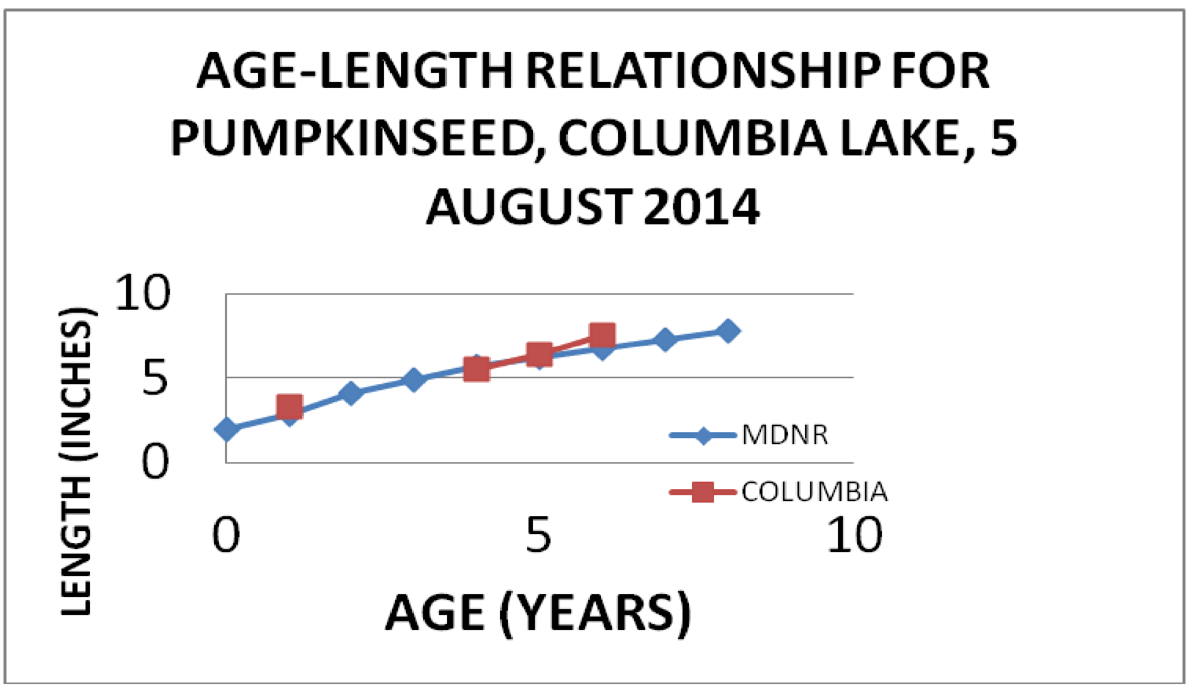

Figure 14. Growth of pumpkinseeds in Columbia Lake (red squares) compared with Michigan state averages (blue diamonds) (see Latta 1958), 5 August 2014. See Table 9 for raw data.

Apparently a number of walleyes have been stocked into Columbia Lake. They appear to be rare, since we caught one during 2014 and one during 2000 (Freshwater Physicians, 2001). As we have previously noted, we believe this is an activity that runs contrary to fish management principles for three reasons: first, walleyes are not native to Columbia Lake and are not expected to reproduce, second, stocking is only acceptable under a number of conditions that must be clearly documented. This includes a situation where the species is native and some catastrophe reduces numbers to very low levels and stocking can assist recovery of the species. In some cases we have seen stunted bluegill populations reduce the number of largemouth bass surviving by eating eggs and larvae from nests. Winterkill can also eliminate susceptible species and re stocking may be the only alternative to restore populations. Third, Columbia Lake is an example of a eutrophic lake which puts the squeeze (see Fig. 9) on cool water species, such as walleye and also northern pike. These species require cool water with high dissolved oxygen. These conditions are met in Columbia Lake during fall, winter, and early spring. However, during summer stratification, water warms in surface waters to unacceptable levels. In addition Columbia Lake is different from most eutrophic lakes, in that it appears to have been destratified, probably due to excess boat traffic and shallowness of the lake. I have seen this situation in other eutrophic, shallow lakes with excessive jet ski and boat traffic. This has resulted in very little, if any cool water on the bottom of the lake, which further detrimentally impacts these cool water species. During this time cool water species are stressed, some probably die, and growth is restricted until other times of the year. There may also be an effect of Goose Creek flow into Columbia Lake. Water is probably oxygenated as it passes through the shallow bay on the south end of the lake and helps replenish the depleted dissolved oxygen on the bottom. However, this is speculation which would require some research to confirm. However, the dissolved oxygen stratification pattern we measured during 2014 was also observed in the studies done in 2000 (Freshwater Physicians 2001) and 1994 (Kevern et al. 1994).

We captured one walleye (18.4 in) (Table 7, Fig. 15). This fish was 4-yr old and appeared to be growing at or slightly above state average levels. These fish could have a depressing effect on yellow perch populations in the lake, since they are important prey of this species.

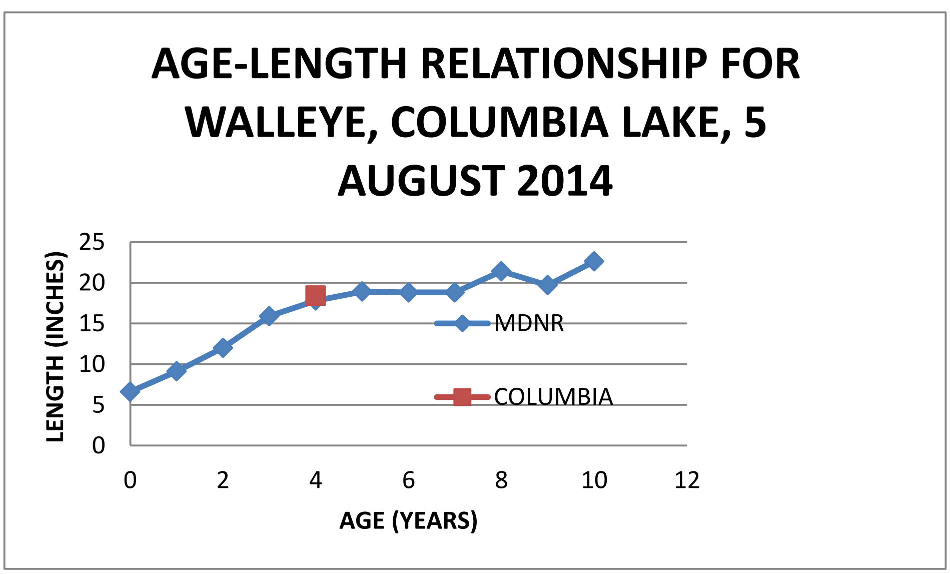

Figure 15. Growth of walleyes in Columbia Lake (red squares) compared with Michigan state averages (blue diamonds) (see Latta 1958), 5 August 2014. See Table 9 for raw data.

We collected three rock bass in Columbia Lake during 2014 (Table 7), while a few were also caught during 2000 studies as well (Freshwater Physicians, 2001). The fish examined during 2014 were growing almost at the same rate as MDNR fish (Fig. 16). These fish are top predators at large sizes (some ate yellow perch) and prefer crayfish, not unlike the small and largemouth basses, which also show a preference for crayfish, if abundant.

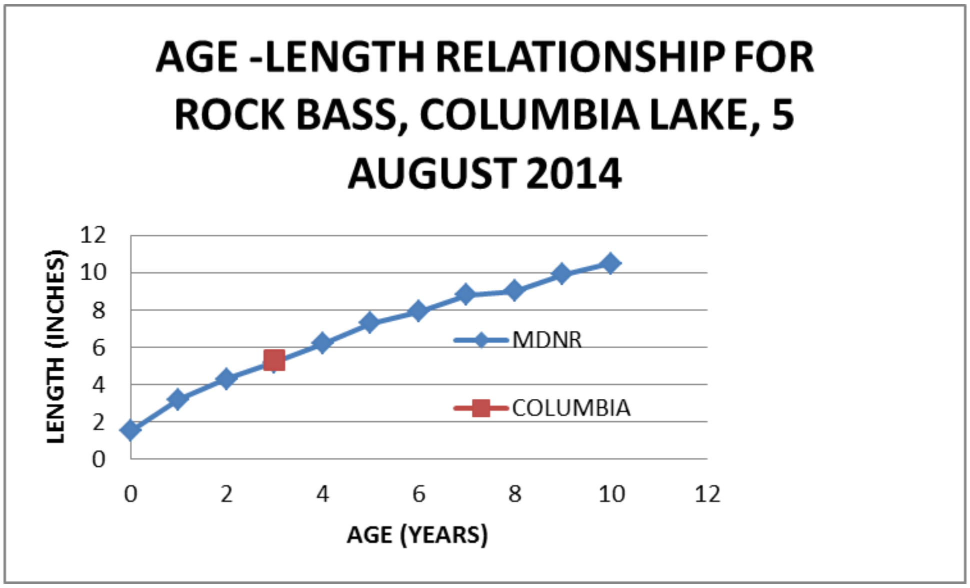

Figure 16. Growth of rock bass in Columbia Lake (red squares) compared with the Michigan state averages (blue diamonds) (see Latta 1958), 5 August 2014. See Table 9 for raw data.

Black crappies (n=12) are somewhere between rare and common in Columbia Lake (Table 7). They are usually found in deeper waters and we do catch them successfully in trap nets set in deep water (along with bullheads). We collected black crappies in a wide range of sizes, including YOY, which provided a good age-length graph (Fig. 17). Fish were growing almost exactly the same as MDNR fish, leading us to conclude they are growing well, provide another fishing opportunity, and are undoubtedly helping to control bluegill populations in the lake, since many were eaten. As reported in the diet section, black crappies were eating zooplankton at small sizes, while juveniles and adults were eating fish, including bluegills.

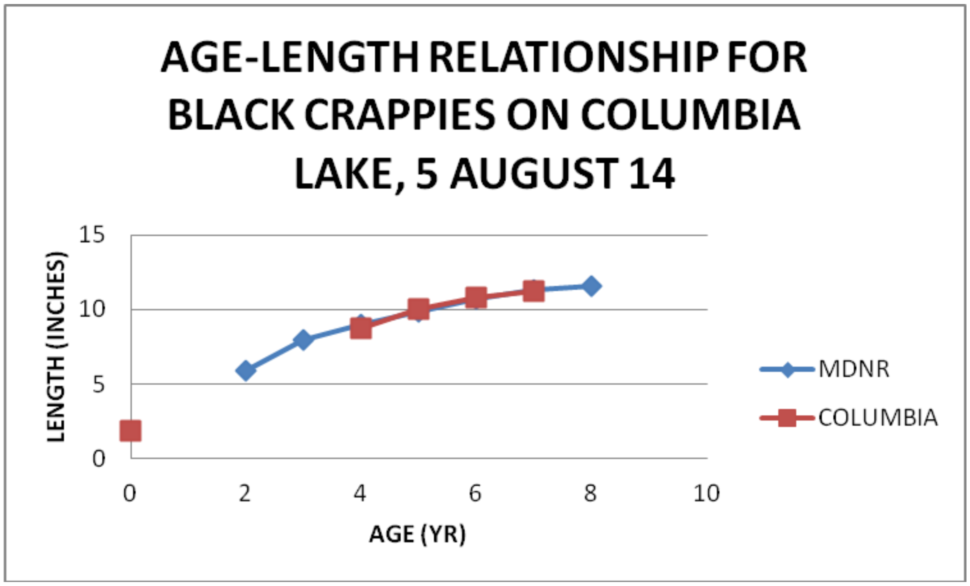

Figure 16. Growth of black crappies in Columbia Lake (red squares) compared with the Michigan state averages (blue diamonds) (see Latta 1958), 5 August 2014. See Table 9 for raw data.

Redear sunfish are not native to Michigan, but have been introduced in the southern part of the state and in some inland lakes. They have molariform teeth, which are pharyngeal teeth that are modified for crushing and ingesting snails and small clams, such as fingernail clams. They also should find zebra mussels acceptable as well. Sometimes, in an effort to reduce snail populations, pumpkinseed and redear sunfish have been stocked in lakes to control swimmers itch. They do grow to large sizes. Obviously some were stocked into Columbia Lake to add to the potpourri of exotic species now in the lake. We only collected one in a trap net and it was a 6-yr old 9.- inch specimen that was growing at similar rates of this species from Arkansas, which suggests they have adequate food supplies (maybe zebra mussels) for growth (Fig. 18). Since they are a southern species, we would have expected them to be growing slower in Michigan.

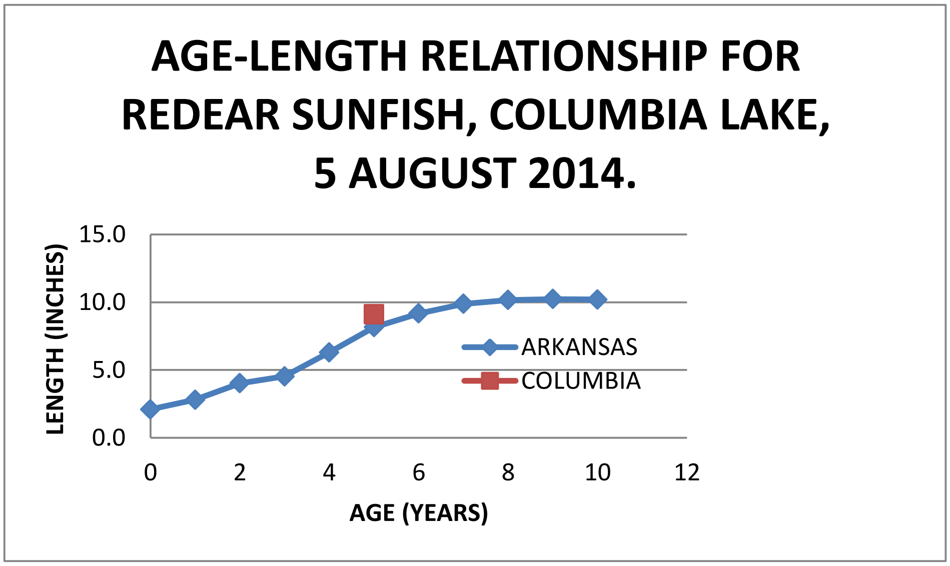

Figure 18. Growth of black redear sunfish in Columbia Lake (red squares) compared with the Arkansas data (blue diamonds), 5 August 2014. See Table 9 for raw data.

We aged 18 smallmouth bass and found YOY to be abundant in our seine hauls. They appeared to be more common than largemouth bass, which were also abundant. This apparently was another species that was stocked into the lake and has now become naturalized in the fish community, reproducing well throughout the lake. Like largemouth bass, they require gravel and sand for building spawning nests; these substrates seem to be common throughout the lake. They appear to be growing at state averages for the first 3 years and the 8-yr old fish was growing above Michigan averages (Fig. 19).

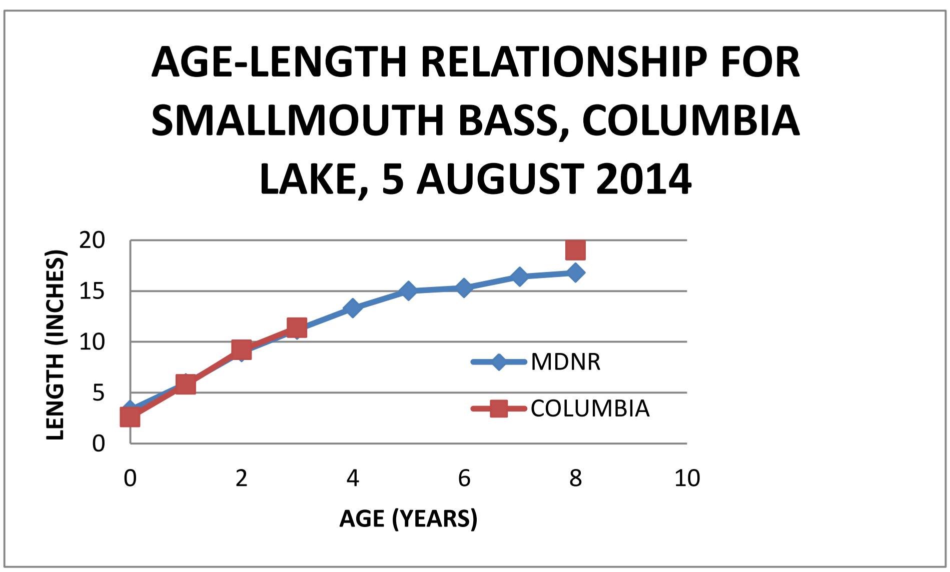

Figure 19. Growth of smallmouth bass in Columbia Lake (red squares) compared with the Michigan state averages (blue diamonds) (see Latta 1958), 5 August 2014. See Table 9 for raw data.

Northern pike are present in Columbia Lake but we caught none in 1976, 2000 (Freshwater Physicians 2001), or 2014. We had reports of at least two caught in one of the canals attached to the lake during summer 2014 (Wanty, T., personal communication). Some attention should be paid to finding out if there are northern pike runs in Goose Creek and whether there are marshes attached which can act as nurseries and in which northern pike are growing and then enter the lake. Like walleyes, northern pike are cool water fishes that are undoubtedly being stressed during the summer stratification period. They are important top predators, since they eat larger and larger prey items as they grow, and other predators do not reach the lengths and gape widths that northern pike do, so they are crucial predators in the lake.

Fish management Recommendations

Fish management strategies emanating from these data include the following. There are currently three exotic fish species in your lake (smallmouth bass, white bass, and walleye that were stocked) and one that probably swam in from other places (common carp). There are also two exotic benthic organisms: zebra mussels and Asiatic clams (Freshwater Physicians 2001) present along with Eurasian milfoil. This indicates a history of people bringing in boats contaminated with plants and benthos and probably some stocking by individuals, a habit that could also bring in Quagga mussels (worse than zebra mussels),VHS (viral hemorrhagic septicemia), and unwanted exotic fish species. There will be more about this later. My point is invasive species like common carp and stocking additional species that are non-native and that did not evolve with the typical fish community in Michigan's eutrophic inland lakes, complicates management recommendations immensely. The concept of carrying capacity comes in here as well. A garden and lake can only produce so much biomass. Higher diversity of native species (biodiversity) promotes greater efficiency of utilization of the food web and so can increase carrying capacity somewhat. However, invasive and some stocked species did not co evolve with the native fish community, and as we have seen time and time again, can destabilize ecosystems where particularly aggressive and fecund species can dominate the populations. In Columbia Lake, I think white bass may be one of those species. They are warm-water species, were present (but not as abundant) in the lake back in 2000, they are aggressive feeders, they school, they have reproduced with young common in our seines, and they are piscivorus at large sizes with our data suggesting they eat a lot of yellow perch, much to the detriment of yellow perch. In addition, their fillets are not as tasty as yellow perch, but I suspect fishers probably like them since they are a fighting fish. There is nothing that we can do about reducing their numbers in the lake, except recommending that any caught be removed from the lake. They are reproducing well now and will continue to produce annual crops of young.

Second, smallmouth bass may be more common than largemouth bass, based on the large number of young we collected compared with largemouth, but we have no way of verifying survival to larger sizes and populations of larger individuals. Never-the-less, smallmouth bass are established, reproducing populations that probably should not have been stocked in the first place, but since they were, they do provide another top predator and sport fish for fishers. They probably have slightly different diet preferences (more crayfish maybe) than largemouth, but probably do compete with them, which probably has reduced the number of largemouth in Columbia Lake as a result. They do probably provide another predator that eats bluegills, helping to control their population.

Third, we collected one walleye in 2000 and one in 2014, suggesting that walleyes are rare in Columbia Lake. They have been stocked in the past but we do not know current stocking practices. Obviously there has been poor survival of this species in the lake, which is partly due to the fish squeeze (Fig. 9) that stresses cool water fish like walleye and northern pike. This stress is somewhat reduced in one respect in Columbia Lake, since the lake appears to be destratified due to boat traffic. This has made the water temperature almost equally warm from surface to bottom and puts a bit more dissolved oxygen in bottom waters than we normally see. However, the fish are still stressed due to the warm water temperatures throughout the water column and low dissolved oxygen on the bottom. As we noted previously, we believe that walleyes should not be stocked in Columbia Lake for several reasons. They are not native, they do not reproduce, water is too warm during summer, they can destabilize the fish community if too many are put in the lake, and they are difficult to catch. In addition, you are playing ecological roulette with stocking, since you could introduce diseases (VHS see below), parasites, or non-indigenous species through stocking of fish, especially if done by non-professionals. We therefore recommend against stocking any more walleyes into Columbia Lake and suggest if fishers want walleyes (they are difficult to catch anyway) they go to Saginaw Bay or Lake Erie where a world-class fishery exists. Never-the-less, I am not opposed to stocking some if there is huge demand, just so there is an awareness of poor survival, probable waste of money, and difficulty in catching them. The cautionary tale I experienced in another lake we studied was the elimination of a cool-water species called lake herring or cisco which co habited the lake with northern pike. Despite my recommendations to the contrary a large number of walleyes were stocked and because of the "squeeze" noted above, the northern pike, walleyes, and ciscos all co occurred in a narrow band of water during summer, apparently resulting in the complete elimination of this prey species, the cisco.

Fourth, northern pike are native to Columbia Lake but appear to be very rare, since we collected none in 2000 or 2014 and only know they are present from reports of fishers. They are native fish, but cool-water fish, so subject to thermal stress during the summer. There are good things and drawbacks to increasing their numbers through stocking. They get bigger than any of the other top predators in the lake and as such will eat some of the larger prey items that currently go uneaten (e.g., white suckers). This would include some of the golden shiners and common shiners we collected, bluegills, and unfortunately yellow perch, a drawback. They are also fun to catch and would help control prey fish populations such as bluegills. They might also eat some of the white bass young, although they prefer soft-rayed species (minnows) over spiny rayed fishes. After looking at Goose Creek physically when we collected the water sample and viewing it on Google earth, the creek and adjacent wetlands, should be excellent spawning sites for northern pike. It would be interesting to know if historically there were more northern pike in the lake and if they ever used the creek for spawning. Considering all the caveats, I believe some consideration should be given to stocking some northern pike in the lake to bolster their populations.

Fifth, we recommend catch and release of the top predators in the lake with the exception of white bass, which should be removed. Both small and largemouth bass, say those > 15 inches, should be released, so they can reproduce and control the prey fish population. It does appear that there is excellent reproduction of small and largemouth bass currently (Table 8, Picture 11). Let's keep it that way. We always encourage people to put back large predators to maintain good fish community balance (in this case with the exception of white bass). In addition, it takes 6 years for a large and smallmouth bass to grow to 15 inches and 5 years for a northern pike to reach 15 inches. It would be a shame to catch these fish only once. Catch and release allows the larger, mature predators to spawn successfully, promotes good growth of bluegills, and prevents fish stunting in the lake, and they are probably contaminated with high concentrations of mercury any way (see M*ercury in Fish* above for a discussion).

Sixth, there was good spawning by the sunfish family, yellow perch, large and smallmouth bass. Hence, because of the favorable substrate (sand and gravel) for sunfish spawning and nest building, there is no need for stocking any of these species.

Lastly, live bait use from outside Columbia Lake (minnows, crayfish) should be discouraged or banned because of the threat of introduction of exotic species (e.g., goldfish) and VHS (viral hemorrhagic septicemia) which killed many muskies and other species in many lakes, including Lake St. Clair. As noted above, any stocking should be done with a guarantee from the fish supply dealer that the fish are VHS-free. Any stocking by individuals should be banned for this very reason: introduction of fish from other water bodies may bring in parasites and diseases, including VHS, which could have a devastating effect on the fish community of Columbia Lake. In conjunction with these recommendations, you also need to be cognizant of the introduction of exotic species from other lakes that are contaminated to Columbia Lake, which has occurred repeatedly in the past. Also the other mode of introduction of exotic species, bringing in boats, gear, and bait from other lakes and rivers, needs to be addressed using drying for long periods or bleach to kill potentially invasive species.

SUMMARY AND HIGHLIGHTS

1. Columbia Lake is an 840-acre, eutrophic lake with two major basins and a maximum depth of 26 ft. It is a dammed lake and takes in considerable amounts of water from Goose Creek in the south. It has a number of small bays and inlets, 16 parks, and is highly developed around the entire lake. The lake has had sewers for 6-7 years now.
2. The limnological conditions in the lake are not typical, since we think the lake is being destratified with excessive boat traffic (see Table 10 for a summary of the status of various parameters characterizing the lake). This had led during summer to similar warm temperatures from the surface to the bottom and a lack of dissolved oxygen (hypoxia or a dead zone) near bottom. This has two consequences: it stresses cool-water fishes such as northern pike and walleye and it may lead to regeneration of nutrients (phosphorus and ammonia) from the bottom sediments (termed internal loading). However, there was no evidence of accumulation of material on the bottom: nitrates, ammonia, and SRP were all at trace concentrations, something we never see in stratified lakes. These observations were consistent with previous data sets in 1976, 1994, and 2000 (there was elevated total phosphorus in 1994 at the bottom- Kevern et al. 2001). Hence it appears that nutrients are constantly being brought up from the bottom decompositional processes and quickly mixed with waters above and taken up by algae and macrophytes. Chlorides were low in 2000 and 2014, ranging around 20-30 mg/L, but they have been increasing from 1976 to 2014 at a rate of about 0.4 mg/L per year. These chronic increases are indicative of input of not only chlorides from the watershed, but also of other deleterious substances, such as nutrients, pesticides and herbicides, and other toxic substances.
3. Excessive nutrients are entering the lake from several sources. The sewer was an excellent option and will help immensely in reducing the input of nutrients. Riparians need to help as well by: eliminating lawn fertilization or greatly curtailing it; only use nitrogen-based products; no leaf burning near the lake or in the watershed; clean up pet

waste and retard waterfowl (do not feed). See Appendix 1 for additional recommendations. The lake board needs to check with their lawn services that service the parks and ensure that they minimally fertilize and use only N-based products.

4. There was a blue-green algae bloom of *Oscillatoria* ongoing during our sampling in summer 2014, while during 1976 there were extensive blooms of three or four different blue-green algae including *Microcystis*, the toxin-producing algae that shutdown Lake Erie water intakes during 2014. This is a further indicator of nutrient enrichment in Columbia Lake, which is detrimental to the ecosystem, causing increased turbidity, degraded water quality which could inhibit swimming, and fish have a difficult time seeing their prey.
5. Zooplankton populations were composed of 15% *Daphnia*, which indicates that fish predation is not excessive and in addition the presence of this species will accelerate the removal of algae from the water column.
6. We found out that there are *Hexagenia*, the large mayfly as well as Baetidae in the lake, which is a bioindicator of good water quality and these organisms are also important fish prey.
7. There are five exotic fish species (common carp, smallmouth bass, walleye, redear sunfish, and white bass), two exotic benthic organisms (zebra mussels *Dreissena polymorpha* and Asian clam *Corbicula*), one macrophyte (Eurasian milfoil and probably *Potomogeton crispus*) now residing in Columbia Lake. As discussed, presence of invasive species can disrupt ecosystems, depress energy transfer between trophic levels, and complicate management efforts. You do not need more exotics, such as VHS and Quagga mussels (a worse relative of zebra mussels). Therefore: A. Suggest a ban on bait (minnows, crayfish) from outside the lake, and B. People need to clean (use bleach or dry for at least a week) any boat, gear, or other equipment that has been in another lake before it is put in Columbia Lake.
8. We collected 19 fish species in 2014, were informed of two more (bullheads and northern pike), so if one combines data from 2000 with these data, there are 25 species in the lake. Ten of these fish were top predators. There were nine members in the sunfish family, including bluegills which are probably the most abundant. There were also three minnow species present. This is moderately good fish species diversity.
9. Northern pike are rare in the lake; we know from reports when the lake was first formed that they were abundant. These are native important predators in the lake and even though they may be stressed during summer, you should encourage their presence in the lake, either by investigating spawning sites (Goose Creek in the spring; other inlets that might be used for spawning). Some may need to be stocked if they are at such low abundance that there are too few present. Catch and release should be practiced for northern pike and large and smallmouth bass to ensure continued spawning success and because the larger individuals probably are full of mercury anyway.
10. Walleyes have been stocked in the lake in the past and we collected them in 1976, 2000, and 2014. Walleyes should not be stocked for the following reasons: A. they are not native, B. they will not spawn in Columbia Lake, C. they are difficult to catch, D. they are stressed by too warm temperatures in summer, and E. there is no compelling, justified fish management reason to stock them, since there is an existing, warm-water fish community that co evolved in the lake, which represents the best species combination of fishes adapted to these environments. Never-the-less, if the board feels

stocking them is appropriate and only the board should make this decision, then fish should be obtained from a certified VHS-free hatchery, stocked during cool water times (spring or fall), and stocked at large sizes (at least 6 inches). Even then, I fear that white bass will decimate them when placed in the lake. Individuals stocking any fish into Columbia Lake risks bringing in disease and parasites and invasive species such as quagga mussels into the lake.

11. Smallmouth and largemouth bass are common in the lake, we saw many YOY indicating excellent reproduction, they are eating acceptable prey, and growing well. They require catch and release and continued monitoring to make sure they continue to do well.
12. White bass were stocked into the lake and appear to be now integrated into the fish community for better or worse. They may be the most abundant predator in the lake, reproducing well, and they are voracious feeders, seemingly decimating juvenile yellow perch and other prey fish in the lake. There is not much one can do about the situation now, except recommend that any caught be removed from the lake.
13. Yellow perch appear to be uncommon in the lake, at least larger individuals. We did catch quite a few YOY in our seine hauls indicating good reproduction, but survival to larger individuals appears to be depressed, probably by predation by white bass and to a lesser extent, other predators such as bass, northern pike, and walleyes. They were eating adequate food and growing well, even faster than state averages at larger sizes. There is not much that can be done except eliminating as many white bass as possible. There appears to be adequate reproduction so stocking more will not improve survival to larger sizes.
14. Bluegills may be the most abundant fish in the lake and they do not appear to be stunted. They were fed on by many predators, especially large and smallmouth bass, which is the classical fish community for eutrophic warm water lakes in Michigan. They were eating typical prey items and growing well. Populations appear to be in balance with predators.
15. There are four minnow species in the lake: common shiner, golden shiner, spotfin shiner, and bluntnose minnows. This is excellent for two reasons: they eat prey items (e.g., algae, detritus) that other fish do not eat and two of them, common and golden shiners, grow to large sizes (up to 10 inches). Hence they provide larger prey items for the larger predators in the lake which sometimes become what is termed gape-limited. This simply means that there are no large prey items for the larger predators to eat, which can limit growth.
16. Lastly, there are common carp in the lake and although we only caught one, indications are that they are common in the lake. This is the only invasive species of fish you currently have and they have become naturalized across Michigan. They can be destructive and increase turbidity which is not good, since water clarity is already low in Columbia Lake. They should be removed whenever captured by hook and line and archers should be encouraged to shoot and spear them anytime, especially during the spawning season.

DISCUSSION AND RECOMMENDATIONS

To summarize, Columbia Lake is a eutrophic lake with a two basins, the deepest being around 26 ft. We tried to summarize the status of various physical, chemical, and biological properties of Columbia Lake above in the **Summary and Highlights** section and in Table 10, which succinctly shows some of the problem areas and issues that need to be addressed for the future benefit of the lake.

Limnologically, Columbia Lake behaves differently than most eutrophic lakes, in that the lake appears to be destrafied during the summer, probably though excessive boat traffic. Consequences of this include: water temperature is similarly warm from surface to the bottom, decomposition products (nitrates, ammonia, phosphorus) are mixed into the water column and provide nutrients for algal and macrophyte growth at a time when both nitrogen and phosphorus are limiting (at trace levels throughout the water column). Warm temperatures stress cool water fishes such as northern pike and walleyes. Hence any additional input of nutrients can accelerate eutrophication effects. Unfortunately, we cannot do much about the buildup of nutrients from the bottom (internal loading). However, riparians play a substantial role and can contribute to the lakes enrichment through lawn fertilization and other activities that bring nutrients into the lake. There may still be septic tank seepage into the ground water, even after 6 years. To reduce the footprint of residents, no lawn fertilization should be done, but if necessary only nitrogen-based fertilizer should be used. No leaf burning, feeding of waterfowl, or washing of vehicles or houses with high phosphate detergents should be done, since these substances will end up in the lake. See Appendix 1 for other suggestions to reduce nutrient input.

There were algae blooms in the past (Freshwater Physicians 1977, Kevern et al. 1994) and we observed one during our sampling on 5 August 2014, which was probably a blue-green alga called *Oscillatoria*. These algae blooms and the infestation of the lake by Eurasian milfoil are manifestations of the nutrient enrichment problem noted above, especially the re-suspension of nutrients from the bottom during summer. The cause needs to be addressed as noted above; Eurasian milfoil has had to be controlled over the years, since it abundant in the lake and can lead to stunting of bluegills if it is not controlled, to say nothing about degrading lake enjoyment experiences.

We collected 19 species of fishes and others, the northern pike and bullheads, avoided being collected but were reported present in the lake. Along with those collected in the past, there are 25 species present in the lake. This is excellent biodiversity, which is analogous to a diverse portfolio- numerous species can protect against upheaval and maintain stability in the ecosystem. We believe the high diversity is due to the high diversity of habitats: varying depths, near shore zone with abundant vegetation, but also some areas of gravel and sand, several inlets and bays, Goose Creek inlet, and the prey food supply, zooplankton, and benthos, appear to be sufficient to feed the diversity of small fishes present, without eliminating *Daphnia* from the zooplankton community. There were ten predators, several species of sunfish, four species of minnows, and some additional species seldom seen, such as brook silversides, longnose gar, lake chubsucker, and Johnny darters.

Walleyes have been stocked into Columbia Lake in the past. Based on our findings, we cannot recommend any further stocking of walleyes into the lake, especially by lake residents who might inadvertently introduce VHS into the lake. We discussed the reasons for this: 1. Walleyes are not native species, 2. The lake has a co evolved fish community that has been in existence for thousands of years and is not out of balance, 3. There is a potential for introduction of VHS with stocked fish, 4. They are difficult to catch, and 5. The fish will be severely stressed during summer due to the "squeeze" of warm surface water throughout the water column (Fig. 9) and forced from the bottom where dissolved oxygen is near zero often during summer stratification. If the board still wants to stock fish, be sure to use a certified VHS-free source, do not stock large numbers, and stock them at large sizes (at least >6 inches) during spring or fall.

Northern pike on the other hand are native, are rare in the lake, and some stocking of this fish is justified, if you want to encourage another predator in the lake. We base this on the rarity of this species and the fact it will prey on larger prey species helping to foster good growth. Some investigation and historical information should be sought about how prevalent northern pike were historically, whether they had spawning runs into Goose Creek, and whether there are impediments to their using this stream as a spawning site.

Smallmouth and largemouth bass are common in the lake, important predators, important sport fishes, and have been spawning successfully based on the large number of YOY we collected. They were eating appropriate prey (bluegills, yellow perch, minnows) and growing well. Catch and release should be practiced for these fishes.

White bass are probably the most common top predator in the lake, are now integrated into the fish community, are spawning very well, eating fish prey, especially yellow perch, and competing with the other native and non-native predators in the lake. We recommend they be removed from the lake as much as possible whenever caught.

Common carp are probably more abundant in the lake, than the one fish we collected would indicate. They are an invasive species that has become integrated into the Columbia Lake fish community. They cause increased turbidity and can eat fish eggs if available, hence they need to be removed by angling, archers, or spearers whenever they are vulnerable.

Lastly, because of the long history of introducing invasive species (Eurasian milfoil, zebra mussels, Asiatic clam) and the authorized and un authorized stocking of non-native species (rainbow trout, white bass, smallmouth bass, redear sunfish, walleye) into Columbia Lake, we are worried about additional invasive species, such as quagga mussels and viral hemorrhagic septicemia (VHS) being introduced into the lake. Hence, we recommend that bait from outside the lake (live fish, crayfish) be banned and that any boats, fishing gear, live wells, SCUBA gear be cleaned via drying or bleach to remove the threat of transmission of exotic species, parasites, and diseases.

SUMMARY OF RECOMMENDATIONS

Recommendations are summarized more concisely below:

1. Nutrient inputs

Nutrients are entering Columbia Lake and being generated and regenerated by hypoxic sediments. They also enter the lake from the following sources:

A. Sediments can generate nutrients near bottom during decomposition processes in winter and summer. Little can be done about this except reducing nutrients from riparians, so less organic material accumulates on the bottom.

B. Runoff, lawn fertilization, and other activities by residents contribute nutrients: Observe suggestions in Appendix 1 – reduce/eliminate lawn fertilization, plant greenbelts, ban/remove pet wastes from lawns, no leaf burning at the lake, reduce impermeable surfaces, etc.

C. Waterfowl, such as Canadian geese need to be discouraged from visiting, nesting, or hanging around the lake eating lawns.

2. Northern Pike

Northern pike are rare, but there are some present in the lake. We recommend, if the board concurs, to stock additional fish into Columbia Lake to assist in population recovery. In addition, efforts need to be made to find out if there are spawning runs into Goose Creek and if not, if there are impediments to successful spawning.

3. Largemouth and Smallmouth Bass

We recommend catch and release for all smallmouth and largemouth bass > 15 inches, unless fish are foul hooked and would die. They help control stunting in sunfish populations and provide an excellent fishery.

4. Yellow Perch

Large yellow perch are not very abundant, but there were quite a few young in the near shore zone. Many top predators fed on juveniles, so not much can be done except to reduce the white bass population.

5. Walleye

Walleye have been stocked into Columbia Lake. Amazingly many have survived, providing a small fishery. We oppose further stocking, because they are not native, they are difficult to catch, they will not spawn, stocking may introduce diseases, and most importantly, they will be severely stressed during summer stratification.

6. White Bass

White bass were stocked into Columbia Lake sometime after 1976, since they were found during 2000 and 2014 studies. This species may be the most abundant top predator in the lake. Since they are voracious feeders especially on yellow perch, have reproduced successfully, and appear to have been integrated into the fish community, nothing much can be done to undo the damage they do in Columbia Lake by reducing the carrying capacity for native species, such as largemouth bass. We recommend that any caught are removed from the lake.

7. Prevent Exotic Species from Entering Columbia Lake

Prevent exotic and un-authorized stocked species, such as Eurasian milfoil, zebra mussels, Asiatic clams, common carp, smallmouth bass, white bass, redear sunfish, and walleye, which have already been introduced, from entering the lake. These would include quagga mussels and VHS. Consider banning bait from outside the lake. Fishers and skiers need to dry out boats and gear or treat them with bleach to eliminate exotic species, diseases, and parasites.

Table 10. A compilation of the various physical, chemical, and biological measures for Columbia Lake and a qualitative assessment (good, bad, no problem) in general. + = positive, 0 = as expected, - = negative. "See guidelines" refers to Appendix 1 – guidelines for lake residents to reduce nutrient input into the lake. C @ R = catch and release, DO=dissolved oxygen.

Condition Documented	Qualitative assessment	Problem Potential	Action to Take
Physical			
Water Clarity	-	Moderate turbidity	Reduce nutrients
Water Depth	0	Sediment buildup	Reduce nutrients
Water Temp.	-	Warms up in summer	Moderate boat traffic?
Sediments	0	Gravel, sandy, organic	None
Chemical			
pH	0	None	None
Dissolved oxygen	-	Reduced DO on bottom	Monitor, reduce nutrients
Chlorides	-/+	Runoff of toxic material	Greenbelts
Nitrates	0/-	Buildup in lake bottom	See Guidelines; reduce N&P
Ammonia	0/-	Buildup on bottom	See Guidelines; reduce N
SRPhosphorus	0/-	Buildup on bottom	See Guidelines; reduce P
Hydrogen sulfide	+	Not present in August	Monitor

Biological

Algae	-	Blue-green algal blooms; turbidity	Reduce nutrients
Macrophytes	-	Eurasian milfoil	Monitor; Continue treatment
Zooplankton	+	*Daphnia* present	None
Benthos	+	*Hexagenia* present	None
Fish			
Largemouth bass	+	Plenty YOY; few big adults	C @ R
Bluegill	+	Adequate	Maintain predator balance
Yellow perch	-	Few large adults seen	Reduce white bass
Minnows	+	Abundant	Monitor
Northern pike	-	Rare	Stock
Walleye	-	Rare, non native	No more stocking
White bass	-	Abundant, eating yellow perch	Reduce thru angling

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APPENDIX

Appendix 1. Guidelines for Lake Dwellers; some may not apply.

1. DROP THE USE OF "HIGH PHOSPHATE' DETERGENTS. Use low phosphate detergents or switch back to soft water & soap. Nutrients, including phosphates, are the chief cause of accelerated aging of lakes and result in algae and aquatic plant growth.

2. USE LESS DISWASHER DETERGENT THAN RECOMMENDED (TRY HALF). Experiment with using less laundry detergent.

3. STOP FERTILIZING, especially near the lake. Do not use fertilizers with any phosphate in them; use only a nitrogen-based fertilizer. In other areas use as little liquid fertilizer as possible; instead use the granular or pellet inorganic type. Do not burn leaves near the lake.

4. STOP USING PERSISTENT PESTICIDES, ESPECIALLY DDT, CHLORDANE, AND LINDANE. Some of these are now banned because of their detrimental effects on wildlife. Insect spraying near lakes should not be done, or at best with great caution, giving wind direction and approved pesticides first consideration.

5. PUT IN SEWERS IF POSSIBLE. During heavy rainfall with ground saturated with water, sewage will overflow the surface of the soil and into the lake or into the ground water and then into the lake.

7. LEAVE THE SHORELINE IN ITS NATURAL STATE; PLANT GREEN BELTS. Do not fertilize lawns down to the water's edge. The natural vegetation will help to prevent erosion, remove some nutrients from runoff, and be less expensive to maintain. Greenbelts should be put in to retard runoff directly to the lake.

8. CONTROL EROSION. Plant vegetation immediately after construction and guard against any debris from the construction reaching the lake.

9. DO NOT IRRIGATE WITH LAKE WATER WHEN THE WATER LEVEL IS LOW OR IN THE DAYTIME WHEN EVAPORATION IS HIGHEST.

10. STOP LITTER. Litter on ice in winter will end up in the water or on the beach in the spring. Remove debris from your area of the lake.

11. CONSULT THE DEPT OF NATURAL RESOURCES BEFORE APPLYING CHEMICAL WEED KILLERS OR HERBICIDES. This is mandatory for all lakes, private and public.

12. DO NOT FEED THE GEESE. Goose droppings are rich in nutrients and bacteria.

From: Inland Lakes Reference Handbook, Inland Lakes Shoreline Project, Huron River Watershed Council.