Picture 1. Hess Lake, Newago County, 19 August 2019

A FISHERIES, ZOOPLANKTON, AND WATER QUALITY SURVEY OF HESS LAKE, 2019 WITH RECOMMENDATIONS FOR SHORT AND LONG TERM MANAGEMENT

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INTRODUCTION

We were asked to perform an ecological study of Hess Lake located in Newaygo County north of Grant, MI and south of Newago, MI to develop short-term and long-term management plans for the lake. We conducted a study of the water quality, algae, zooplankton, and fish populations during July and August 2019. These data will provide a rich background dataset for 2019 and benchmarks from which to assess any ecological changes to the lake in the future to go along with a wide array of previous studies of the lake limnology and fishery conducted by many entities. We drew on these datasets to provide a historical record of changes that have occurred to the lake ecosystem. We measured the dissolved oxygen and temperature profile and obtained nutrient samples in early July and did more extensive sampling during late August. Zooplankton samples were also obtained to document whether their populations were healthy, which components were eaten by fishes, and whether the zooplankton species diversity may have been disrupted by the ecological changes wrought by nutrient enrichment, especially low water clarity and blue-green algae blooms, which zooplankton do not eat. This report will be organized around each food web component and water quality parameter and compared with any existing prior data sets if available to detect any substantial changes that may have occurred. We relied heavily on previous MDNR/IFR reports, studies conducted by Edmonds Engineering Company and Fishbeck, Thompson, Carr, and Huber. In addition, we thank Tony Groves for providing Progressive Engineering datasets for comparison.

We learned that Hess Lake has undergone a dramatic number of changes to the lake's food web with the most notable being the switch from being dominated by macrophytes to one being dominated by algae. Many entities have grappled with identifying the changes that have induced these shifts and the many rippling effects on water quality, the fishery, water transparency, algae, and aquatic plants. There are several major factors that have been implicated in the complex changes that have occurred. First, the lake is shallow and large (755 acres) and has a long fetch which allows predominant west winds to destratify the lake and stir up the sediments, resulting in an almost continuous release of nutrients from the bottom. The large number of outboard motor craft on the lake and common carp contribute substantially to this problem. Second, Wheeler Creek has been identified as a major contributor of sediment and nutrients (phosphorus and nitrates) to the lake, especially in spring. Wheeler drain used to drain the lake to the south, but developers redirected the drain north into the lake to drain marsh and other wetlands. Now it drains extensive agricultural lands, which are fertilized and often accumulate water saturated with fertilizer, which is then drained into Wheeler Creek and then into Hess Lake. This source has been identified as a substantial component of nutrients entering Hess Lake. Third, there is an abundant population of common carp in the lake, which are well known to disturb sediments, root up plants, and increase turbidity in lakes. Fourth, the lake used to have an abundant population of aquatic plants in the lake prior to the early 1980s. Complaints from residents, who could not get their boats out easily, resulted in a macrophyte control program including both harvesting and treatment with herbicides. This program resulted in the decimation of macrophytes, which predictably resulted in algae dominating the lake's plant balance. Once turbidity increased to the point of no return, algae dominated and utilized the nutrients leaching in from septic tanks, those stirred up by boats, carp, wind, and those coming in from Wheeler Drain and other drains around the lake. These algae were dominated by the worst group of algae: the blue-greens, which are inedible, produce toxins, and reduce water clarity. This has resulted in them dominating the water column through most of the summer. Depressed water transparency, diminishment of the more favorable algal groups (the diatoms), which are optimal food for zooplankton and some benthic organisms, and these algae along with dead macrophytes, upon decomposition, accumulated on the bottom in a sort of primal green, soup-like layer on the bottom of the lake, which is easily stirred up by wind- and boat traffic - induced currents, re-distributing the nutrients into the water column. These forces all combined to provide a situation in 2019 that has residents concerned with the poor fishery, blue-green algal blooms, which reduce swimming opportunities, and high turbidity caused by wind, common carp increasing turbidity in shallow water during spawning, and watercraft.

Hess Lake is a hyper-eutrophic, shallow lake with a large, mostly shallow, littoral zone, with three major basins, which are around 15-20- ft deep now even though the deepest one was listed as 29 ft during 1955. It is part of a two-lake chain composed of Hess and Brooks lakes. Water runs from Hess Lake into Brooks Lake, thence into Brooks Creek leading into the Muskegon River and eventually Lake Michigan. There are six drains/inlets and one outlet in the NE end of the lake. Hess Lake is a hard water lake. Houses are all on septic systems. There are a few areas around the lake that have patches of lily pads; otherwise, we saw very few dense beds of macrophytes. Some areas we examined and seined were thick with sediment (up to 2 ft), while a few were sandy (by the public access). It was difficult to find an area we could seine, since a considerable amount of the shoreline is hardened with riprap and sheet piling.

The lake is about 755 acres. There are a large number of sport fishers on the lake. Our dissolved oxygen data and that of Progressive Engineering (2018) showed that sometimes the major deep basins near bottom go anoxic (no dissolved oxygen) during summer stratification when the lake is calm. Unfortunately, anoxia will stress fish and unfortunately release the barbarian at the gate: chemical conditions (anoxia) that favor the release of large quantities of phosphorus and nitrogen from bottom sediments (internal loading) that will further fertilize the lake and cause it to shift towards being more productive (more plants and algae), a trend noted by many entities studying the lake and confirmed by our sampling during 2019. This internal loading could be one of the major source of nutrients to Hess Lake along with the Wheeler Drain, septic tank seepage into groundwater, and that contributed by riparians through lawn fertilization, runoff of nutrient-laden water, erosion, and inappropriate disposal or burning of leaves in the watershed and other organic material (see Appendix 1). It should also be noted, that Hess Lake is different from most stratified eutrophic lakes, in that the lake is so shallow, that it becomes de-stratified during wind events and excessive boating activity. This causes the accumulated products of decomposition that are usually released only during the fall overturn (see methods) to be released during summer. Normally, during summer most eutrophic lakes become phosphorus- and nitrogen-limited due to plant activity taking up these nutrients to grow. The decomposition products in these lakes are not released during the time when nutrients are lowest, leading to reduced plant growth. Hess Lake is very different, since it leaks these nutrients during the summer stratification period.

Our approach in this report was to document the status of the various components of the study, discuss previous datasets for each parameter, then present the 2019 data with a comparison with the prior datasets to detect changes, identify problem areas, and propose solutions.

HISTORY

We drew heavily on several datasets provided by Edmonds Engineering, Fishbeck, Thompson, Carr, and Huber, Progressive Engineering, and the Michigan Fish Commission, DNR, and Institute for Fishery Research to document current conditions and compare them with historical datasets to detect substantial changes to the ecosystem. These datasets were also summarized by Newaygo County (Newaygo County, 2011). These reports provide excellent background data from which to measure changes that may have occurred over the past and will help us focus on problem areas and generate manageable solutions for improving the health of Hess Lake. These studies/communications will be summarized here to provide background data.

1944: Westerman of the Michigan Fish Division noted that 349 walleyes and 728 smallmouth bass were stocked into Hess Lake. One resident complained about too many billfish, which we take to mean longnose gar. We never caught any during our sampling in 2019.

1949: There was a meeting of several officials that were concerned about the Wheeler Drain. Some resident requested that the drain's sediment accumulation be addressed. It was noted in the record that the creek actually drained Hess Lake to the south and it was reversed so as to drain marshes and wetlands for agricultural purposes and now runs into Hess Lake.

1950: Newaygo County (2011) states that the area was logged and developed, which resulted in a period from 1950 to 1970 of declining health in the lake.

1953: Mr. Crowe of the Michigan Department of Conservation instituted special regulations based on a 1947 study that found fish were abundant but stunted in Hess Lake. It was deemed legal to catch fish throughout the year; fish needed to be > 6 inches with a limit of 25. There was no limit on smaller panfish. This referred to: yellow perch, rock bass, black crappie and was in effect from 1949 to1953. There was also a report (no. 1306 of the Institute for Fishery Research –Levardsen 1951) that studied the macrophytes in Hess Lake. He reported that Hess Lake was the "weediest" he had ever seen. The entire lake was covered with macrophytes. The most-dense stands were out in front of the Wheeler Drain and were mostly the large-leafed pondweed *Potamogeton amplifolius* and milfoil *Myriophyllum*. Offshore there were extensive mats of *Polygonum*. There were also dense beds of coontail *Ceratophyllum* found on the west end and they were floating on the surface and rotting. This appeared to result in a fish kill. There was a creel census done from 1936 to 1952 with the following species noted in fishers' creels: largemouth bass, bluegill, pumpkinseed, black crappie, yellow perch, walleye, and northern pike. Interestingly, walleyes apparently were surviving in Hess Lake. In 1953, C. Norden noted that there was a "weed puller" being used or tried out on the lake to reduce the amount of vegetation in nearshore areas. He further noted, that Hess Lake was productive, but fish still seemed stunted. He attributed the stunting to the abundance and density of aquatic macrophytes. He strongly noted that no walleyes should be stocked in the lake again.

1955: Clarence Taube of Michigan Fish Division, commented on the 1953 fish study and noted that bluegill and black crappie were growing below state averages and that pumpkinseeds were growing at average rates.

1956: Apparently there was still a problem with too abundant macrophyte growth in Hess Lake, since Ellen Aquatic Week Control Service used sodium arsenite (550 gallons) to spray on the lake to control *Potamogeton* spp., eel grass *Valliseneria*, and milfoil. Plants were deemed thick.

1958: A resident of Hess Lake requested a permit to build and run a northern pike marsh to improve survival of young of this species. A permit was also requested for algae and macrophyte control. Macrophytes were still abundant. They wanted to control pickerelweed *Pontederia*, water lily, bladderwort *Hydrodicton*, and milfoil. Most of these are native species. Some fish growth data were provided by P. Laarman IFR from a collection on 6 May 1958.

1960: A permit was requested from Cooper of Michigan Fish Division to treat macrophytes with Kuron and 2,4-D.

1965: Legal lake level of 763 ft established for the lake.

1969: A fish survey was done on Hess Lake by IFR, Michigan Fish Division. They found there was a substantial common carp population in Hess and Brooks lakes, that the yellow perch and panfish were stunted. They proposed to rotenone the two lakes with the state bearing the costs. By September, a cadre of lake residents protested, hired a lawyer, and the DNR dropped the proposal.

1970: Frykberg did a study in 1970 that documented 384 riparians on the lake and that the large number of water craft they deployed on the lake resulted in re-suspension of sediments.

1981: An article in the Fremont Times discussed a study by Edmonds Engineering that found that phosphorus was a critical component of the problems in Hess Lake and that there were two blue-green algae genera found in the lake. Apparently, the lake was beginning or had shifted from macrophyte dominated to algae dominated by this time. Progressive Engineering was also working on the lake preparing a report to bring sewers to the lake. This study was funded by a 1-year special assessment. Sewers were not adopted.

1982: There was a lot of activity during 1982. Edmonds Engineering delivered a report on the lake and it was discussed by a group of officials (stakeholders, MDNR, lake board, etc.) working on the lake. The discussion focused on two recommendations made: a bypass taking Wheeler Drain around Hess Lake into Brooks Creek and dredging Hess Lake (cost 7 million). Discussion continued on the high turbidity in Hess Lake, which was attributed to sediments from Wheeler Drain, common carp, wind fetch, and waves generated by boat activity. They noted there was constant input of nutrients from bottom sediments which were being recycled whenever such events occurred. They also noted that if the now algae-dominated system were to revert back with more transparency, that the macrophytes would return and generate dense beds of plants. Their recommendations focused on Wheeler Drain and included: 1. Improve best management practices in the Wheeler Drain watershed, 2. Control erosion along the drain, and 3. Construct settling basins along the drain to collect sediments before they entered Hess Lake.

The Edmonds study also presented data on algae stating phytoplankton counts were 2-4 x 10^6 μm^3/mL, which is considered eutrophic according to published literature. (Note, our 2019 data are similar at: 2.9-3.5 μm^3/mL – Table 3, showing not much change over 37 years!). Blue-green algae were present from June to September. Chlorophyll a (surrogate for algae) data for September 1974 and April 1980 (from EPA STORET data) were respectively 7.1 and 17 ug/L. These are very high values and indicate a severely nutrient-enriched system. A study by Frykberg in 1972 concluded that boat use was responsible for the declining Secchi disk readings along with common carp and wind events that stirred up sediments from the bottom fueling blue-green algae blooms depressing water transparency. He further concluded that nutrient input was autochthonous (generated within the lake by decomposing algae and macrophytes) rather than outside the lake (allochthonous). Sampling the sediments in the deep basins showed that there was a layer of material thought to be dead algae that was unconsolidated and easily re-distributed into upper layers releasing nutrients fueling further algal growth. Deeper down, these sediments were gray indicating reducing (no dissolved oxygen) conditions. The algae were dominated by blue-greens the entire summer season. The dominants were: *Microcystis* (the species that caused the shutdown of the Toledo, Ohio water intakes in Lake Erie and the dominant species in our July and August 2019 study – Table 4) and *Anabaena*. Both species can produce toxins that can and have killed cattle and dogs and have made humans sick by ingesting water while swimming. The Edmonds study (1982) recorded Secchi disk readings of 2.5 ft, similar to what our 2019 study showed. They attributed it to “green turbidity”, algae in the water fueled by re-cycled sediments and nutrients from the bottom. Brian Kroll of Edmonds Engineering wrote that the low zooplankton density was due to the switch to blue-green algae which are inedible by zooplankters. They prefer diatoms, which were rare in the lake (not during 2019). The MDNR studies of fish growth showed poor growth and stunting and an abundance of small fishes, which would further reduce zooplankton abundance, since they feed on these organisms at small sizes. He found benthos (aquatic insects, clams, mayflies, chironomids) to be depauperate. This was also expected from the unconsolidated sediments on the bottom and the poor food supply (blue-green algae). During June of 1981 there was a severe *Microcystis* bloom and subsequently a fish kill. A severe bloom of *Anabaena* was also noted during 1976 when a Secchi disk reading of zero was recorded and there was a 5-cm (2-inch) thick mat of algae on the surface of the lake. They also calculated that that at the current rate of sedimentation of 1 inch/year that the lake would fill in in 72 years. Certainly, that is occurring since the map showed the site where we sampled was supposed to be 29 feet, but we only found 20 ft, if that. The authors speculated that eventually that macrophytes will eventually dominate again, accelerating the rate of organic matter production and sedimentation, since macrophytes are much more difficult to decompose. Next developed a discussion of the importance of phosphorus in the system. There is way too much coming in and generated in the lake proper. The analogy to Lake Erie was made. Lake Erie was declared dead in the 1960s, but public will was expressed and sewage treatment plants were upgraded not only in Lake Erie, but in the other lakes as well. The result was a return to more balanced conditions and even the return of dissolved oxygen to the dead zone as well as the resurgence of the mayfly *Hexagenia*, an ikon of good water quality conditions. In Hess Lake too much phosphorus has fueled algae growth, which die and sink to the bottom decomposing as sediment. Light penetration is reduced causing a cascade of events. Blue-green algae depress the food web, causing a decline in zooplankton and benthos, which fosters stunting in small panfish. Even dredging will not solve the problem, it will help, but there will still be excessive phosphorus loading, blue-green algae blooms, and common carp will not be seriously affected. Hess Lake was mesotrophic prior European arrival based on their studies. They project that an 800 kg/yr decline in P input is required to see changes; that is 40% of the 1982 loading into the lake. If P can be reduced, it will foster optimal algae (diatoms and green algae), increase zooplankton densities and improve *Daphnia* numbers, and hence fish. They noted that the bypass of Wheeler Drain flow around Hess Lake would eliminate 800 kg/yr of P. However, even this diversion would increase Secchi disk readings by only 1 to 2 ft; there would be little effects on plants. They also suggested dredging of the lake and the removal of 3.5 million cubic yards of material.

Macrophyte harvesting began as the first effort to control plants in the lake this year. Over 900 tons were removed.

1985: The SCS (Soil Conservations Service) identified erosion as a problem along Wheeler Drain. The harvester harvested 330 tons from the lake. Chemical treatment also began to control macrophytes.

1986: A sediment basin was constructed on Wheeler Drain. Over 200 tons of macrophytes were harvested and chemical treatment continued with some success at reducing Eurasian milfoil.

1987: Wheeler Drain was stabilized with riprap and seeding of the banks. Over 112 tons of macrophytes were harvested and 125 acres of macrophytes were controlled with chemicals.

1990: Wade Trim did a study on the lake and recommended sewers for Hess and Brook lakes and dredging (30% of the area of both lakes) to 15 feet. About 200 tons of macrophytes were harvested, while 125 acres were treated chemically.

1991: Richard O'Neal, MDNR sent a letter to D. Kenega of the Inland Lakes Unit about a short survey he conducted in July and September. He electroshocked and noted there were very few fish in the open waters and the only large fish he caught were largemouth bass near patches of lily pads. He concluded that the lake had switched from macrophyte to algae dominated and that the fishery was in decline. He noted the lake fish community was stable for 40 years (1950-1990) and was only recently declining. He attributed the decline to overharvesting of aquatic plants, destroying critical fish habitat. Management has shifted from protecting fish habitat to favoring boat activity with a concomitant rise of algae as a result as freed nutrients were utilized by algae. Turbidity was also implicated, and he attributed increased turbidity to the lack of macrophytes, excessive watercraft activity, and the switch to algae fueled by decaying macrophytes. He also examined a plant harvester on the lake and noted only waterweeds *Elodea* on the harvester. *Elodea* is a native species. It should also be noted that a resident got a permit to stock fathead minnows, yellow perch, hybrid bluegills, and northern pike. Dr. Ron Waybrant of Fishbeck, Thompson, Carr, and Huber was brought in to manage the macrophyte situation.

1992: There is a letter from a Hess Lake resident that quotes Waybrant's study concluding the dissolved oxygen levels were good, that the lake was great, and that fishing was good.

1993: Waybrandt did a vegetation survey in spring 1993 and found: milfoil, pondweeds, *Chara* (an alga), cattails, pickerelweed *Pontederia*, willow, loosestrife, Eurasian milfoil, curly-leaf pondweed, and *Elodea.* Around 50 acres of macrophytes were harvested, 50 acres of Eurasian milfoil were treated with 2,4-D, and 25 acres of pondweed were also treated during 1993. The dissolved oxygen data showed that at 9 ft, dissolved oxygen was 4-5 mg/L on bottom and 9 mg/L at the surface. At 17 ft it was 9 mg/L at the surface and 4 mg/L near bottom, and at 26 ft, it was 7 mg/L at the surface and 3 mg/L near bottom. An interesting point is that 26 ft of depth was recorded at this time, which contrasts with our 20 ft found during 2019.

1994: A permit was granted to Hess Lake to treat Eurasian milfoil and curly-leaf pondweed. A vegetation map of the lake was produced by Waybrant. Some stocking of fish occurred.

1996: The harvester was dry docked and plant control was exclusively by chemicals. It was noted that there were 383 riparian homes on the lake and that compared to earlier, boats and skidoos were larger and the impact on re-suspending sediments was much larger than earlier.

1997: A extensive fish contaminant study was conducted on Hess Lake during 1997 by R. Day of MDNR. For mercury, most small fish were below the target level of 0.5 mg/g (ppm) including common carp, except for one 20-inch largemouth bass. For PCBs, 4 of 10 common carp exceeded the trigger level for PCBs. This is a common pattern in most Michigan lakes, small fish are under limits for mercury, while large non-fatty fish such as northern pike, largemouth bass, black crappies, and walleyes usually exceed Michigan standards. In contrast, PCBs accumulate in fatty fish, such as common carp and now channel catfish. Read the MDNR guide for fishers on how much fish and who should consume them for guidance. Macrophyte treatment continued using 2,4-D to control Eurasian milfoil, curly-leaf pondweed, and waterweed *Elodea*. Some fish planting occurred.

2001: The whole lake was treated with Flurodone to control Eurasian milfoil. A September survey afterwards showed the presence of 12 native species.

2002: A sewer vote was taken with a 50:50 split for going ahead with it. The effort was tabled.

2002: A unique year since no plant treatment was conducted.

2003: Eurasian milfoil was treated (45 acres) with Renovale.

2004: Eurasian milfoil was treated with Renovale. However, algae now became a problem.

2006: A lake-wide treatment with Renovale was done for Eurasian milfoil, but it was late and ineffective resulting in another treatment later. Algae was also treated with copper sulfate.

2007: There were no macrophytes left to treat. Algae now dominated the lake. On 2 July the algae were treated.

2008: There were 3 acres of Eurasian milfoil treated; the rest was copper sulfate for the now dominant algae in the lake.

2009: There was a lake-wide algae treatment, while 25 acres were treated with 2,4-D, 40 acres with Renovale, and 10 acres with Aquathol.

2010: There were 40 acres of pondweed treated with Aquathol, 15 acres of Eurasian milfoil treated with Renovale, and 40 acres of Eurasian milfoil treated with 2,4-D early and another 40 acres of Eurasian milfoil was treated with 2,4-D in June. Spicer Engineering did a study and found the Secchi disk measurement to be 3 ft. They recommended BMPs (best management practices) in the Wheeler Drain watershed. They also noted that the watershed for the lake was 15 square miles and land use there was agriculture, residences, and forest. They also noted that Wheeler Drain had six rock check dams and a sediment basin to help control erosion in Hess Lake.

2017: A resident reported that black crappies were spawning in the Wheeler Drain outlet area during spring (see PICTURE 2). Subsequently, apparently during rain events, there were fish kills that resulted.

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 several 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. We sometimes run transects across a lake and record the depths if there are no data about the depths of the lakes. These soundings can then be 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 used to show where we sampled, important areas, tributaries, and depth contours. This map will assist us in identifying where past stations were sampled in prior studies and in making assessments of 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 Petite Ponar sampler is used to sample bottom sediments for examination. It is lowered to the bottom, tripped with a weight, and it "grabs" a 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 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. Secchi disk measurements also dictate what trophic state: eutrophic, mesotrophic, or oligotrophic a lake has. The criteria for this Secchi disk measurement are as follows: <7.5 ft = eutrophic, 7.5-15 ft = mesotrophic, and >15 ft = oligotrophic.

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.

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 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).

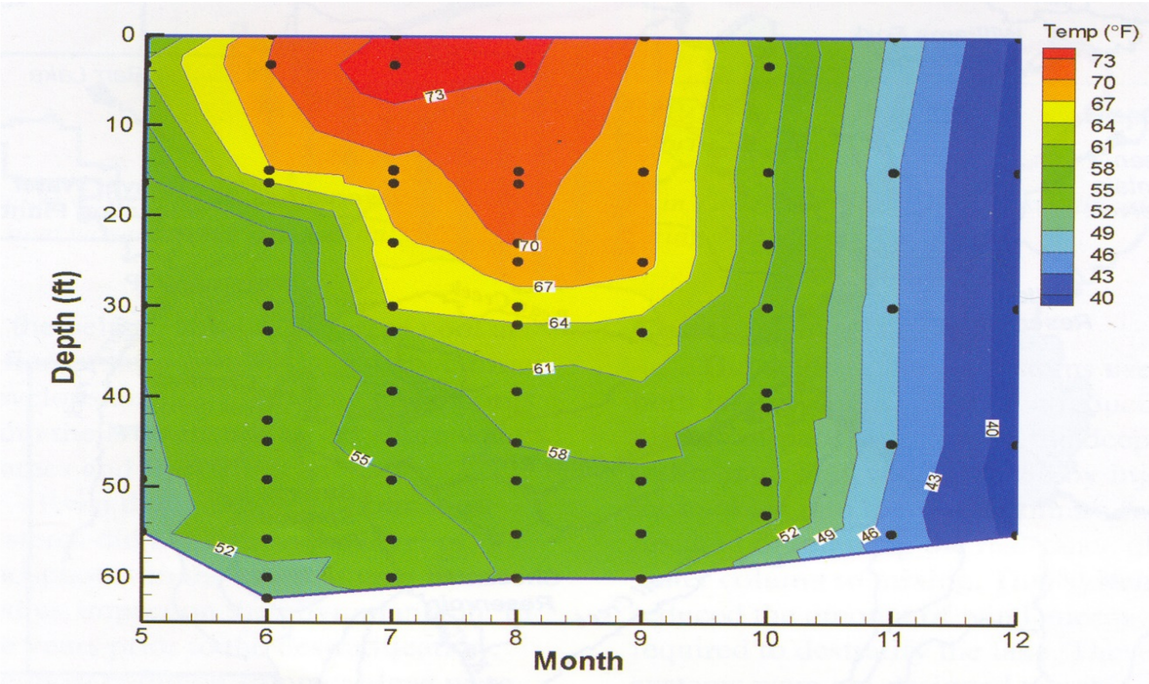

Figure 1. Depiction of the water temperature relationships in a typical 60-ft deep lake over the seasons. Note the blue from top to bottom during the fall turnover (this also occurs in the spring) and the red yellow and green (epilimnion, thermocline, and hypolimnion) that forms (stratification) during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

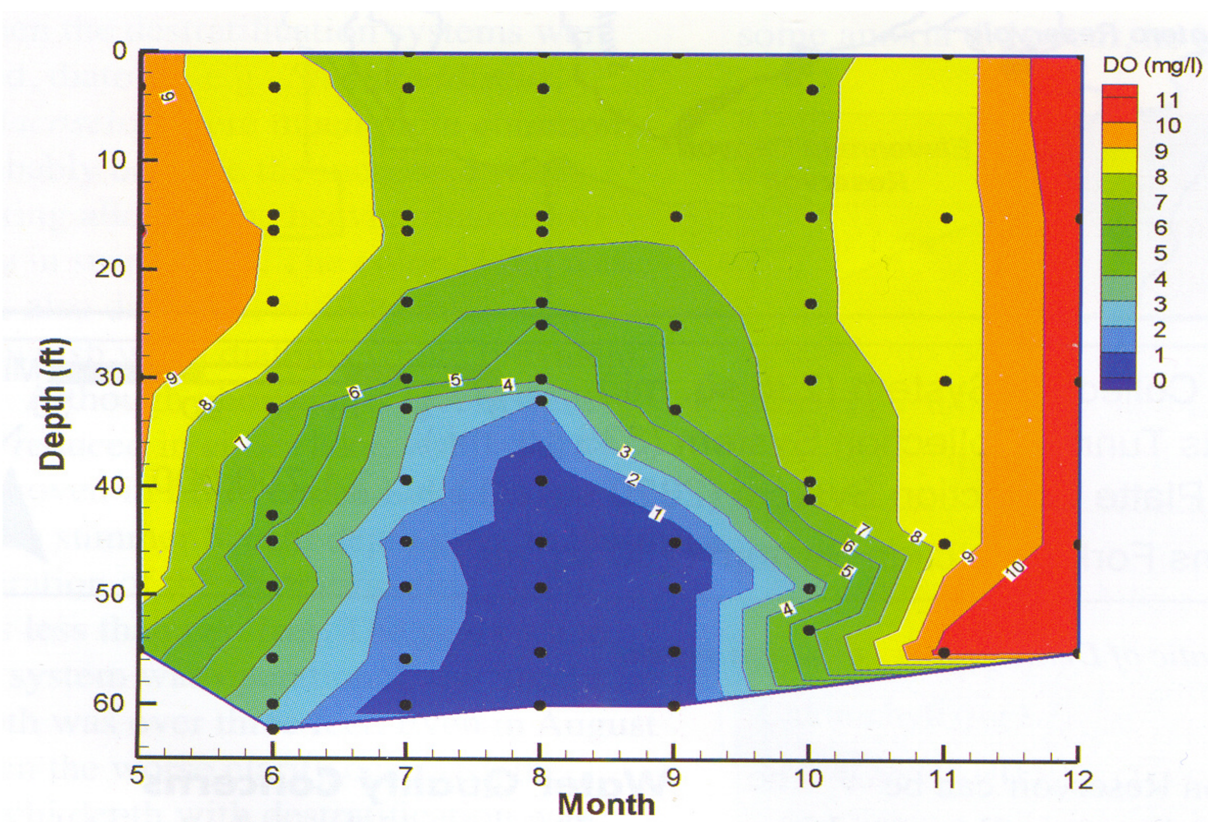

Figure 2. Dissolved oxygen stratification pattern over a season in a typical, eutrophic, 60-ft deep lake. Note the blue area on the bottom of the lake which depicts anoxia (no dissolved oxygen present) during summer and the red section in the fall turnover period (there is another in the spring) when 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 the dissolved oxygen in the bottom layer is lost (consumed 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 there and changes basic chemical reactions in and near the sediment layer (from aerobic to anaerobic). In eutrophic lakes, the surface waters can be too warm for cool-water fish, while the optimal cool waters in the hypolimnion are devoid of oxygen, squeezing fish in a thin layer in the middle. Fish like northern pike can be stressed, while more sensitive species, such as lake herring can perish when the dissolved oxygen levels decline too much (see Fig. 3).

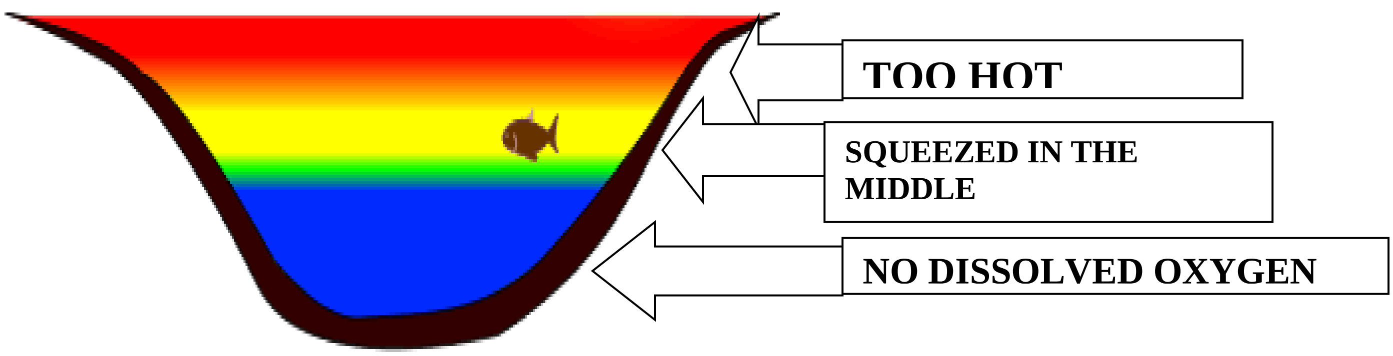

Figure 3. Depiction of the dissolved oxygen concentrations in a stratified lake during summer, showing the surface layer (epilimnion) where warmest temperatures exist, the thermocline area where temperatures and dissolved oxygen undergo rapid changes, and the bottom layer, where the coolest water exists, 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.

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 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.

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 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 (NH3), 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 (NO3=) when exposed to the oxidizing effects of oxygen. Nitrite (NO2-) 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 several 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 can 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 (we collected *Chara* in our benthos samples from 2 ft) and grows on the bottom in the littoral zone, sometimes in massive beds. Starry stonewort *Nitellopsis obtusa* is an exotic invasive alga that looks like *Chara*. It is important to identify it in lakes since it can dominate large areas of the lake and damage spawning sites and prevent boat access and fishing in areas where it is present. It is spread from lake to lake on boats and other equipment from infected lake. Hence, it is important to prevent its spread by having good education of lake residents and signage at boat launch sites to prevent its spread. 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.

The algae consist of many biological groups of organisms that do not represent a single lineage on the evolutionary tree of life but are linked by function—freshwater algae are generally small, photosynthetic, and do not have organized tissues like higher plants (flowers and trees). From an ecological perspective the algae are critical to the functioning of the earth (algae account for about 50% of the photosynthesis—hence half the oxygen we breathe) and form the base of the food web in most lake and river systems. The different algal groups are separated based on their cell structure (bacterial type or prokaryotes—the Cyanobacteria; or true cells or eukaryotes—the rest of the algal groups), storage products (starch, lipids, proteins), pigments, cell wall or membrane structure, cellular organization, and life history types.

Cyanobacteria—the blue-green algae are photosynthetic bacteria and are common in lakes, streams, and even wet soils. The blue-green algae are well adapted to living in lakes that have a wide range of nutrients. They can adjust their buoyancy in the water column (get light and nutrients as needed), they often grow in large colonies that are not preferred food by zooplankton, and they are most notorious for their production of toxins under certain growth conditions (e.g., cyanobacteria in Lake Erie (*Microcystis* caused to shut down of the Toledo water supply in 2015).

Chlorophytes—the green algae range in size from single cells to large filamentous forms that are common on rocks and logs along the shorelines of many lakes. The green algae are most often common in mid-summer but can produce nuisance accumulations in the spring following ice-out.

Bacillariophyta—the diatoms are characterized by having a cell wall made of opaline silica or biologically produced glass. The size, shape, and ornamentation of the cell wall provide the clues for species identification. Diatoms are generally found in two major ecological groups. The planktonic forms are either round or long and spindle-shaped and are common during spring and fall turnover. The benthic forms are found living attached to plants, rocks, and sediment but can be found in the water column if there is enough mixing due to wave action, wind, or boating.

Chrysophytes—the golden-brown algae or chrysophytes live in small motile colonies or as single cells. Many of the forms have small silica scales that cover their cells (*Synura*, *Mallomonas*) or live in organic vase-shaped structures (*Dinobryon*). The chrysophytes are typically common in cooler months of the year.

Dinophyceae—the dinoflagellates are a group of large-celled algae where most species surround themselves with an organic set of plates (called a theca). The dinoflagellates can be very common in some lakes under the ice or in the summer. The dinoflagellates are probably best known for producing red tides in nearshore marine settings.

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 considering 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. Aquatic plants are important spawning substrate, habitat for fish, nursery areas for small fish, they produce aquatic insects, and they are important for stabilizing sediments. They can slow down currents and prevent re suspension of sediments, which contain nutrients, which can be released into the upper water column and fuel algal blooms.

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, since they are 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 (153 microns) through the water and the resulting sample is preserved with 10% formaldehyde or alcohol 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 always requires high dissolved oxygen 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 or a petite ponar. It is lowered to the bottom in the open position, a messenger sent down the line and tripped. This results in about a 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, trap 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 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 or help us explain perplexing problems discovered in the lake ecosystem.

RESULTS

WATERSHED

Hess Lake is in Newago County (Brooks and Grant Townships) and drains north to Brooks Lake and then through Brooks Creek into the Muskegon River and then into Lake Michigan. The lake is listed as 750-770 acres (Table 1). The local watershed for the lake is composed of the land surrounding the lake which, when water lands on it, it then flows into the lake. The Hess Lake watershed is 9,336 acres (Table 1) or about15 square miles, with much of it south of the lake and is drained by Wheeler and Alger Drain into Hess Lake. The primary uses of the land are agriculture (39%) and forest (39%). Open space composed 9%, wetlands 6%, followed by lakes (<1%). Hence, there is considerable nutrient input from the 40% of the land that is farmed, based on the water quality data we collected and cited. The open space, wetlands, and forest will act as buffers reducing the impact of these other negative inputs.

Runoff and seepage into groundwater from septic tanks and from the developed houses around the lake contribute to the nutrient problem in Hess Lake, along with the lake going anoxic during summer, which will increase the amount of what is termed “internal loading”. Internal loading is derived from in-lake conditions (decomposition of sediment, algae, and macrophytes) that produce nutrients that are released at an accelerated pace when the bottom of the lake becomes anoxic (no dissolved oxygen). Unlike most lakes, as we described above, Hess Lake because of its shallowness, long fetch, common carp rooting, and excessive boat traffic has a continual input of decomposed sediments into the lake water column because of wave action stirring the sediments and resuspending nutrients. The increased large lawns that are fertilized by riparians, removal of vegetation, septic tank leakage into the groundwater will continue to exacerbate the addition of nutrients (termed cultural eutrophication) into Hess Lake.

The local riparian zone, as we noted above, is very important, especially that band right at the lake, which is the interface between land and water. Residents in the watershed need to see Appendix 1 in this report and the Hess Lake Guide (Newaygo County, 2011) for recommendations on how to reduce impacts on Hess Lake. Since some of the soil is sandy, water will percolate through it much faster into the groundwater than it would if the soils were all loamy. There are signs starting in 1950 to 1970 that the lake water quality and fish communities were being degraded. During 1980, the lake began a major shift from a macrophyte-dominated to an algae-dominated 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), 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 in the watershed of the lake, prevention of leaves and other organic matter from entering the lake, 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, protection of undeveloped land and wetlands, and pumping septic tanks at least every 2 years and more often to prevent nutrients from entering the lake via the ground water (summarized in Appendix 1).

Table 1. Land-use data for Hess Lake. Provided by Progressive AE (2020).

LAND USE TYPE	ACRES	% OF TOTAL
Lakes	41	0.4
Residential	459	4.9
Wetland	578	6.2
Open	902	9.7
Forest	3,672	39.3
Agriculture	3,684	39.5
Totals	9,336	100

STATION LOCATION

Hess Lake is a 750-770-acre, deep, shallow eutrophic lake located in Newaygo County, MI. We established four types of stations on Hess Lake for sampling various parameters in this study (Fig. 4, 5). Water quality was measured at stations A and B and Wheeler Drain during July and again in August; zooplankton at stations Z1 (shallow) and Z2 (deep); algae sampled from station A (AL); and fish sampling sites were established for seining (S1-S3), gill netting (G1, G2, G3), and trap netting (T1-T3). Fish stations were set up in various locations around the lake to maximize catch of fishes (see Table 6 for set times, GPS locations, and catches).

Figure 4. Google map of Hess Lake showing the extensive development around most of the lake.

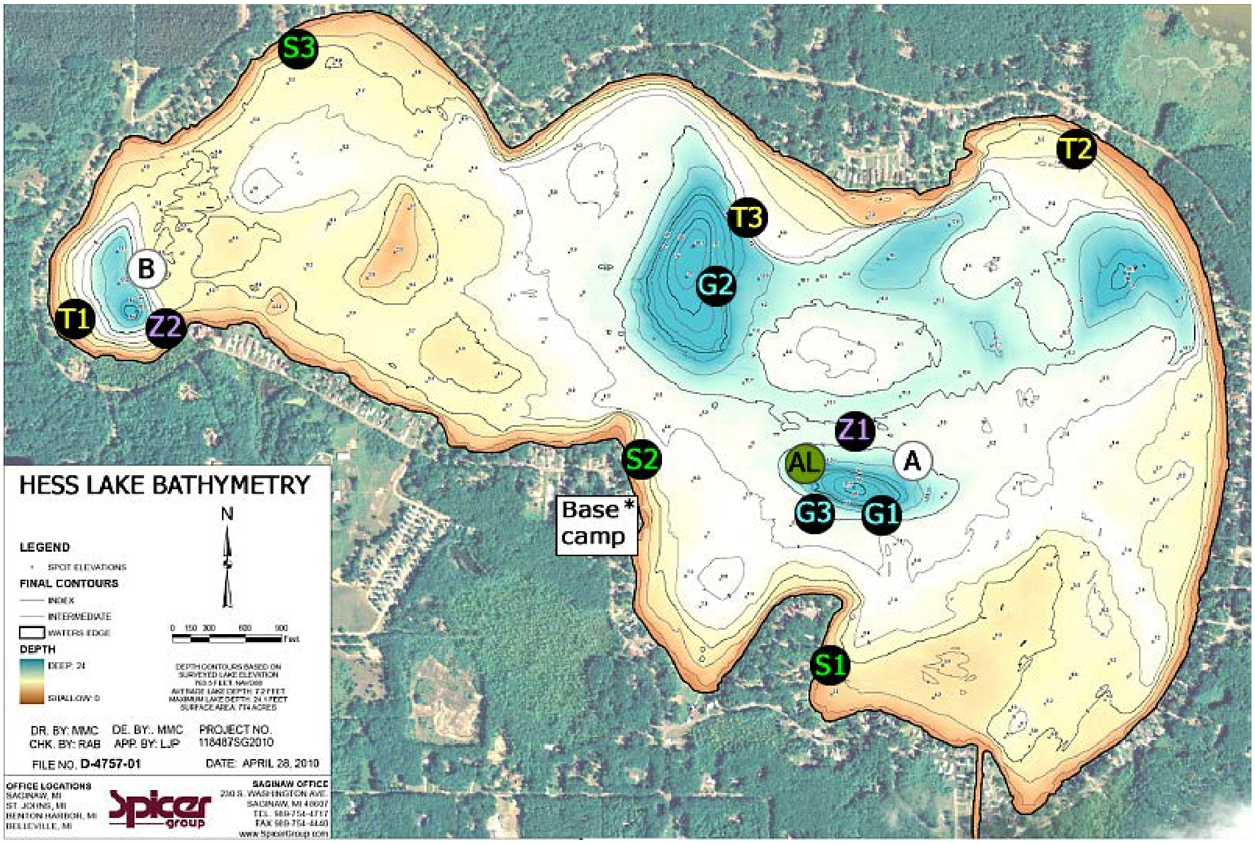

Figure 5. Map of Hess Lake showing the water quality stations A and B, zooplankton stations at Z1 and Z2, algae sampling at AL, and fish sampling sites for seining (S1-S3), gill netting (G1, G2,G3), and trap netting (T1-T3). Note Wheeler Drain (see Picture 2) in SW corner of lake east of where a seine haul at station S1 was made. Adapted from Spicers Group.


Picture 2. Wheeler Creek on the southern end of the lake. We collected water quality samples here on 23 July. This area is an important nursery and spawning area for fish, provides shelter and fish-food organisms, and has some macrophytes (example: see lily pads).

PHYSICAL PARAMETERS

Depth

Hess Lake is unusual among Michigan eutrophic (productive) lakes, in that it is very shallow with only three deep basins that are listed up to 29 ft deep, but we were only able to find depths of 19-20 ft in the station A area (Fig. 5). Most eutrophic lakes in Michigan stratify during the summer, which gives them some protection from the nutrients that are generated by decomposition of sediments in the deep basins (termed internal loading or autochthonous inputs as opposed to inputs from outside the lake, like Wheeler Drain, which are termed allochthonous inputs). During summer stratification, algae and macrophytes take up nutrients from the surface of the water column (the epilimnion), so many times plants are limited by either phosphorus or nitrogen or both. During stratification, plants decompose on the bottom, accumulate there and are circulated throughout the lake in the fall overturn period when the water temperatures reach a uniform 4 C. Hess Lake is different, since because of its size, long fetch with predominate west winds, wave activity generated by the many watercraft and common carp on/in the lake, the lake, although it does stratify, has stratification disrupted often, which results, we think, in re-suspension of nutrients during times when the plants need them most. This scenario is further exacerbated by the fact that the lake has switched from macrophyte-dominated to algae-dominated around 1981 and was confirmed by MDNR O'Neal's surveys and comments at that time in 1990. Our data confirm that conclusion as well. The lake is very shallow and is condemned by its morphology to a continuing saga of dominance by algae unless some substantial steps are taken to reduce phosphorus input from both internal and external sources. The shallow nature of the lake and high turbidity has resulted in a dearth of macrophytes, sediment buildup in many areas nearshore (site S1, our seining station was barely able to be seined since the sediments were almost 3 ft thick), and habitat favored by the invasive fish species, common carp, which appear to be abundant. Loss of aquatic plants is a serious problem, since macrophytes are keystone habitats in a lake for fishes; they provide aquatic insects for food, spawning habitat, and probably most importantly, nursery and shelter for smaller fishes. It also anchors the sediment and prevents wind-generated currents from re-suspending bottom sediments. Macrophytes also are important since nutrients in a lake can be tied up in algae or macrophytes, and it is critical that macrophytes predominate and prevent blue-green algae from taking over and shading the plants and increasing turbidity, which appears to now be the case in Hess Lake. Increased turbidity can thwart visual predators from catching prey favoring predators such as black crappies and channel catfish, which can feed in the dark. Loss of macrophytes results in loss of shelter for prey fish, and re-suspended sediments can put more nutrients into the water column, which can fuel algal and macrophyte growth. Some places we seined were relatively macrophyte depauperate and fish catch reflected this with low catches.

Acreage

Hess Lake is (see Fig. 5 map) 777 acres, but other sources list it as 750 acres. The lake is extensively developed in the riparian zone, but it does have some forest areas in the watershed (see Fig. 4). The outlet of the lake runs into Brooks Lake to the north. We did not examine this creek; it could be important habitat for spawning and a nursery area for small fishes as well.

Sediments

Edmunds Engineering apparently sampled the sediments of Hess Lake (see summary above). They concluded that there was a soup of decomposed algae on the bottom, which was easily disturbed and resuspended by wind and watercraft activity. Deeper in the sediments, they found gray material which was in a reduced state. They were concerned that eventually the lake would shift back to being macrophyte-dominated, which would accelerate the eutrophication of the lake because macrophytes are more difficult to decompose and that would result in a faster rate of accumulation of sediment in the bottom of Hess Lake.

Light Penetration

The water transparency at station A and B during 23 July ranged from 0.8 to 0.9 m or 2.6 to 3 ft (Table 3). During 19 August stations A and B had values of 1 m or 3.3 ft. The lake seemed green because of the extensive algal blooms which were visually present along shore and appeared in our zooplankton net sample (see Picture 5). During the August sampling the zooplankton net was covered with green filamentous algae. The criteria for trophic status criteria using Secchi disk data are: eutrophic <7.5 ft, mesotrophic (7.5-15 ft), and oligotrophic (>15 ft) making Hess Lake on the low end of eutrophic (Secchi disk readings < 7.5 ft), even hyper eutrophic.

Other data from 1984 showed similar readings and Progressive AE found Secchi disk values during April 2018 to be 2.5 ft, while in August they ranged from 1.5 to 2 ft.

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 (internal loading: 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 cannot go there) and chemical parameters (phosphorus and ammonia) are released from the sediments under anoxic conditions; these nutrients are then mixed into the lake during the fall and spring overturn fueling plant growth. Dissolved oxygen data are also important to determine if cool water fishes might be affected. Hence, it is important to determine if dissolved oxygen conditions have deteriorated over time, detrimentally impacting northern pike, since it was not found in gill net catches when fish sampling was done in 2019.

We collected water temperature and dissolved oxygen data at two sites in Hess Lake, one deep spot (station A – see Fig. 6) and another on the SW end of the lake (station B – Fig. 7) on 23 July. The water transparency data showed very turbid conditions with readings of 2.6-3.3 ft. The dissolved oxygen data at station A was around 10 mg/L (over saturated) at the surface to 4 m, then was zero at 5 m (bottom) (Table 2). Conditions could have been worse, since it was very windy during sampling and we had to re anchor a couple times to get the data. These winds probably mixed surface waters providing elevated dissolved oxygen conditions and re-distributed nutrients that built up on the bottom at this time. During 19 August, at station A (listed as 29 ft on the map drawn in 1955, but we could only find 20 ft), there was a stratified condition and low dissolved oxygen (<1 mg/L) on the bottom (Fig. 8), probably again higher than it would have been without windy conditions and the long fetch of the lake elevating dissolved oxygen. At station B, which is more isolated and somewhat shallower, we found about 10 mg/L of dissolved oxygen from the surface to 2 m; it was anoxic (no dissolved oxygen) from 3 m to the bottom (Fig. 9). It should also be pointed out that with the current situation with dense blue-green algae blooms ongoing in Hess Lake during summer, that at night these algae will respire and use dissolved oxygen instead of producing it in excessive quantities, like it does during the day. This will result in dissolved oxygen sags during the night. We do not know the extent of this phenomenon, but this situation is termed summer kill, when the dissolved oxygen drops so much, it kills fish. This type of situation was probably documented during 2010 (see History above) when black crappies moved into Wheeler Creek to spawn, then experienced a rain event or possibly summer kill reducing dissolved oxygen so far that a fish kill resulted.

Let us discuss what is probably happening in the deep basins of Hess Lake. First, whenever the bottom of the deep basins of Hess Lake go anoxic and there are windy conditions, which must happen often during summer, this dead zone will stress cool water fish like northern pike, confining them to an increasingly smaller layer of optimal habitat (Fig. 3). Growth will slow down and fish may suffer increased mortality. This may be the reason that there are apparently few pike in Hess

Lake. Second, anoxia opens the nutrient pump flood gates generating large amounts of nitrogen (ammonia - which was the case on the bottom of station B in July- Table 3- to be discussed) and phosphorus production on the bottom. Ammonia is not only a nutrient, but it is also toxic to fish in the high concentration noted (see below) in this study. Hence, this is fairly strong evidence that deteriorating dissolved oxygen levels due to increased eutrophication in Hess Lake has led to very low abundances of northern pike in the lake. Note that the optimal water temperature for walleyes, northern pike, and smallmouth bass is around 22 C (72 F) and their upper lethal temperature is around 30-31 C (Hokanson 1977). On 23 July surface water temperatures ranged from 25.4 to 26.3 C and on 19 August water temperatures at the surface were 26.0-26.1 C (26 C = 78.8 F) at station A and B (Table 2) - - close to their upper lethal temperature. Worse conditions could easily develop during a calm, hot period or later during a summer that lasted a long time. 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 fishes will be subjected to the squeeze noted in Fig. 3: warm temperatures in surface water forces them downward, while low or no dissolved oxygen in the preferred bottom cool waters of the lake forces them into too warm surface waters. Conditions may also get worse with increasing temperatures we are experiencing due to climate change. This point is important for fish management considerations.

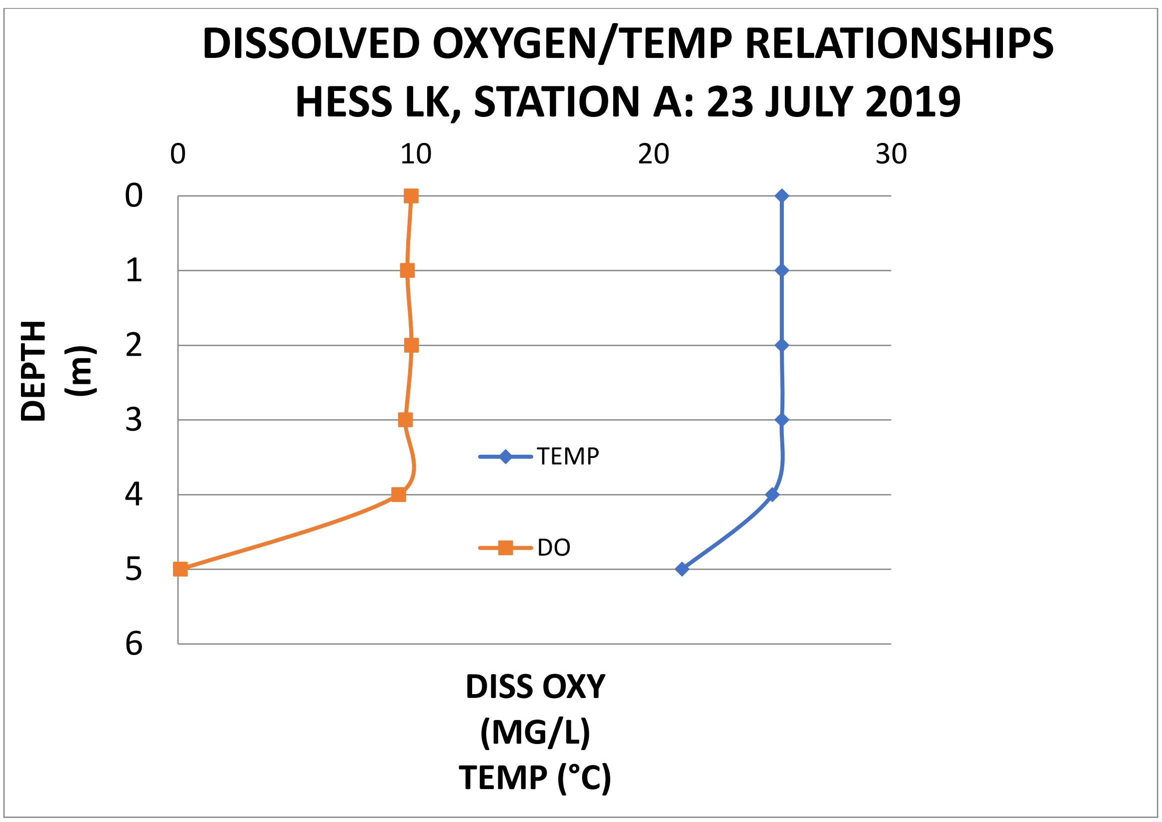

Figure 6. Temperature-dissolved oxygen curve for Hess Lake, station A, 23 July 2019.

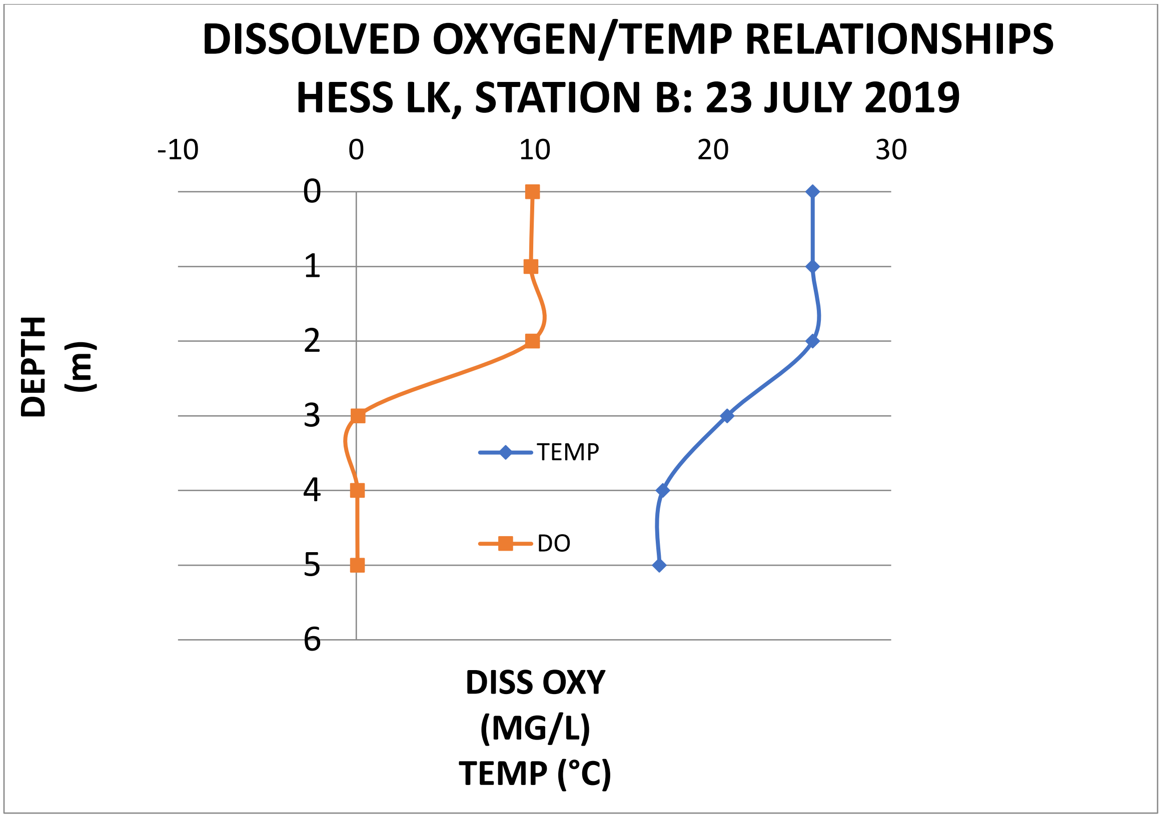

Figure 7. Temperature-dissolved oxygen curve for station B Hess Lake, 23 July 2019.

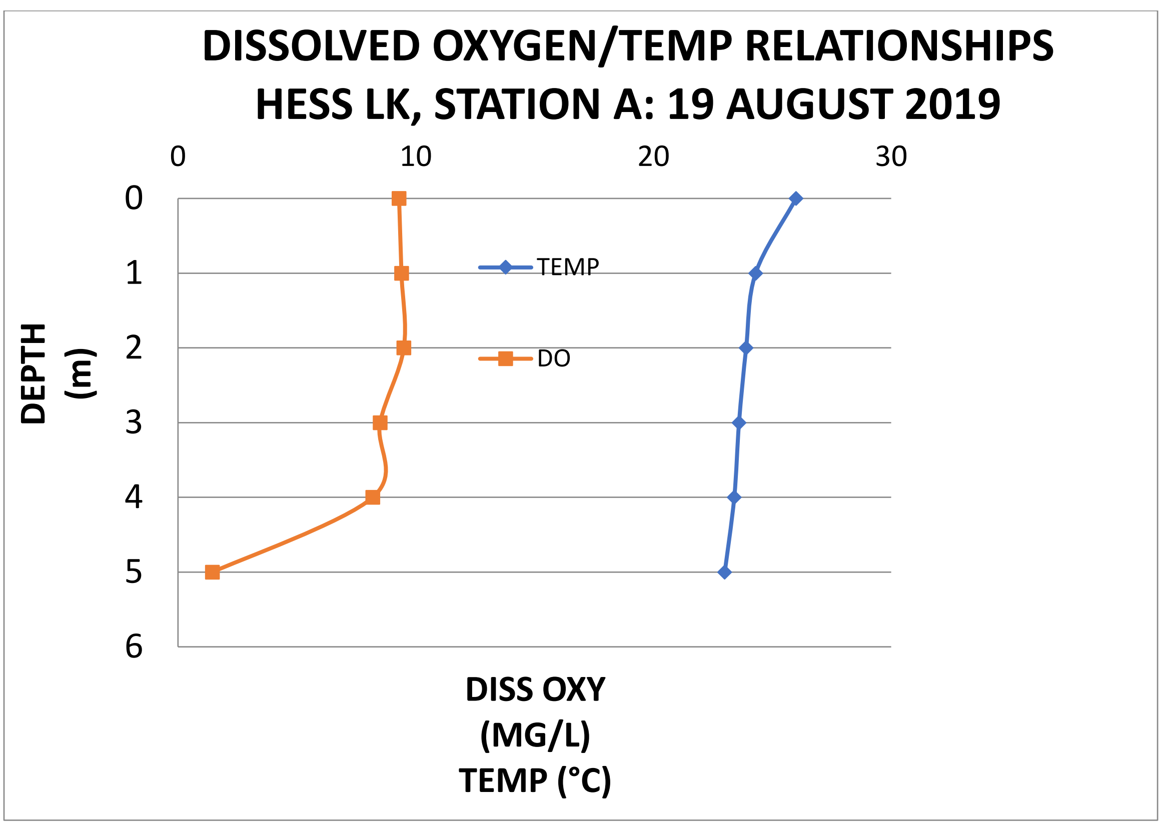

Figure 8. Temperature-dissolved oxygen curve for station A in Hess Lake, 19 August 2019.

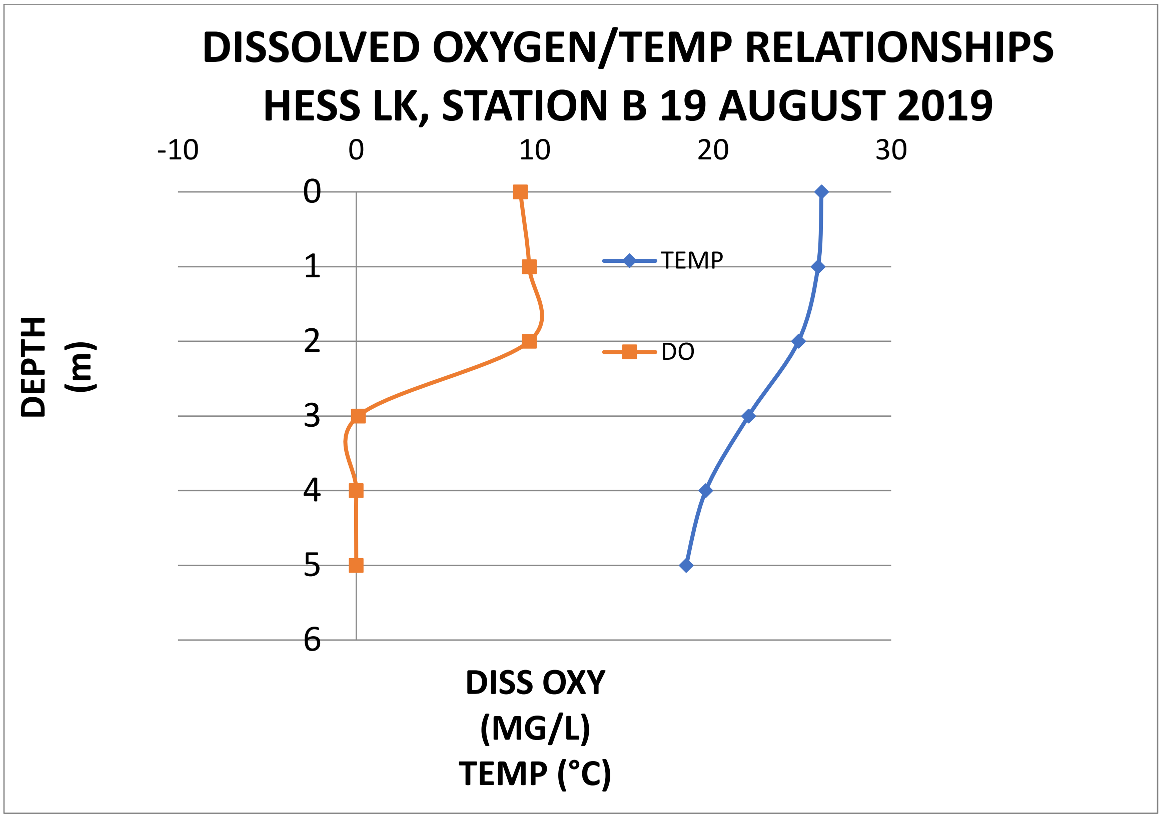

Figure 9. Temperature-dissolved oxygen curve for station B in Hess Lake, 19 August 2019.

Table 2. Listing of the raw dissolved oxygen/temperature data from the 2019 study on Hess Lake, Newagyo County, Michigan. DO = dissolved oxygen (mg/L). See Fig. 5 for station locations. Data are also graphed in Figures 6-9.

DEPTH (M)	TEMP - C	DO
23-Jul	Station A	
0	25.4	9.81
1	25.4	9.65
2	25.4	9.82
3	25.4	9.57
4	25	9.28

5	21.2	0.1
6	18.4	0.06
7	18	0.07
23-Jul	Station B	
0	25.6	9.89
1	25.6	9.8
2	25.6	9.88
3	20.8	0.1
4	17.2	0.06
4.5	17	0.07
19-Aug	Station A	
0	26	9.3
1	24.3	9.4
2	23.9	9.5
3	23.6	8.5
4	23.4	8.19
5	23	1.45
5.5	22.5	0.11
19-Aug	Station B	
0	26.1	9.2
1	25.9	9.7
2	24.8	9.7
3	22	0.12
4	19.6	0
4.5	18.5	0
5	18.1	0

It should be noted that Progressive AE datasets from 2018 (Progressive AE, 2018) showed saturated dissolved oxygen values (9.4-11.5 mg/L) at all depths during April. During August, dissolved oxygen was saturated in surface waters at their three stations (the three deep basins in the lake), then went to zero on the bottom at two stations and was 0.7 mg/L at the third, which was similar to findings from this study.

CHEMICAL PARAMETERS

pH

The pH in the water column was as expected, elevated at the surface at stations A and B (8.93-8.91), lower at mid depths (8.78-8.79), and lowest (7.16-7.97) at the bottom, where decomposition was highest (Table 3). Decomposition generates carbon dioxide lowering pH and generates phosphorus and ammonia from the bottom sediments during anoxia, which allows a chemical reaction involving iron, to release P from the sediments. This is undoubtedly one of the sources of increasing total phosphorus (internal loading) noted below in Hess Lake along with inputs from septic tanks and Wheeler Creek. During 19 August, pH did not follow this pattern. Values were high at the surface (8.47-8.67) where algae remove carbon dioxide from the water, but also high at mid depths (8.10-8.72), and 8.23-8.46 on the bottom. This seems to indicate that there were active algae throughout the water column taking up carbon dioxide, keeping pH high.

Table 3. Secchi disk readings, conductivity (uSiemens), pH, chlorides (CL), nitrates (NO^3), ammonia (NH^3), total phosphorus (TP), and soluble reactive phosphorus (SRP) for station A, B, and Wheeler Creek (W. Cr.) in Hess Lake, 23 July and 19 August 2019. See Fig. 5 for location of stations where sampling occurred. All concentrations are in mg/L. NA = not available. S = surface.

DEPTH (M)	SECCHI DISK (M)	pH	COND	H^2S	CL	NO^3	NH^3	SRP	TP
				23-Jul					
A-S	0.8	8.93	386		12	0.10	<0.01	0.009	0.052
A 2.5 M		8.79	374		12	0.10	0.05	0.005	
A 5 M		7.97	423	NA	15	0.14	0.14	0.020	0.055
B-S	0.9	8.91	380		12	0.11	0.02	0.011	0.031
B 2.5 M		8.78	380		12	0.11	0.03	0.006	
B 4 M		7.16	568		13	0.22	2.10	0.007	
W. Cr		8.49	502	NA	11	0.93	0.04	0.010	
				19-Aug					
A-SURF	1	8.47	387		13	0.11	0.01	0.006	0.023
A-2.5 M		8.72	413		12	0.11	<0.01	0.007	
A-5 M		8.26	396	0	13	0.12	0.02	0.008	0.050
B-SUR	1	8.68	257		12	0.09	0.02	<0.005	0.024
B 2 M		8.1	505		13	0.15	0.03	0.007	
B 4 M		8.43	368	ND	12	0.12	<0.01	0.005	0.022

Total Alkalinity

Total alkalinity provides a measure of the productivity of the lake and measures the carbonate system in the lake. Progressive AE measured it during 2018 at three stations during April and August 2018. During April when the lake was mixed, alkalinity ranged from 135 to 142 mg/L, which is typical of Michigan's eutrophic, hard-water lakes. During August, carbon dioxide is taken out of the surface waters by macrophytes and algae, reducing alkalinity, while decomposition on the bottom is increasing alkalinity. This pattern was documented at all three stations with surface alkalinities ranging from 112-114 mg/L, while on the bottom alkalinities ranged from 164 to 192 mg/L.

Chlorides

The long-term changes in chlorides are instructive of the forces of development and destruction of the natural order around Hess Lake. Although not toxic or of concern at the levels we usually measure, chlorides are bellwethers of ecosystem integrity. They enter lakes through runoff, septic tank discharge into ground water, and they occur naturally in soils. Pristine conditions usually have chlorides in the 4-10 mg/L range. Another characteristic of chlorides is they are not modified by chemical or biological processes. Hence once in the lake they stay there and can only be modified or diluted by inputs of higher concentrations of chlorides, rainwater, or evaporation. Therefore, the concentrations of chlorides reveal something about the history of runoff, road-salting activities, or other changes to the landscape that may affect chloride concentrations. In addition, if chlorides are high, other deleterious substances may also accompany them, so serve the purpose of warning us of ongoing pollution. Chlorides in Hess Lake were unusually low, ranging from 12 to 15 mg/L during 23 July and 19 August (Table 2). Chlorides can be important measurements in determining the amount of salting and runoff that comes into Hess Lake from the watershed. Wheeler Creek was even lower than values measured in Hess Lake, so that water must drain areas of low input of chlorides and must contain much rain water low in chlorides. We concluded that despite the number of roads surrounding the lake, that salting must be low. However, some sampling of the ground water by testing wells may yield additional information on how much the groundwater may be contaminated with salt, nutrients (especially nitrates), and/or other deleterious substances. Our data were similar to what Progressive AE found during 2018: chlorides from many depths at three different stations during April and August, only ranged between 13 and 16 mg/L with one outlier value of 31 mg/L.

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. SRP, the soluble phosphorus available for plant growth during 23 July at station A was low in surface water (0.009 mg/L), and at mid-depths (0.005 mg/L), but much higher on the bottom, where 0.020 mg/L was found (Table 3). This value is an elevated concentration of SRP and indicates that phosphorus is not being taken up by algae on the bottom and in addition, is still being generated by the decomposition of dead algae on the bottom. Obviously, although we did not find anoxia on the bottom at station A during our 23 July bout, values were low on the bottom and most likely went anoxic during periods of light wind and hot temperatures. The situation at station B was somewhat different, with values in the water column: 0.011 mg/L at the surface, 0.006 mg/L at mid depths, and 0.007 mg/L on the bottom. The dissolved oxygen values here were also very low on the bottom similar to findings at station A.

During 19 August, a pattern of similar SRP values from surface to bottom at stations A and B was documented; SRP was from <0.005 to 0.008 mg/L, showing more SRP was taken up by plants during July than during August. Wheeler Creek SRP values were lower than expected at 0.010 mg/L during July. This was during a non-rain event and not early spring where more would be expected in this drain. Data on Wheeler Creek from April 2018 (Progressive AE 2018) showed TP values of 0.329 mg/L, extremely high values, but these data were collected just after the settlement basins above were cleaned out, so values are not representative of concentrations found in the creek. During August, Wheeler Creek had a TP value of 0.061 mg/L, which is also high.

Total phosphorus values in Hess Lake were measured on 23 July at station A and showed that TP was very high in surface and bottom waters at 0.052-0.055 mg/L. TP was also high at the surface of station B, measuring 0.032 mg/L (Table 3). During 19 August, TP was lower in surface waters at station A and B, ranging from 0.023-0.024 mg/L than found at the same site during July. Bottom TP at station A during July was similar to bottom values measured at stations A and B during July at 0.050 mg/L. However, station B concentrations on the bottom were lower at 0.022 mg/L. These differences are probably related to different algae densities at these sites and times. The available criteria for trophic status of lakes is: oligotrophic <0.010 mg/L TP, mesotrophic 0.010-0.020 mg/L, and eutrophic > 0.020 mg/L. Most values are eutrophic, with the highest ones 3-fold higher than the upper value criterion of >0.020 mg/L that is used to designate lakes as eutrophic and is clearly a loud signal to the residents of Hess Lake that conditions in the lake have deteriorated substantially from previous years. Since TP values were 3-6 fold higher than SRP values at the various sites, there was a considerable amount of probably blue-green algae in the water column that contributed to these high concentrations.

Comparable data were collected by Progressive AE during April and August 2018 (Progressive AE 2018). Values of TP were <0.005 mg/L to 0.025 mg/L at three stations and all depths during April. During August, TP was 0.016 mg/L at the surface of station 1, then increased to 0.090 mg/L on the bottom of station 1. At station 2, TP was 0.016 mg/L at the surface then increased to 0.043 mg/L on the bottom. At station 3, TP values were 0.012 mg/L at the surface, 0.090 at mid depth, and 0. 048 mg/L on the bottom. The highest value we measured in this study was 0.055 mg/L making some of Progressive AE's concentrations almost 2-fold higher than our findings. All these high values point to phosphorus as being a major problem in the lake, documenting the high density of algae permeating the water column during summer months when blooms proliferate. These data document a major indicator of ongoing change in Hess Lake and if a nutrient budget were to be developed, we believe that the three major sources of phosphorus and to some degree nitrogen, would be internal loading (decomposing algae and sediments on the bottom - see Carey et al. 2009), Wheeler Drain, and septic tank leakage into groundwater. Riparian contributions of nutrients are also important, since many nutrients can run off of riparian lands near the lake. Since the land area around the lake contains a considerable amount of sandy soils, nutrients in groundwater from septic tanks will not be slowed down or absorbed by the soil and contribute to polluting the lake. Decomposition on the bottom that generates these nutrients during summer may be the main reason for the high TP (along with high densities of blue-green algae in water) nutrients, since they are also responsible for the loss of dissolved oxygen. The obvious solutions to these problems are expensive and complex and have been suggested before in previous studies. They include: 1. Diverting Wheeler Creek around the lake. Many improvements have already been made in the watershed, including small dams, and a sediment basin, and plantings on the banks to reduce erosion. 2. Dredging the lake, 3. Putting in sewers, 4. Switching the lake back to being macrophyte-dominated. This option would be assisted by enacting recommendation no. 1, by controlling common carp populations to reduce turbidity, and taking some major actions to reduce the impact of watercraft with large engines. This could take the form of restricting boats to the main lake, having a no-wake rule in shallow water, and trying an experiment of making one bay (station B might qualify) a bay with no wake by marking it off with buoys to allow macrophytes to grow without the high turbidity in the rest of the lake affecting it. No native macrophytes should ever be treated with chemicals and the continual treatment of algae with copper sulfate will kill mollusks (snails, clams) and accumulate in the sediments. Riparians, if they are really concerned about the water quality of the lake will need to take difficult steps like these and take on more responsibility for managing and reducing nutrients on their property (see Appendix 1).

We need information on how much the riparians may be contaminating ground water, so propose some sampling of the wells in the watershed, with concentrations of chlorides and other parameters (nutrients) being important information we need to determine if the residents in the watershed are contributing to the degradation of the water quality of Hess Lake.

Nitrates

During 23 July 2019 at stations A and B, we found nitrates, the readily available nutrient of the nitrogen forms, to be similar, ranging from 0.10 to 0.22 mg/L (bottom at station B- Table 3) abundant and should be taking up the available nitrogen. Since the highest value was documented on the bottom at station B, there must be substantial decomposition on going at that site. Wheeler Drain concentration was 0.93 mg/L, a high value, showing the high inputs of nutrients coming in from that drain. During 19 August, values in Hess Lake were comparable to the July concentrations, ranging from 0.09 to 0.15 mg/L. The lake's fate resides in the behavior of people whose interests are best served through serious consideration of draconian measures to enact some of the measures noted here to curb nutrient input to Hess Lake.

Ammonia

We focus on how much ammonia is generated on the bottom of a lake, since those that become anoxic in the summer can generate large amounts of ammonia from sediment decomposition, which then gets converted to nitrates and contributes to the nitrate-enrichment problem in Hess Lake. Since ammonia is toxic to fish and a nutrient which is re – distributed into the lake during fall and spring turnover to fuel plant growth, we use the presence of amounts of ammonia as an indicator of how enriched the lake is and as a symbol of ecosystem health in the lake. The data we examined showed the usual pattern we expect in lakes with low to no dissolved oxygen in bottom waters and high rates of decomposition of bottom sediments. There are usually reduced amounts of ammonia in the surface and mid depths through conversion to nitrates and uptake by plants, but elevated concentrations on the bottom. During 23 July ammonia concentrations were trace to 0.14 mg/L at station A, which is probably a reflection of mixing by wind and boat traffic on the main part of the lake. However, at station B, which is somewhat sheltered, ammonia was low (0.03 mg/L) in surface waters due to uptake by plants but had an astounding concentration in bottom waters of 2.10 mg/L (Table 3). Wheeler Drain had expected low concentrations of ammonia (0.04 mg/L). During 19 August, ammonia at all stations and depths were at barely detectable concentrations. The high ammonia concentrations of 2.10 mg/L on the bottom at station B is a terrible sign, signaling that ammonia is being produced in great quantities on the bottom during summer. It indicates a rich sediment that will continue to produce large amounts of ammonia over time, leading to increased nitrates in the water column after each spring and fall turnover period and during summer, when wind fetch or boat activity is strong enough to de-stratify deep basin areas. It is also consistent with the extraordinarily high conductivity measured at the same station.

Conductivity

Conductivity is a measure of the ability of water to conduct current and is proportional to the dissolved solutes present. Conductivity during 23 July 2019 at station A ranged from 386 uS at the surface to 423 uS on the bottom (Table 3). This is the usual pattern of higher conductivity on the bottom, generated from decomposition on the bottom increasing conductivity to maximum values there. A similar pattern of 380 at surface and mid depth and 568 uS on the bottom at station B was observed. The conductivity values are moderate among lakes we study and is way above values for pristine lakes. Wheeler Drain had a value (502 uS) comparable to values observed on the bottom of Hess Lake. During 19 August, conductivity followed a different pattern, with lowest values at the surface at stations A and B (257-387 uS), highest values at mid-depth (413-505 uS), and somewhat lower values on the bottom (368-398 uS). These measures are not explained by chlorides, since they were very low. The high ammonia values may have contributed to elevated conductivity on the bottom of station B.

Total Suspended Solids

Total suspended solids (TSS) were measured by Progressive AE (Progressive AE 2018) during spring and summer, 2018. Total suspended solids are a measure of the filterable material in a water sample and can be sediment, silt, decaying plants or animals, or algae. They are essentially another way to measure water clarity and high TSS can be generated by common carp activity, wind fetch stirring up sediments, boat running, and contributions from runoff, like those from Wheeler Drain. High TSS causes water temperatures to rise, decreases the ability of visual-feeding fish and larval fish to see well enough to catch prey, and when it settles to the bottom, can close interstitial spaces and produce an unconsolidated substrate, unfit for benthos or egg-laying fishes. TSS at three stations and several depths during April 2018, ranged from 8 to 24 mg/L, which is not excessive, but not good either. During August, values were a bit higher, ranging from 12 to 26 mg/L. This is another data point that corroborates what we have already established: there are extensive, on-going algal blooms that, along with stirring up sediments from the bottom, have resulted in low water clarity and impeded and degraded the food web from the zooplankton to the fish community.

BIOLOGICAL PARAMETERS

Algae

The algae consist of many biological groups of organisms that do not represent a single lineage on the evolutionary tree of life but are linked by function—freshwater algae are generally small, photosynthetic, and do not have organized tissues similar to higher plants (flowers and trees). From an ecological perspective the algae are critical to the functioning of the earth (algae account for about 50% of the photosynthesis—hence the oxygen we breathe) and form the base of the food web in most lake and river systems. The different algal groups are separated based on their cell structure (bacterial type or prokaryotes—the Cyanobacteria; or true cells or eukaryotes—the rest of the algal groups), storage products (starch, lipids, proteins), pigments, cell wall or membrane structure, cellular organization, and life history types. There were visible blue-green algae blooms ongoing during our July and August study (see Picture 3). The groups of algae that we encountered in Hess Lake in July and August 2019 included:

Cyanobacteria—the blue-green algae are actually photosynthetic bacteria and are common in lakes, streams, and even wet soils. The blue-green algae are well adapted to living in lakes that have a wide range of nutrients. They have the ability to adjust their buoyancy in the water column (get light and nutrients as needed), they often grow in large colonies that are not preferred food by zooplankton, and they are most notorious for their production of toxins under certain growth conditions (e.g., cyanobacteria in Lake Erie caused to shut down of the Toledo water supply in 2015). Cyanobacteria are the dominant late summer algae in Hess Lake, making up nearly 50% of the biomass there in July and over 63% in August (Fig. 10).

Bacillariophyta—the diatoms are characterized by having a cell wall made of opaline silica or biologically produced glass. The size, shape, and ornamentation of the cell wall provide clues for species identification. Diatoms are generally found in two major ecological groups. The planktonic forms are either round or long and spindle-shaped and are common during spring and fall turnover. The benthic forms are found living attached to plants, rocks, and sediment but can be found in the water column if there is sufficient mixing due to wave action, wind, or boating. Diatoms are present in the summer 2019 flora of Hess Lake, accounting for almost 49.9 % of the algal biomass in July, and over 36% of the biomass in August (Fig. 10).

Chlorophytes—the green algae range in size from single cells to large filamentous forms that are common on rocks and logs along the shorelines of many lakes. The green algae are most often common in mid-summer but can produce nuisance accumulations in the spring following ice-out. The greens were a small fraction of the late summer 2019 algae in Hess Lake accounting for less than 1% of the algal biomass in the July and August samples (Fig. 10).

Hess Lake Algae – July 2019

The late summer algal flora of Hess Lake (sampled 23 July 2019) was dominated by diatoms and cyanobacteria namely the cyanobacterium *Microcystis aeruginosa* and the diatom *Aulacoseira ambigua* (Table 4). *Aphanothece*, another cyanobacterium, was also common. The diatom species *Aulacoseira ambigua* made up the bulk of the diatom flora in Hess Lake contributing over 97% of the diatom biomass (Fig. 10). Cyanobacteria made up nearly 50% of the algal flora in Hess Lake on 23 July 2019 (Fig. 11). There were 3.5 million µm^3/mL of algae biomass in July 2019 with total cells at over 165,000 cells/mL including 1,700 diatom cells/mL and 163,000 cyanobacteria cells/mL (Fig. 11). Hess Lake is very productive (grows a lot of algae) and the dominance of *Microcystis*, a potential toxin producer, is of concern for lake residents, pets, and wildlife.

Hess Lake Algae – August 2019

The August 2019 algal flora of Hess Lake (sampled 19 August 2019) had decreased in abundance somewhat compared with July 2019. Hess had similar dominant species compared to July, namely the cyanobacterium *Microcystis aeruginosa* and the diatom *Aulacoseira ambigua* (Table 4). In addition, other cyanobacteria were common including *Aphanothece*, *Aphanocapsa*, and *Chroococcus* species (Table 4). August 2019 samples had slightly lower density (as biovolume) of algae compared with July 2019 with 2.9 million µm^3/mL in August 2019 vs 3.5 million µm^3/mL in July (Fig. 11). Cyanobacteria continued to be numerically abundant in August with total cell density of 275,000 cells/mL, higher than seen in July due to greater numbers of small-celled cyanobacteria (*Aphanocapsa* and *Aphanothece*). Total cell density was just over 276,000 cells/mL with diatoms only found at 400 cells/mL. Unfortunately, the cyanobacteria (two species of *Microcystis*) that dominate Hess Lake in late summer can produce nasty cyanotoxins that put pets and wildlife at risk and may cause skin and respiratory sensitivities in people.

Table 4. Predominant (>5% of total algal biovolume, µm^3/mL) algal species or genera in in Hess Lake sampled 23 July and 19 August 2019. Abbreviations of algal groups: CY = cyanobacteria, BA = diatoms, GR = greens, DI = dinoflagellates, CH = chrysophytes, CR = cryptomonads, EU = euglenoids.

Hess Lake	**Dominant algae**
Jul 2019	*Aulacoseira ambigua (BA), Microcystis (2 species including M. aeruginosa) (CY), Aphanothece (CY)*

Hess Lake	***Dominant algae***
Aug 2019	*Aulacoseira ambigua (BA), Microcystis (2 species including aeruginosa) (CY), Aphanothece (CY) Chroococcus (CY), Aphanocapsa (CY)*

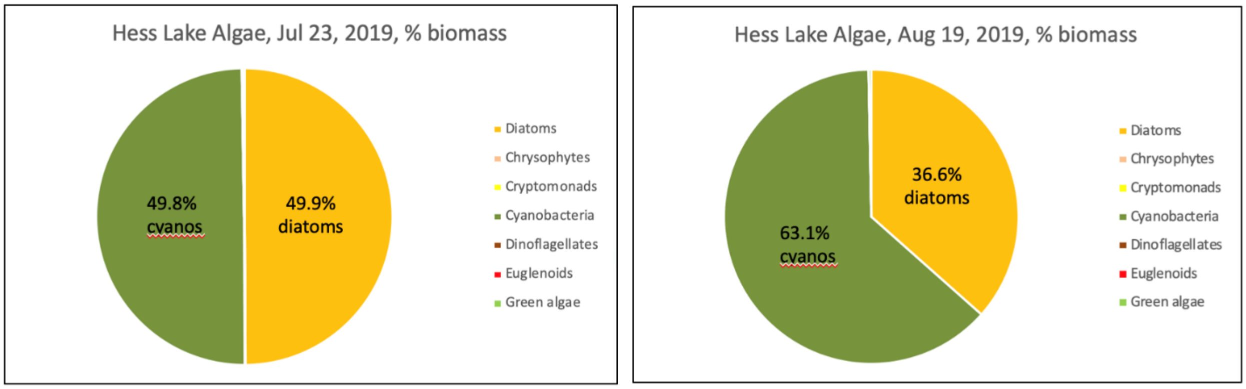

Fig. 10. Proportion of algal biovolume (measured as biovolume/mL) by algal group for Hess Lake, July 23 (left panel) and August 19, 2019 (right panel).

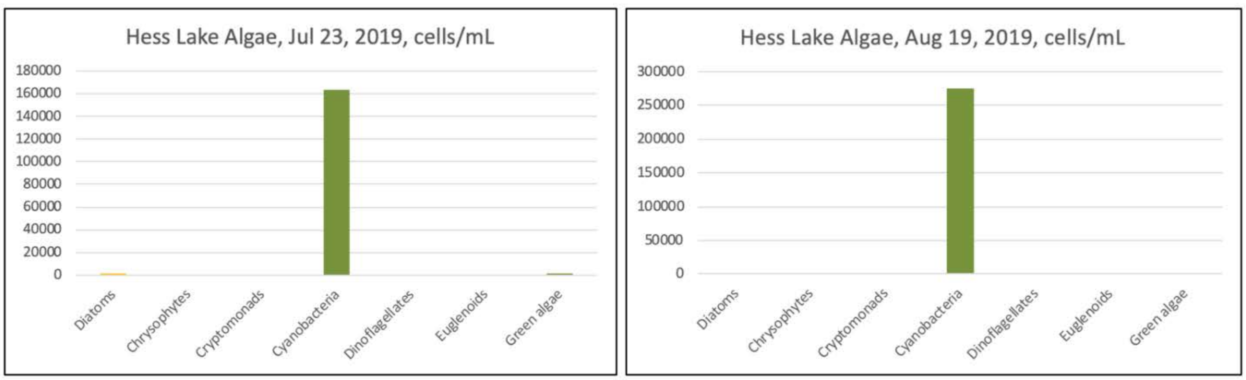

Fig. 11. Abundance of algae (cells/mL) by algal group for Hess Lake, July 23 (left panel) and August 19, 2019 (right panel). Note scale difference on y-axis

Algae are composed of two major groups: macro algae of which *Chara* is an example and of which much is growing in Hess Lake, and micro algae or phytoplankton, which are mostly microscopic organisms (discussed above), which can turn the lake to green or brown or cause massive floating mats of filamentous green algae (*Cladophora*) or blue-green algae, some members (*Microcystis*) of which have become famous in Lake Erie for closing down the Toledo water intake. We saw *Chara* in many places during our seining activities. It is an important plant, since it can take up nutrients, provides cover for insects and fish, and because it ties up nutrients, it can modulate algal blooms. Since this plant is an alga, a native species that provides cover for benthos and small fish, and it can tie up phosphorus by complexing phosphorus with calcium carbonate precipitation, it should not be treated chemically and encouraged to grow.

Picture 3. This is a zooplankton sample from Hess Lake on 23 July 2019. Note the greenish color of the sample. We seldom see this density of algae in a zooplankton sample.

We wanted to ensure that residents be on the lookout for an exotic alga species, called starry stonewort (Picture 3). Note this species is an alga, grows on the bottom in large tumble-weed like accumulations, and is a very destructive plant which can alter dissolved oxygen patterns and cover spawning sites for warm water centrachids (sunfish). It looks a lot like *Chara*, another green alga, but is somewhat different in that *Chara* usually has white calcium carbonate encrustations on its stems and feels gritty. Starry stonewort can enter a lake with boats contaminated with plants (and invertebrates and viruses) from other lakes, so efforts need to be made to alert residents who bring watercraft and gear in from other lakes and others who launch boats, canoes, and other water craft, to be careful about cleaning off their boats of any plant material or water, since zebra and quagga mussel veligers (larval forms) are a threat not yet experienced in your lake. A recent Michigan law has been passed to ensure these preventive measures. Quagga mussels are a closely related species to zebra mussels, but are much worse, since they do not require hard substrates to cling to like zebra mussels and can exist on oxygenated sediment bottoms. Quagga mussel adults or their young (veligers, which are microscopic) can come into the lake via the ballast water, bait buckets, or other infested water sources in boats/equipment from other contaminated lakes. Residents, who are out on the lake, often are on the front line and need to be observant and in-lake detectors. Report if seen.

Picture 4. Starry stonewort *Nitellopsis obtusa*. Note it can easily be confused with *Chara,* which is abundant in your lake and which is a closely related alga. *Chara* usually has gritty encrustations on the outside of the plant and is a positive feature of your lake. Google both to make sure.

Chlorophyll a

We measure densities of algae in a lake by using one of its pigments, Chlorophyll a, to approximate their density in the water. Algae are an important component of the Hess Lake ecosystem, since they convert sunshine to carbohydrates, which are eaten by zooplankton, essential food for larval fish. In addition, algae along with macrophytes are the living manifestation of the nutrient status of your lake and there are many unfortunate examples of the degradation of inland lakes by invasive macrophytes, such as Eurasian milfoil and the ruination of lakes with blue-green algae blooms that decompose, cause high-water turbidity, and are useless food for zooplankton. Unfortunately, this is the case for Hess Lake. The trophic status criteria for Chlorophyll a are:<2.2 ug/L - oligotrophic, 2.2-6 ug/L – mesotrophic, and >6 ug/L – eutrophic. The spring data from Progressive AE ranged from 4 to 12 ug/L making Hess Lake mostly eutrophic. Summer values were much lower, ranging from 3 to 5 ug/L, which are mesotrophic values. These data suggest that algae were very dense at two of the three stations in April, but that they were less dense during the August survey. Early data from September 1974 and April 1980 (from EPA STORET data) were respectively 7.1 and 17 ug/L, both way over the upper limit for eutrophic conditions.

Aquatic Macrophytes

We transected the lake many times during our sampling efforts during summer 2019. We did not specifically look for aquatic plants but noted them where ever we could. It was clear that the lake was dominated by algae, since our zooplankton sample was green (see Picture 3) and there were visible scums of blue-green algae floating along the shoreline. During August, our zooplankton net was covered with what looked like a green filamentous alga. We saw patches of lily pads in the Wheeler Creek area (Picture 2) and nearshore where we set our trap net (T3 – see Fig. 5). These patches of aquatic plants were scattered in a few places around the lake, but we did not see any large tracts of macrophytes. Consulting the historical dataset documented above (see History), we note that Levardsen (1951) stated that Hess Lake was the "weediest" lake he had ever seen. This is a clear depiction of Hess Lake as being dominated throughout the lake with dense stands of aquatic plants, making its current switch to algae-dominated all that more shocking. He noted that there were dense stands of *Potamogeton amphifolius* large-leaf pondweed and Eurasian milfoil *Myriophyllum spicatum* in front of Wheeler Drain, further implicating that drain as a major source of sediments and nutrients. There were other plants (coontail *Ceratophyllum demersum*) on the west end that were reported rotting and a subsequent fish kill was noted thereafter. A further examination of the records shows that in 1956 there was chemical control of: *Potomogeton* spp., eel grass *Vallisneria*, and milfoil. During 1958 *Pontoderia*, water lilies, bladderwort (*Utricularia*), and milfoil were treated, while during 1981 the lake had shifted mostly to algae. Ron Waybrant identified Eurasian milfoil, pondweeds, *Chara*, cattails, pickerel weed, curly-leaf pondweed, and *Elodea* waterweed as present in Hess Lake. During 1994 to 2010, there was some form of chemical control executed for Eurasian milfoil and curly-leaf pondweed. Schneider (2003) noted that ideal plant cover is about 30% and by this standard Hess Lake is way below that criterion. Hess Lake has shifted to algae dominance and some of the consequences are fewer benthos, high turbidity, affected zooplankton community, inability of visual-feeding fish to find prey, and lower fish survival.

Areas of macrophyte cover in Hess Lake are important fish habitat for several reasons. They provide nursery areas for small fish, shelter from predation, food organisms, spawning substrate; they also remove phosphorus, keeping algae under control and can be important in lakes with severe wave action, since they can retard wave action disturbing sediments. Most areas we seined had sparse to no macrophytes in the main lake.

Benthos

We did not collect any benthos samples but some information is available from previous studies and from our fish diet studies to make some inferences about them. No zebra mussels were noted by Edmonds Engineering studies in the early 1980s, nor did we see any during our collections. This is somewhat surprising given the large number of boats that ply Hess Lake waters. Follow good protocols to keep it that way. Our 2019 diet studies suggest there are some high-quality benthic organisms in the lake, despite its degraded condition. We found two mayflies

(Baetidae and *Caenis* spp.) and caddisflies, which require suitable substrate (probably gravelly shores) and high dissolved oxygen conditions. *Hyalella*, sometimes called fairy shrimp, are amphipods, which also flourish in water of high quality, usually in the presence of plants, such as *Chara*, which we observed in the lake. We also documented the presence of chironomids, sometimes called midges (members of the fly family, which usually dwell in sediments) and Ceratopogonidae (biting midges). Lastly, we found phantom midges (*Chaoborus* spp. – see Picture 12), which are unique creatures in that they are usually found in lakes with high turbidity or anoxic conditions in the hypolimnion, where they secure protection from fish predation. They are almost transparent and also perform a diel vertical migration, sitting on the bottom during daylight and rising to the surface at night to feed usually on zooplankton with their unique grasping legs. As we will discuss in the Fish Section below, these individuals were found in great abundance in channel catfish stomachs we examined.

Zooplankton

Zooplankton of the subphylum Crustacea are comprised of three major groups: Rotifera (rotifers), Copepoda (copepods), and Cladocera (cladocerans). Rotifers are usually smaller than most other zooplankters (pass through the net mesh) collected in this study. Copepoda (Picture 3) is comprised of three suborders or subgroups: Calanoida (calanoids), Cyclopoida (cyclopoids), and Harpacticoida (harpacticoids). The Copepoda group is usually faster and smaller than cladocerans; hence they are preyed on less than the cladocerans by fish, while on the other hand they are not as efficient feeders on algae as are the cladocerans. If Cladocerans are eating green algae, they provide a more nutritious food source for fish. Cladocerans are characterized by two main genera: *Daphnia* and *Bosmina*. These two groups, especially *Daphnia*, are large prey items for fish and in addition are more efficient at eating algae. This has two implications. First, fish will feed on the largest zooplankton prey available and examination of a sample of zooplankton can indicate if there is severe fish predation (e.g., stunted bluegills) or undesirable algae food supplies (blue-green algae), if one finds few *Daphnia* present in a sample collected during summer. Second, *Daphnia* can be very important in controlling algae and therefore increasing water clarity in a lake. *Daphnia* at around 20/L can filter the algae from an entire lake volume more than once per day if temperatures are moderate. Fish through predation can change the distribution from large to small sizes (e.g., small cladocerans, a few-fast moving copepods, and a lot of tiny rotifers). Copepods have low predation potential and cannot do much to reduce algae. Aquatic plants and low dissolved oxygen can provide refugia (shelter) for *Daphnia*, allowing them to flourish and feed at night; however, high turbidity and lake fertility diminish their survival, but can provide cover from fish predation. Zooplankters were sampled at two sites during two time periods (See Picture 3 and 5 for a picture of a zooplankton sample, Picture 6 for an example of a copepod, and Picture 7 for an example of *Daphnia*, a cladoceran). If there are large quantities of *Daphnia* present in the lake (the largest and most efficient at eating algae), they can have a positive effect on water clarity by removing algae from the water column, while also providing excellent food for fishes. On the other hand, if *Daphnia* are depauperate, then we can conclude that there could be intense fish predation and possible stunting ongoing, usually with bluegills. It may also mean that water quality conditions are deteriorated and that the algae have shifted to blue-green species, which are inedible by zooplankton. These conditions usually cause a shift in the zooplankton community to forms less susceptible to these conditions. Based on the high turbidity and blue-green algae bloom we observed when we did sampling, we hypothesized that the zooplankton would resemble the former explanation -- few if any *Daphnia* present.

We sampled zooplankton with a vertical tow of a plankton net at two stations (Z1 and Z2 – see Fig. 5) on 23 July and 19 August 2019. Results at the deep station (Z1) (Table 5) during July and August showed a startling presence of *Daphnia*, since they composed from 45% in July to 81% of the zooplankton community during August. This is not only surprising, but also one of the few favorable findings of our study. One of the main reasons we sample zooplankton, as noted above, was to determine how abundant *Daphnia* is, since they are important as consumers of algae (improves water clarity) and can inform us of how intense fish predation pressure is in a lake. Fish target the largest and slowest of its zooplankton prey and *Daphnia* is both. This suggests that fish predation is not very intense, since *Daphnia* are so abundant. Interestingly, a similar pattern was noted for the phantom midge, an insect that was apparently common at the deep station A, since channel catfish ate them almost exclusively. We seldom see phantom midges in clear water lakes or lakes with no anoxia, as fish consume them. *Diaphanosoma*, a crustacean, was also abundant in our zooplankton sample, composing 39% of the community in July. The remaining groups were all copepods, including *Diaptomus, Mesocyclops,* which are smaller than *Daphnia*, and faster and can usually escape predation or are not targeted if larger prey are available. Since *Daphnia* were common, more algae should be removed from the lake leading to lower algal abundance and increased water clarity. It also suggests that the zooplankton prey food source is underutilized, probably because of the high turbidity, and has led to fewer fish (yellow perch, bluegills, etc.) being produced. This is another example of the importance of understanding how food webs function. The zooplankton are important members of the Hess Lake ecosystem and appear to be healthy and functioning very well. Therefore, *Daphnia* filtration of algae acts as a small countermeasure to the increased nutrients in Hess Lake which will promote additional algae blooms.

Brian Kroll of Edmonds Engineering wrote that the low zooplankton density was due to the lake switching to blue-green algae, which are inedible by zooplankters, with which we agree. They prefer diatoms, which made up 37-50% of the algae we sampled during 2019 and may be the reason we had so many *Daphnia* in the zooplankton samples (45-81% of the totals in July and August – Table 5), despite the abundance of blue-green algae in the lake. However, they appear to be finding enough algal food to survive and flourish in Hess Lake, a great sign.

During July and August at the shallow station (Z2), *Daphnia* composed a high proportion of the zooplankton community as was found at the deep station, making up from 20% during July to 56% during August (Table 5). *Diaphanosoma* was the next most-abundant zooplankter making up 37% of the zooplankton community during July. Among copepods, immature *Diaptomous* composed 37 and 20% respectively during July and August. Comparing the deep with the shallow station results suggests that there was not much difference between them in the abundance of *Daphnia*, indicating that turbidity must be the factor reducing predation on zooplankton by the planktivores in Hess Lake.

Picture 5. Zooplankton sample.

Table 5. A listing of the abundance (% composition based on counting a random sample of at least 100 organisms) of zooplankton groups (see Picture 6-7) collected with a 153-micron-mesh plankton net towed vertically on 23 July and 13 August 2019 (Table 5) at stations Z1 and Z2 (see Fig. 5) in Hess Lake. Imm. = immature, M=male, F=female.

Station		Z1		Z1	
Date		23-Jul		19-Aug	
Taxa	Order	no	%	no	%
Diaptomus Imm.	**CALANOIDA**	32	20.4	4	2.3

Diaptomus ♂	CALANOIDA	2	1.3	2	1.1
Diaptomus ♀	CALANOIDA	7	4.5	4	2.3
Mesocyclops Imm.	CALANOIDA	8	5.1	4	2.3
Mesocyclops ♂	CALANOIDA	5	3.2	2	1.1
Mesocyclops ♀	CALANOIDA	7	4.5	4	2.3
Cyclops ♂	CYCLOIPDA				
Daphnia galeata	CLADOCERA	15	9.6		
Daphnia retrocurva	CLADOCERA	56	35.7	142	81.6
Diaphonosoma	DIPOSTRACA	61	38.9	12	6.9
Ceriodaphnia	CLADOCERA	5	3.2		
Leptodora kindtii	CLADOCERA	3	1.9		
Chydorus	DIPLOSTRACA				
Eubosmina	DIPLOSTRACA			2	1.1
Bosmina	DIPLOSTRACA	2	1.3		
Totals		157	100	174	100

Table 5. Continued.

Station		Z2		Z2	
Date		23-Jul		19-Aug	
Taxa	Group	no	%	no	%
Diaptomus Imm.	**CALANOIDA**	87	36.7	29	20.4
Diaptomus ♂	**CALANOIDA**	2	0.8	5	3.5
Diaptomus ♀	**CALANOIDA**	8	3.4	10	7.0
Mesocyclops Imm.	**CALANOIDA**	3	1.3	3	2.1
Mesocyclops ♂	**CALANOIDA**			2	1.4
Mesocyclops ♀	**CALANOIDA**	1	0.4	5	3.5
Cyclops ♂	**CYCLOIPDA**			1	0.7
Daphnia galeata	**CLADOCERA**			9	6.3
Daphnia retrocurva	**CLADOCERA**	48	20.3	70	49.3
Diaphonosoma	**DIPOSTRACA**	88	37.1	7	4.9
Ceriodaphnia	**CLADOCERA**			1	0.7
Leptodora kindtii	**CLADOCERA**	1	0.4		
Chydorus	**DIPLOSTRACA**	1	0.4		
Eubosmina	**DIPLOSTRACA**				
Bosmina	**DIPLOSTRACA**				
Totals		239	100	142	100

Picture 6. A copepod (zooplankter).

Picture 7. *Daphnia*, a large zooplankter, adept at eating algae.

Fish

We set three trap nets, two gill nets, and seined at three sites around the lake (Table 6). We had difficulty locating good sites for seining, since most of the shoreline has been hardened by riprap, sheet piling, or other structures or was so mucky we could not deploy a seine there. Station 2 west of Wheeler Drain was barely able to be seined because of thick (2 ft+) sediments. There were 13 species of fishes collected during our studies, which is low for most Michigan lakes (Table 7). Some largemouth bass scales from large fish were donated by Terry Roelofs, for which we are thankful. We collected scales, length, weight, sex, and diet information on selected species of fishes. The biggest surprise was the presence of channel catfish, which saturated our gill nets. Someone obviously stocked these fish in the lake previously. These fish, which ranged from 8.4 to 10.4 inches were from 4 to 5 years old, using St. Lawrence River data for comparison. They may be growing faster in Hess Lake. If true, these fish were stocked or hatched during 2015. These fish represent a future with a large number of hungry fishes as they grow bigger and turn their predation on fish. Fishers we spoke with said there were larger individuals in the lake as well. All of the individuals we examined that had food in their stomachs were eating mostly phantom midges *Chaoborus*, some chironomids, and sometimes a mass of plant material with green algae filamentous strands. Phantom midges live in or on the bottom muds and stay on the bottom during the day and rise to the surface at night to eat zooplankton and other invertebrates. They are usually not present in lakes with well oxygenated water and high water clarity, since fish eat them readily. Hence, the degraded dissolved oxygen conditions and low Secchi disk readings measured at the deep holes probably favors this insect.

We collected 40 largemouth bass (see Picture 13) that ranged in size from 2.1 to 14.9 in and we received more scale samples from larger fish donated to us by a local fisher. Apparently there is a good bass fishery in the lake and the presence of many YOY (young-of-the-year) fishes in our seine hauls and the gravelly and sandy substrate in some areas has favored good reproduction of this species, despite the degraded water quality and low visibility of the water. Larval fish will still have difficulty surviving since the water transparency is low impeding visual feeders and zooplankton they must have to survive (critical period) is degraded.

Yellow perch ranged in size from 2.9 to 5.7 inches, which is a small size range, indicating that there are not too many large perch in the lake. We would have captured larger individuals if they were common, since we set two gill nets in prime waters. The fish we did examine were feeding on insects and invertebrates, a good source of food, and one ate a Johnny darter. Fishers report northern pike in the lake, which are predators on yellow perch; however, reports are they are reduced in numbers recently and we caught none in our gill nets. Largemouth bass, which are common in the lake and voracious predators were eating yellow perch, so predation could be a factor in their lower survival.

One large black crappie (see Picture 13) and some YOY were captured indicating there is a population, although small, of this species in the lake. Since they do well under low transparency conditions, we expect them to possibly expand their populations under these turbid conditions. Like yellow perch, we caught no large bluegills, although YOY and some larger specimens to 4.8 in were captured. Pumpkinseeds were even rarer, since we only caught two small fish. These species will be stressed under the turbid conditions now existing in Hess Lake. We collected three species of minnows, golden shiners (see Picture 13) and bluntnose minnows, which are excellent forage and the common carp (see Picture 11), which is well known for its disruptive behavior in disturbing sediments and fostering increased turbidity. They appear to be common in Hess Lake. There were four other species captured in low numbers, including the banded killifish, Johnny darters (small members of the perch family), white sucker, and brook silversides.

The fish sampling we did during 2019 showed the presence of 13 species: golden shiners, bluntnose minnows, yellow perch, largemouth bass, white sucker, bluegill, pumpkinseeds, brook silversides, Johnny darter, black crappie, banded killifish, channel catfish, and common carp (Table 7). There are several prey species in the lake including an abundant bluegill YOY presence in several areas, especially near the public access site (station S3). We also caught brook silversides there. Pumpkinseeds, Johnny darters, small yellow perch, golden shiners, bluntnose minnows, white suckers, and brook silversides make up the rest of the prey species. Top predators included largemouth bass, northern pike (present but we caught none), channel catfish, and black crappie. Golden shiners are great prey for lakes, since they are prolific, grow to large sizes (up to 10 inches), and thus provide a range of sizes for the various sizes of the fish predators in the lake. Overall, our fish sampling efforts were sub-optimal for our trap nets, but the gill nets caught large numbers of channel catfish. Seining was more successful, but usually there had to be some macrophytes or other thick cover to provide good catches. This is in strong contrast with other more eutrophic lakes where we used these same gear and collected large numbers of fishes and did not set gill nets overnight for fear of over kill. This reflects the poor fish community present in Hess Lake. However, there is an apparently good largemouth bass fishery for those who are skilled at catching them. Catch-and-release fishing is suggested to maintain the current fishery for northern pike and largemouth bass. It appears there are an abundance of channel catfish, which should be utilized freely.

Table 5. Sampling times, fish catches, depths, and GPS locations where various fish samples were collected in Hess Lake, Newaygo County, Michigan, 19 August 2019. Also given are water quality sampling stations A and B. See Fig. 5 for station locations. G = gill net, T = trap net, S = seine, AL = algae, and Z = zooplankton sample. NP = northern pike (reported present), BG = bluegill, BC = black crappie, LB = largemouth bass, YP = yellow perch, PS = pumpkinseed, BM = bluntnose minnow, SV = brook silversides, SB = smallmouth bass, CP = common carp, CC = channel catfish, BK = banded killifish, YP = yellow perch, WS = white sucker GL=golden shiner, and JD = Johnny darter.

STA	TYPE	TIME START	TIME END	DEPTH (FT)	GPS	GPS	FISH SPECIES CAUGHT
A	WQ	19-Aug	19-Aug	19	N43 23.028	W85 45.861	WATER QUALITY SAMPLE
B	WQ	19-Aug	19-Aug	15	N43 23.255	W85 47.205	WATER QUALITY SAMPLE
Z1	ZOOP	19-Aug	19-Aug	10	N43 23.255	W85 47.205	ZOOPLANKTON
Z2	ZOOP	19-Aug	19-Aug	16	N43 23.028	W85 45.861	ZOOPLANKTON
AL	ALGAE	19-Aug	19-Aug	16	N43 23.028	W85 45.861	ALGAE
T1	FISH	19-Aug	20-Aug	3-5	N43 23.203	W85 47.199	BG YOY - FEW
	FISH	1800	1145				
T2	FISH	19-Aug	20-Aug	5-6	N43 23.457	W85 45.402	BC-LARGE
	FISH	1830	1210				
T3	FISH	19-Aug	20-Aug	5-6	N43 23.474	W85 46.064	BC,LB,BG - FEW
	FISH	1815	1200				
S1	FISH	19-Aug	19-Aug	2-5	N43 22.734	W85 45.903	BG,BM,JD,LB,YP,BK
	FISH	1915	1925				
S2	FISH	19-Aug	19-Aug	2-3	N43 23.033	W85 46.247	LB,BG,SV,YP
	FISH	1945	1925				
S3	FISH	19-Aug	19-Aug	2-3	N43 23.589	W85 46.972	BG,BM

	FISH	2030	2050				
G1	FISH	19-Aug	19-Aug	12-16	N42 23.058	W85 45.809	LB1,CP1,BC1,
	FISH	1600	2059				
G2	FISH	19-Aug	19-Aug	15-20	N43 23.267	W85 46.210	CC- ABUNDANT
	FISH	1610	2059				
G3	FISH	19-Aug	20-Aug	9-12	N42 23.058	W85 45.809	CC-MANY,WS-FEW,CP-FEW
	FISH	2100	1030				

Fish diversity

We collected 13 fish species (Table 7) using three different gear types in Hess Lake: Seines (Picture 8), trap nets (Picture 9), and gill nets (Picture 10, 11) (see Table 6 for GPS and times of gear deployment). This fish community is suboptimal and a reflection of the current degraded water quality conditions in the lake. Channel catfish, which are not native to the lake, are common, eating insects, and eventually will create a substantial appetite/demand for prey fish and since they feed efficiently at night, will have a big impact on nearshore fishes. Whether the fishers on the lake regard this as a good outcome, remains to be seen. Catfish are certainly good eating. There are three minnows in the lake, two are great prey fish (bluntnose minnows and golden shiners) while the third is the curse of many lakes, the common carp. Common carp appear to be common based on our catches and reports from lake residents. They are well known for rooting up sediments, consuming fish eggs, and creating turbid conditions. They need to be controlled by any means possible by residents (via hook and line and bow and arrow fishing). We are aware of efforts to control this species with awards given out during summer as designated times for killing this species. This should be continued, and we can make two additional recommendations, that if the MDNR supports these efforts, could also contribute to lowering of their populations. One would be to do some trammel netting during the spawning season in known spawning areas of the lake, which has been given support by MDNR. Second, a weir could be installed at the mouth of Wheeler Drain and fish within disposed of during the spawning season. This would require not only MDNR approval but also acquiescence of the people who live along the canal because access from land would make harvesting easier. It could be placed far enough toward the dam that it would not impede any boat progress. We need to study this option further if it is agreed on to implement.

There are four main predators in the lake: northern pike (we caught none), black crappies, channel catfish, and largemouth bass. Bullheads are efficient predators as well, are undoubtedly present, but we caught none. Largemouth bass seem to be at moderate levels. Spawning by northern pike is one of our concerns. Hess Lake has an outlet and several creeks that enter the lake that may be northern pike spawning areas. They require vegetation of some sort to lay eggs and for attachment of larvae and plants are rare in the lake now. Flooded vegetation can also provide adequate spawning substrate, but it appears that northern pike are scarce in the lake, both due to degraded spawning sites, high turbidity which will depress their ability to catch prey fish, and warm temperatures, which will stress them during the warm months of the year. There are several prey species in the lake including bluegills (small to large specimens are present), brook silversides, which is a small smelt-like fish, which jumps out of the water often when predators are chasing it. Pumpkinseeds, Johnny darters, small yellow perch, white suckers, golden shiners, bluntnose minnows make up the rest of the prey populations. However, those fishes that are present seem to be healthy and there is a moderate diversity of sport fishes that should provide a continuing fishery, especially if catch-and-release fishing is practiced for the large northern pike and largemouth bass.

The yellow perch population seems truncated and small, since we only caught small yellow perch. We have seen this in many lakes where northern pike were abundant, since they prefer yellow perch when they cannot catch the soft-rayed fishes. Obviously, there is still modest reproduction ongoing for yellow perch, since we collected some small specimens (YOY- Young-of-the-Year) of this species.

Picture 8. Seine deployment. A 50-ft seine was used to collect fish for diet and ageing studies.


Picture 9. Two of the trap nets used in Hess Lake fish sampling activities, 13 August 2019.

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Picture 10. An example of an experimental, nylon gill net being brought into the boat in Hess Lake, 19 August 2019. Note channel catfish in net.

Picture 11. One of the fishes collected in gill nets set in Hess Lake, 19 August 2019. This specimen is called a mirror common carp (*Cyprinus carpio*) and is one of many invasive carp inhabiting Hess Lake.

Table 7. Common name, sample size, and size range (inches) of the fishes collected from Hess Lake during 19-20 August 2019. Scales from a number of largemouth bass from 14 to 18 inches were submitted by a fisher. N = 13 species captured.

Species	**Sample size**	**Size range (in)**
Black crappie	9	2.7-10.8
Bluegill	20	1.4-4.8
Banded killifish	1	2.7
Bluntnose minnow	39	1.4-3.3
Channel catfish	92	8.4-10.4
Common carp	4	21.3-23.4
Golden shiner	11	2.9-7.1
Johnny darter	10	1.8-2.2

Largemouth bass	40	2.1-14.9+
Pumpkinseed	2	3.2-3.5
Brook silversides	13	2.4-2.8
White sucker	2	9.7-10.7
Yellow perch	11	2.9-5.7

Fish Diets

During 2019, we examined the stomachs of many fishes of the 13 species we caught (Table 8). Most fish were eating productive food items, some of which testify to the high water quality of Hess Lake, such as mayflies and caddisflies and the amphipod *Hyalella*.

Black crappies (9 sampled) ranged from 2.7 to 10.8 inches with the smaller fish (YOY) eating zooplankton *Bosmina*, phantom midges (*Chaoborus* spp. – see Picture 12), and chironomids (Table 8). The larger individuals all had empty stomachs.

Bluegills we caught only ranged from 1.4 to 4.8 inches, which suggests they are not as common nor as large as we usually find in eutrophic lakes. Certainly, there are adequate sites of sand and gravel for spawning beds, but the high turbidity may inhibit their larval forms and YOY from visually locating food. The YOY were all eating zooplankton (copepods), while the larger individuals (3.5-4.8 inches) were eating mayflies, caddisflies, water mites *Hydracharina*, ostracods, ants, and the amphipod *Hyalella*, which is also a sensitive species.

Also, recall that one of the reasons we sampled zooplankton was to find out how abundant *Daphnia* were (very) and whether they were being eaten intensely by fish. The answer for Hess Lake was that zooplankton were eaten, but not *Daphnia*. This is a vastly underutilized prey resource.

PICTURE 12. **A**. Stomach contents of one channel catfish captured in Hess Lake, 19 August 2019. These are mostly phantom midges **B**. (*Chaoborus* spp.) members of the fly (Diptera) family that are usually not present in lakes because of fish predation. They appear to be very abundant in Hess Lake, probably because of the high turbidity giving them protection from predation and the low dissolved oxygen on the bottom in the two deep holes, preventing fish from feeding there. This species exhibits a diel vertical migration pattern, wherein they stay on the bottom during the day to avoid fish predation and come to surface waters at night to feed, usually on zooplankton.

Channel catfish was a surprise fish in our study, both because they were even present and because they were so numerous. There was no mention of them in the historical data we searched which went through 2010; we estimated they were stocked sometime during or around 2015. They are present in adjacent Brooks Lake. They ranged from 8.4 to 10.4 inches with reports from fishers that there were many larger ones in the lake. Fish stomachs we examined contained mainly phantom midges (see Picture 12 above), but also some other insects and algae were eaten. Other prey included: filamentous green algae, insect parts, zooplankton *Leptodora* (a large zooplankton predator), chironomids, the mayfly *Caenis*, and an unknown fish thought to be a golden shiner. Up to 200 phantom midges were observed in individual stomachs and in several cases large numbers of chironomids were also consumed. As we noted above, phantom midges are usually absent from eutrophic lakes unless they have high turbidity and/or anoxia in the bottom waters, which prevents fish from accessing to them. They also reside on the bottom during the day and ascend to surface waters at night to avoid predation. Hess Lake may be providing refuge for phantom midges because of high turbidity and low dissolved oxygen, but channel catfish have a high tolerance for low dissolved oxygen and seem to have zeroed in on this prey species eating them on the bottom or perhaps when they enter the water column at night when most channel cats feed. Since they also ate zooplankton they certainly are feeding in the water column and the fact they ate one fish indicates they will switch over to fish when opportunity arises. We should expect that in future years these channel cats will grow much larger and will affect the fish ecology of the lake by eating large numbers of prey species. Lastly, some were eating filamentous green algae. This is unusual for channel catfish. We can only speculate that they may have been trying to eat insects embedded in the algae, but we did not see any in the stomachs with algae we examined.

We caught four large common carp, which were eating what could best described as detritus with some algae as well. Common carp are known for eating insects, detritus, fish eggs, and plants.

Largemouth bass are typically benthivorous, while young then switch over to piscivory when older. Data we collected mostly confirmed this with the exception that some YOY were eating fish. YOY largemouth bass 2.1-4.8 in were eating zooplankton (*Bosmina*), ants, bluegills 1.3-1.4 in, and bluntnose minnows 1.8 inches (Table 8). The larger largemouth bass (14.4-14.9 inches) were exclusively eating fish: two yellow perch YOY that were 1.5-2.8 in long. Clearly, largemouth bass are helping control the prey fish population in Hess Lake, but to the detriment of the yellow perch population.

Pumpkinseeds are known for being molluskivores (snail eaters), but those in Hess Lake were not following that pattern. First, pumpkinseeds were scarce in our catches. The two fish we did catch were YOY fish (3.2-3.5 in) and were eating10 chironomid larvae and 2 caddisflies. Since the lake has been overtreated with copper sulfate to control algae, snails, which are susceptible to copper have probably been reduced drastically. This would reduce growth and survival of pumpkinseeds in Hess Lake.

Yellow perch collected were 2.8-5.7 inches. Again, we expected to catch more and a wider size range of fish. Usually we can attribute the lack of larger yellow perch to northern pike predation, but northern pike are not abundant in Hess Lake. Never-the-less, some reproduction of yellow perch is ongoing. Yellow perch 2.8-3.3 in (YOY) consumed insects, including caddisflies, chironomids, and the biting midge Ceratopogonidae (Table 8). Many of these prey items depend on macrophytes for food and habitat, again, stressing the importance of these plants in the overall ecology of the lake. The larger yellow perch (4.4-5.7 in) were eating caddisflies, the small mayfly *Caenis*, and one Johnny darter.

Picture 13. Two predators (A. Largemouth bass and black crappie) and one of the minnows (B. Golden shiner) captured in Hess Lake 19 August 2019.

Table 7. List of specimens caught including lengths, weights, sexes, and diets of selected species of fishes collected from Hess Lake, 19 August 2019. M= male, F = female, 1 = gonads poorly developed, 2 = moderately developed, and 3 = well developed, NA= not available, MT=empty stomach, YOY=young-of-the-year, XX=unknown. See Table 6 for gear set times and Fig. 5 for locations. S=seine, T=trap net, G=gill net. Number after gear code is a station designator.

STATION	SPECIES	Len(in)	WT (Oz)	SEX	DIET
		Black Crappie			
S3	BC	2.7	0.1		
S3	BC	2.8	0.2	II	ZOOPLANKTON
T1	BC	2.9	0.2	II	ZOOPLANKTON,PHANTOM MIDGE-8,CHIRONOMID-3
T1	BC	3.0	0.2	II	ZOOPLANKTON,PHANTON MIDGE-7
T1	BC	3.0	0.2	II	PHANTOM MIDGE-10,CHIRONOMID-5,ZOOP-BOSMINA
S3	BC	3.1	0.2	II	MT
T3	BC	5.9	1.6	F1	MT
G1	BC	5.9	1.6	F1	MT
T2	BC	10.8	8.1	M1	MT
		Bluegill			
S3	BG	1.4	NA	NA	NA
T1	BG	1.5	0.03	II	MT
T1	BG	1.5	NA		
T1	BG	1.5	NA		
T1	BG	1.6	0.03	II	ZOOPLANKTON- LONG ANTENNA: COPEPODS
T1	BG	1.6	0.02	II	MT
T1	BG	1.7	NA		
T1	BG	1.7	NA		
T1	BG	1.7	0.04	II	ZOOPLANKTON
S1	BG	1.9	NA	NA	
S1	BG	1.9	NA	NA	
S1	BG	2.6	NA	NA	
S3	BG	3.5	0.4	CC	
S1	BG	3.5	NA	NA	
T1	BG	3.5	0.4	II	WATER MITE,HYALELLA,OSTRACOD,BAETIDAE,FIL ALGAE
S1	BG	3.5	NA	NA	
S3	BG	4.1	0.7	II	
S3	BG	4.5	0.9	CC	CADDISFLIES 2, ANTS 2
S1	BG	4.6	1.0	F1	INSECT PARTS
T3	BG	4.8	1.2	II	INSECT PARTS
		Banded Killifish			

S1	BK	2.7	0.1		
		Bluntnose Minnow			
S2	BM	1.4	NA		
S2	BM	1.5	NA		
S1	BM	1.7	NA		
S2	BM	1.8	NA		
S2	BM	1.8	NA		
S2	BM	1.9	NA		
S3	BM	2.0	NA		
S2	BM	2.0	NA		
S2	BM	2.1	NA		
S3	BM	2.1	NA		
S3	BM	2.3	NA		
S3	BM	2.4	NA		
S3	BM	2.4	NA		
S2	BM	2.4	NA		
S3	BM	2.4	NA		
S3	BM	2.4	NA		
S1	BM	2.4	NA		
S3	BM	2.5	NA		
S2	BM	2.5	NA		
S1	BM	2.5	NA		
S3	BM	2.5	NA		
S2	BM	2.6	NA		
S3	BM	2.6	NA		
S3	BM	2.6	NA		
S3	BM	2.7	NA		
S1	BM	2.8	NA		
S3	BM	2.9	NA		
S3	BM	2.9	NA		
S1	BM	3.0	NA		
S3	BM	3.1	NA		
S3	BM	3.1	NA		
S3	BM	3.1	NA		
S3	BM	3.1	NA		
S3	BM	3.1	NA		
S3	BM	3.1	NA		
S3	BM	3.2	NA		
S3	BM	3.2	NA		
S3	BM	3.3	NA		
S1	BM	3.3	NA		
		Channel Catfish			
G1	CC	8.4	2.5	M1	MT

G2	CC	8.4	2.0	F1	ALGAE IN GUT
G3	CC	8.5	2.2	M1	MT
G3	CC	8.5	2.1	F1	MT
G3	CC	8.6	3.0	F1	MT
G3	CC	8.7	2.6	F1	PHANTOM MIDGES 50
G3	CC	8.7	2.9	F1	PHANTOM MIDGES 45, INSECT PARTS
G3	CC	8.7	2.3	M1	MT
G3	CC	8.8	2.8	M1	MT
G3	CC	8.8	2.7	M1	PHANTOM MIDGES 65
G1	CC	8.9	2.9	M1	FILAMENTOUS GREEN ALGAE
G2	CC	8.9	3.0	M1	MT
G3	CC	8.9	2.8	F1	MT
G3	CC	8.9	2.9	F1	PHANTOM MIDGES 75
G3	CC	8.9	3.0	M1	MT
G2	CC	9.0	3.1	F1	MT
G2	CC	9.0	3.0	F1	MT
G2	CC	9.0	3.1	M1	PHANTOM MIDGES 60
G1	CC	9.1	3.5	F1	MT
G2	CC	9.1	2.9	F1	PHANTOM MIDGES 90
G2	CC	9.1	2.8	M1	MT
G3	CC	9.1	2.7	F1	ZOOP: LEPTODORA, P MIDGES 30, CHIR - 5, CAENIS 2
G3	CC	9.1	2.8	F1	PHANTOM MIDGES 40, CHIRONOMIDS 50, FIL. ALGAE
G3	CC	9.1	3.0	F1	PHANTOM MIDGES 70, CHIRONOMIDS 20, FIL ALGAE
G2	CC	9.1	3.1	M1	ALGAE IN GUT
G1	CC	9.1	3.1	F1	MT
G1	CC	9.1	3.1	M1	MT
G3	CC	9.2	2.9	F1	MT
G1	CC	9.2	3.2	M1	MT
G2	CC	9.2	2.9	M1	MT
G3	CC	9.2	2.9	NM1	MT
G3	CC	9.2	2.9	F1	PHANTOM MIDGES 80, INSECT PARTS
G3	CC	9.2	2.8	F1	MT
G3	CC	9.2	3.0	F1	MT
G3	CC	9.2	2.9	F1	MT
G1	CC	9.3	3.4	F1	MT
G2	CC	9.3	3.4	F1	MT
G2	CC	9.3	2.7	M1	MT
G2	CC	9.3	2.8	M1	MT
G2	CC	9.3	3.4	M1	PHANTOM MIDGES 60, INSECT PARTS, FIL. ALGAE
G1	CC	9.3	3.5	F1	MT
G1	CC	9.3	3.2	F1	MT
G2	CC	9.3	2.9	F1	MT
G1	CC	9.3	3.1	M1	MT

G1	CC	9.3	3.2	M1	MT
G3	CC	9.3	2.8	M1	MT
G1	CC	9.3	2.9	F1	MT
G2	CC	9.3	3.0	F1	MT
G3	CC	9.3	3.2	F1	MT
G3	CC	9.3	3.0	F1	ALGAE IN GUT
G1	CC	9.3	3.4	M1	MT
G3	CC	9.3	2.9	M1	PHANTOM MIDGES 30
G3	CC	9.3	3.1	M1	ALGAE IN GUT
G3	CC	9.3	3.0	M1	MT
G1	CC	9.4	3.5	F1	MT
G1	CC	9.4	3.1	M1	XX FISH GOLDEN SHINER?
G1	CC	9.4	3.6	M1	MT
G2	CC	9.4	3.3	M1	MT
G2	CC	9.4	3.2	M1	PHANTOM MIDGES 200
G2	CC	9.4	3.2	M1	MT
G3	CC	9.4	3.4	M1	PHANTOM MIDGES 60
G3	CC	9.4	3.1	M1	PHANTOM MIDGES 60
G3	CC	9.4	3.3	F1	MT
G3	CC	9.5	2.9	M1	MT
G3	CC	9.6	3.2	f1	ALGAE IN GUT
G3	CC	9.6	3.2	F1	MT
G3	CC	9.6	3.2	F1	PHANTOM MIDGES 50
G3	CC	9.6	3.3	M1	MT
G1	CC	9.6	3.4	F1	MT
G2	CC	9.6	3.5	M1	FILAMENTOUS ALGAE IN GUT
G3	CC	9.6	3.1	M1	MT
G3	CC	9.6	3.0	M1	MT
G1	CC	9.7	3.8	F1	CHIRONOMID-1, DETRITUS
G1	CC	9.7	3.7	M1	MT
G2	CC	9.7	3.4	M1	MT
G2	CC	9.7	3.4	M1	ALGAE IN GUT
G2	CC	9.7	3.2	M1	MT
G3	CC	9.7	3.3	M1	MT
G1	CC	9.7	3.5	M1	MT
G3	CC	9.8	3.4	M1	MT
G3	CC	9.8	3.6	M1	MT
G2	CC	9.9	3.7	F1	MT
G2	CC	9.9	3.8	M1	MT
G1	CC	9.9	3.8	M1	MT
G3	CC	10.0	4.1	F1	MT
G2	CC	10.1	3.4	F1	MT
G3	CC	10.1	3.8	M1	FILAMENTOUS ALGAE IN GUT

G1	CC	10.1	4.1	F1	MT
G3	CC	10.3	3.5	F1	PHANTOM MIDGES 5
G3	CC	10.3	4.5	M1	ALGAE IN GUT
G3	CC	10.3	3.9	M1	PHANTOM MIDGES 80, CHIRONOMIDS 8
G3	CC	10.4	3.8	M1	PHANTOM MIDGE (*Chaoborus*) 1, CHIRONOMIDS 20
		<u>Common Carp</u>			
G1	CP-m	21.3	NA	M2	THICK DETRITUS; ALGAE?
G1	CP	22.0	NA	F2	MT
G1	CP	22.8	NA	F2	THICK DETRITUS; ALGAE?
G1	CP	23.4	NA	F2	MT
		<u>Golden Shiner</u>			
S3	GL	2.9	NA		
S3	GL	2.9	NA		
S3	GL	3.1	0.1		
S3	GL	3.2	NA		
S3	GL	3.3	0.2		
S3	GL	3.4	NA		
S3	GL	3.4	NA		
S3	GL	3.5	NA		
S3	GL	3.5	NA		
S3	GL	3.5	NA		
G3	GL	7.1	6.3	NA	NA
		<u>Johnny Darter</u>			
S1	JD	1.8			
S1	JD	1.8			
S1	JD	1.8			
S1	JD	1.9			
S1	JD	1.9			
S1	JD	1.9			
S3	JD	1.9	0.03	CC	NA
S3	JD	2.0	0.03	CC	NA
S3	JD	2.0	0.04	CC	NA
S1	JD	2.2			
		<u>Largemouth Bass</u>			
S3	LB	2.1	NA		
S2	LB	2.2	0.1	II	FLYING ANT
S2	LB	2.2	0.1	II	ZOOPLANKTON
S1	LB	2.4	NA		
S3	LB	2.4	NA		
S2	LB	2.4	0.1	II	FLYING ANTS
S1	LB	2.4	NA		
S1	LB	2.4	NA		
S3	LB	2.5	NA		

S3	LB	2.6	NA		
S3	LB	2.6	NA		
S3	LB	2.6	NA		
S1	LB	2.6	NA		
S3	LB	2.7	NA		
S3	LB	2.7	NA		
S2	LB	2.7	0.1	II	FLYING ANTS
S1	LB	2.7	NA		
S3	LB	2.9	0.2	II	
S2	LB	2.9	0.2	II	FLYING ANTS
T1	LB	3.0	0.2	II	BG 36 MM
T1	LB	3.1	0.2	II	BG 33 MM
S2	LB	3.1	0.2	II	BM 45 MM
S3	LB	3.1	0.2	II	
S1	LB	3.1	NA		
S2	LB	3.1	0.2	II	FLYING ANT-20
S2	LB	3.1	0.2	II	FLYING ANTS,UNKNOWN FISH 38 MM
T3	LB	3.2	0.2	II	ZOOPLANKTON Bosmina abundant
T1	LB	3.2	0.2	II	MT
T3	LB	3.3	0.2	II	ZOOPLANKTON Bosmina abundant
S2	LB	3.3	0.2	II	UNKNOWN FISH 35 MM
S2	LB	3.4	0.3	II	FLYING ANTS
S1	LB	3.4	NA		
S1	LB	3.5	0.2		
S2	LB	3.5	0.3	II	BM 45 MM
S1	LB	3.5	0.3		
S2	LB	3.6	0.4	II	UNKNOWN FISH
S1	LB	4.8	0.8		
SP	LB	14.4	2.5	F1	YELLOW PERCH 38, 70 MM
G1	LB	14.9	24.0	M1	MT
		<u>Pumpkinseed</u>			
S3	PS	3.2	0.3	F1	
S3	PS	3.5	0.4	F1	CHIRONOMID LARVAE 10, CADDISFLIES 2
		<u>Brook Silversides</u>			
S2	SV	2.2	NA		
S2	SV	2.4	NA		
S2	SV	2.4	NA		
S2	SV	2.5	0.05		
S2	SV	2.5	NA		
S2	SV	2.6	NA		
S2	SV	2.6	NA		
S2	SV	2.6	NA		
S2	SV	2.6	NA		

S2	SV	2.6	NA		
S2	SV	2.8	NA		
S2	SV	2.8	NA		
S2	SV	2.8	NA		
		White Sucker			
G3	WS	9.7	5.2	NA	NA
G3	WS	10.7	7.8	NA	NA
		Yellow Perch			
S1	YP	2.8	0.1	F1	MT
S3	YP	2.9	0.1	F1	CADDISFLIES
S2	YP	3.0	0.2	M1	CHIRONOMID LARVAE-5, PUPAE-11,CADDISFLIES
S3	YP	3.2	0.2	M1	CERATOPOGONIDAE 1, CHIRONOMID 5, CADDISFLIES 3
S2	YP	3.3	0.2	F1	MT
S2	YP	3.3	0.2	F1	CHIRONOMID-30
S1	YP	4.4	0.5	F1	CADDISFLIES 4, CAENIS 1
S1	YP	4.6	0.5	F1	CADDISFLIES 4, WATER MITE 1, CHIRONOMIDS 4
S1	YP	4.6	0.6	F1	CADDISFLIES 3
S3	YP	4.9	0.6	M1	MT
S3	YP	5.7	1.0	F1	JOHNNY DARTER 38 MM

Fish Growth

Growth of bluegills during our 2019 study (Table 9, Fig. 12) had a maximum size in our catches of 4.8 inch and showed that age-0 (YOY), 1-yr-old, and 2-yr old fish were growing slightly below state means. Bluegills appear to be common in the lake, but the lack of larger fish in our nets is especially concerning. There was a good crop of YOY fish that will provide forage for some top predators. Growth and diet for the fish we examined were certainly adequate, but the lack of big fish is an issue.

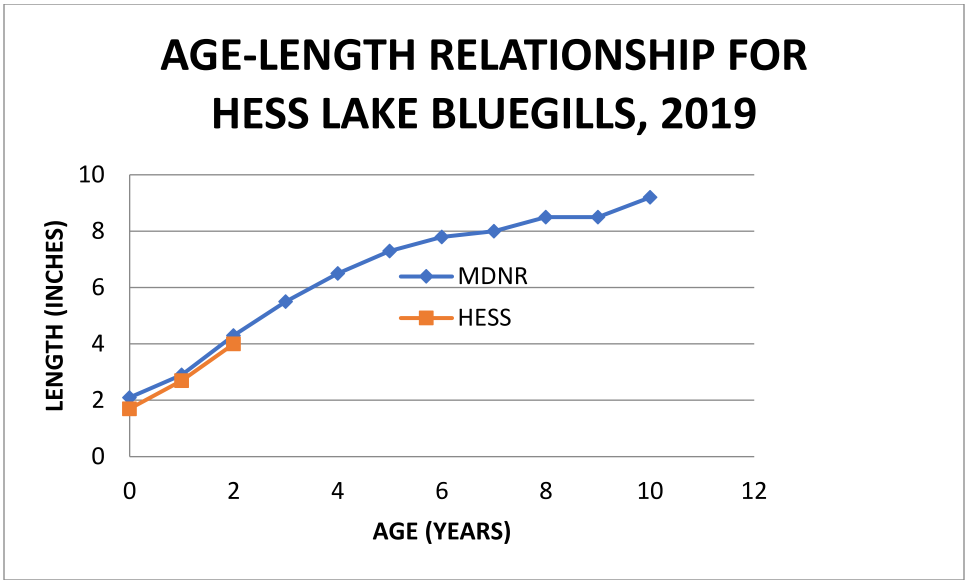

Figure 12. Growth of bluegill in Hess Lake (red circles) compared with the Michigan state averages (blue circles) (see Latta 1958, Laarman 1963), 19 August 2019. See Table 9 for raw data. N=21.

Table 9. Growth of selected fishes collected from Hess Lake, Newago Co., 19 August 2019. 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; Laarman 1963). Shown is the age (years) of the fish, its total length (inches) based on MDNR state of Michigan mean lengths, and the mean length-at-age of Hess Lake fishes. Total no. fish aged given at top as N. See Figs. 12-16 for a graphical display of these same data.

Age (yr)	**MDNR** Len (in)	**HESS** Len (in)
BLUEGILL		**N=21**
0	2.1	1.7(12)
1	2.9	2.7(1)
2	4.3	4(8)
3	5.5	
4	6.5	
5	7.3	
6	7.8	
7	8	
8	8.5	
9	8.5	
10	9.2	

LARGEMOUTH BASS		**N=52**
0	3.3	2.9(37)
1	6.1	4.8(1)
2	8.7	
3	10	
4	12.1	
5	13.7	14.2(6)
6	15.1	15.5(4)
7	16.1	16.8(4)
8	17.7	
9	18.8	
10	19.8	
11	20.8	
PUMPKINSEED		**N=3**
0	2	
1	2.9	3(2)
2	4.1	3.5(1)
3	4.9	
4	5.7	
5	6.2	
6	6.8	
7	7.3	
8	7.8	
YELLOW PERCH		**N=11**
0	3.3	3.1(6)
1	4	4.5(3)
2	5.7	5.3(2)
3	6.8	
4	7.8	
5	8.7	
6	9.7	
7	10.5	
8	11.3	
9	11.7	
BLACK CRAPPIE		**N=15**
0	3.6	2.9(6)
1	5.1	5.9(2)
2	5.9	
3	8	
4	9	
5	9.9	
6	10.7	10.8(1)
7	11.3	

8	11.6

Largemouth bass were present in the lake at all our seine sites, but we did not catch any larger than 14.9 inches. However, there were a number of larger individuals provided by a fisher. There were many YOY fish indicating good reproduction, probably because of abundance of sand and gravel in some places for making nests. Age-1 fish grew below state means, while larger fish (5-7-yr old) were all growing at state means (Fig. 13).

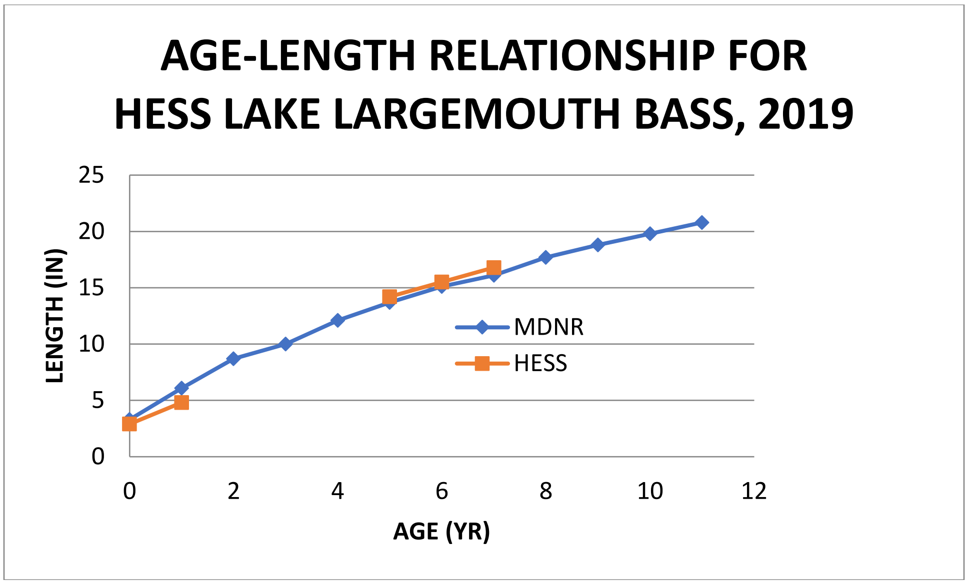

Figure 13. Growth of largemouth bass in Hess Lake (red circles) compared with the Michigan state averages (blue circles) (see Latta 1958, Laarman 1963), 19 August 2019. See Table 9 for raw data. N=52.

We caught nine black crappies (2.7-10.8 in) in Hess Lake and they were growing mostly at state means (Fig. 14, Table 9). YOY grew slightly below state means, while 1- and 6-yr olds were growing at state means. They are important predators in the lake, seem to be uncommon, and provide another good sport fish for the sport fishers plying the lake.

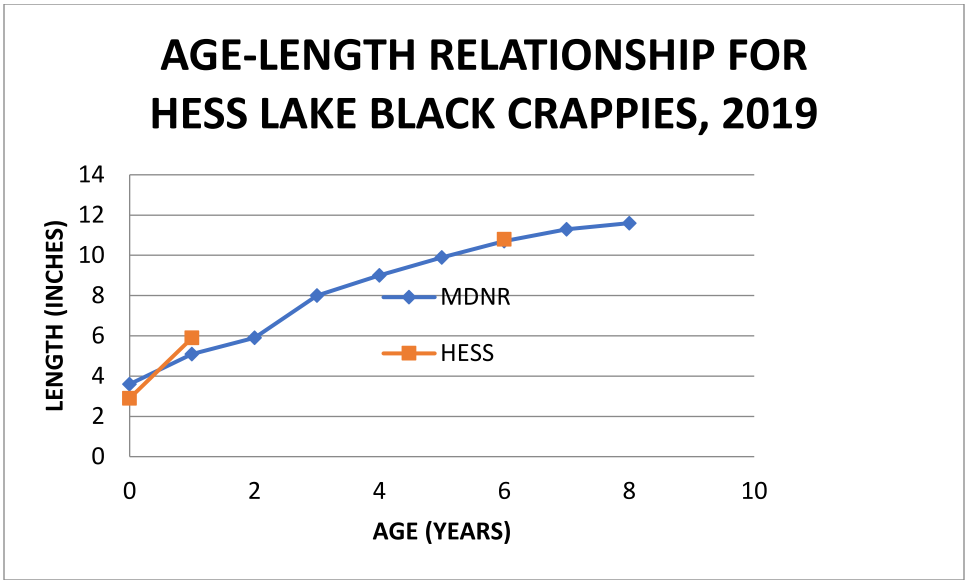

Figure 14. Growth of black crappies in Hess Lake (red circles) compared with the Michigan state averages (blue circles) (see Latta 1958, Laarman 1963), 19 August 2019. See Table 9 for raw data. N=15.

We collected only two pumpkinseeds (3.2- 3.5 in) in the lake during our 2019 study. They were growing at about state standards (Fig. 15, Table 9) and we attribute their scarcity to the fact they rely heavily on mollusks (snail, clams) and the past and current efforts to control algae in the lake by treatment with copper sulfate, will also kill snails and clams, denying them an important source of food. Pumpkinseeds are an important component of the fish community because they prey on an underutilized prey source: snails, mussels, and clams, so their poor representation in the fish community is a serious loss of biodiversity.

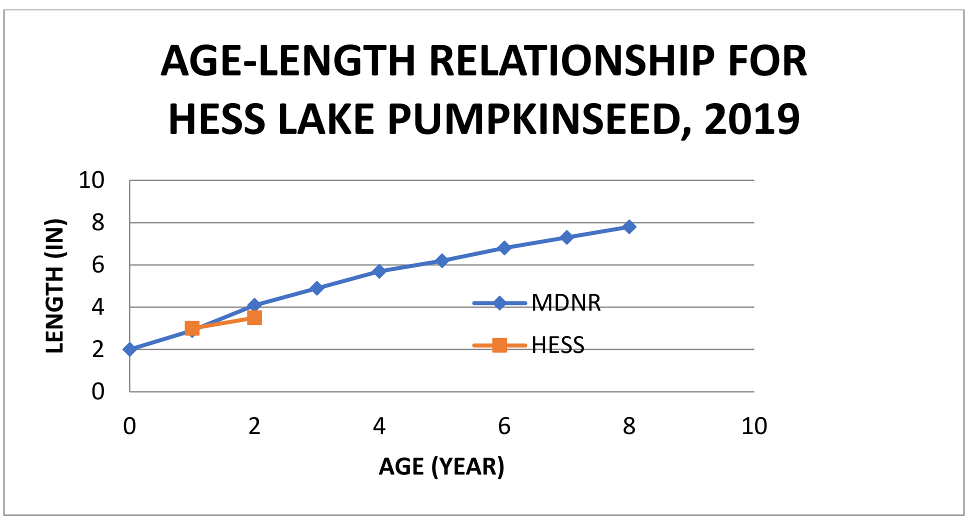

Figure 15. Growth of pumpkinseed in Hess Lake (red circles) compared with the Michigan state averages (blue circles) (see Latta 1958, Laarman 1963), 13 August 2019. See Table 9 for raw data. N=3.

We collected only 11 yellow perch (2.8-5.7 in) in Hess Lake, indicating probable severe predation by northern pike (preferred prey) and largemouth bass and/or such degraded water quality conditions, that it fosters poor survival. Prime-sized fish were not caught in our nets, suggesting they are rare. The young ones we caught (YOY - 2-yr olds) were growing at state means (Fig. 16, Table 9). Yellow perch appear to be scarce in the lake and will remain so with the current severe turbidity, degraded food web on which they depend, and northern pike and largemouth bass predation effects.

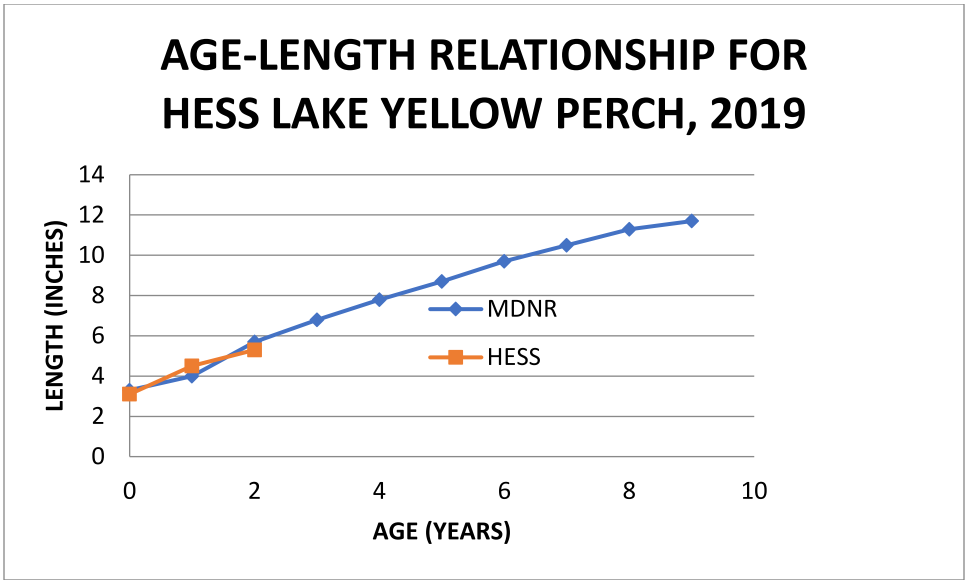

Figure 16. Growth of yellow perch in Hess Lake (red circles) compared with the Michigan state averages (blue circles) (see Latta 1958, Laarman 1963), 19 August 2019. See Table 9 for raw data. N=11.

DISCUSSION

Water quality based on low to no dissolved oxygen on the bottom at one station and low water transparency (2.5 ft), along with dramatic concentrations of nutrients (ammonia of >2 mg/L, TP of 0.050 mg/L) (confirmed by data from Progressive AE), dense blue-green algae blooms lake-wide, shows Hess Lake to be productive, stressed, has Eurasian milfoil and common carp infestations, and apparently it has a degraded fishery based on our data and what fishers expressed about its history. There are very few large yellow perch, bluegills, or pumpkinseeds in the lake based on our sample data, but reports are that largemouth bass fishing is good, if you know how to catch them. The introduction of channel catfish will have to be evaluated as time goes on, but they are not native to Hess Lake, they are extremely abundant based on our sample data, and they have the potential to change fish community ecology drastically. They are everywhere based on fisher's reports and are currently dominated by one group 10-12 in long. These fish will grow larger and pose a threat to what forage fishes remain. These fish are adapted to feed in the dark and should do well in Hess Lake. Whether this is desirable will depend on the response of the fishers and other fishes to this influx of an abundant, non-native predator. There are three species of minnows (golden shiner and bluntnose minnows) in the lake, which is great. The golden shiner (Picture 13) especially does well in turbid water, grows to large sizes (12 inches), reproduces well, and will provide excellent forage for top predators. The lake also has an abundant population of a third minnow, the common carp, an invasive species, which needs to be reduced by all means possible.

Hess Lake is a large, shallow, eutrophic lake that has switched from macrophyte-dominated around 1980 to a blue-green algae-dominated state, with resultant low water clarity, degraded food web components, abundant common carp populations, and a sub-optimal fish community. The dissolved oxygen was zero (anoxic) on the bottom at some stations during our summer sampling, which is unfortunate for two reasons: phosphorus will be regenerated at a much higher rate under anoxia and this dead zone will prevent fishes from utilizing this part of the lake during summer stratification. Causes of the degradation of the lake are closely related to excessive phosphorus (and nitrogen) inputs to the lake. If one were to prepare a nutrient budget for the lake, which would be useful to focus management options, several sources of nutrients would appear in that budget including:

1. **Septic Tank leakage into Hess Lake.**

The lake riparians (some 384 residences) are on septic systems, which are notorious for leaking phosphorus into groundwater and thence into the lake. We can make a rough calculation using the following information to calculate the pounds of P coming into the lake and then the pounds of plants that would be produced from that poundage. There are 384 residences, we assume 3 people per residence, we use a literature value of 1.4 g of P per person per day contributed by septic tank inputs, multiply that by 365 days yields 1,297 pounds of P produced per year by the septic tanks on Hess Lake. Since about 500 pounds of macrophytes are produced for each pound of P, this will yield 648,500 pounds of macrophytes.

2. **Drains that enter Hess Lake**. Wheeler Drain and five other drains enter Hess Lake based on Progressive AE (2018). Wheeler Drain has been identified as a major source of P and sediments to Hess Lake. Edmonds (1982) noted that diversion of Wheeler Drain around Hess Lake would eliminate 1,764 pounds of P/yr, which could produce 882,000 pounds of macrophytes.

3. **Internal loading from anoxia in Hess Lake**. Hess Lake has switched from being dominated by aquatic plants to algae-dominated. The input of sediments from the drains and dead and dying plants (algae and macrophytes) have accumulated over the years in the deep basins of Hess Lake and probably these processes have accelerated with the recent switch to algae. During stratified conditions during summer and winter, these sediments decompose and release P (and

nitrogen compounds like ammonia). These releases are accelerated during anoxic episodes. Under "normal" conditions in most Michigan eutrophic lakes, the lakes stratify during summer and P accumulates in bottom waters called the hypolimnion. That material is prevented from reaching the surface waters because the stratified condition allows no mixing with the epilimnion, surface waters where plant growth is most prominent. In addition, during summer, N and P are usually in very low concentrations in surface waters or even limiting because of uptake by plants. That material then is re distributed during the fall and spring overturn, when water reaches one consistent temperature (4 C – see methods for more detail) and fuels algae and macrophyte growth the next year. However, as we pointed out, Hess Lake is different, since it is so shallow, with three deep basins that are also shallow (maximum depth listed as 29 ft, but we could not find any deeper than 20 ft) and big (755 acres). Because of the long wind fetch in the lake, the shallow nature, common carp rooting activities, and excessive watercraft activity, the lake is periodically de stratified, releasing nutrients to algae and macrophytes, promoting increased growth during times of slow growth. Measuring the contribution of internal loading is difficult in average lakes, but even more so in Hess Lake because of the situation described above. We believe it is a substantial source of additional P in the lake and requires control efforts.

4. **Waterfowl**. Ducks and geese can have a detrimental effect on the nutrient balance in a lake. They can bring in nutrients from outside the lake, by feeding in cornfields and grasslands, then depositing their waste products in the lake. They can also feed in the lake, however, since there are few macrophytes left, we expect most nutrient deposits originate from elsewhere. Obviously, they need to be discouraged from being on the lake.

5. **Atmospheric inputs**. Nutrients, as well as mercury, are deposited on Hess Lake from outside the watershed. It falls on the land and water as both wet and dry deposition, and ends up contributing to the growth of algae and macrophytes. Estimates can be made of the contribution of atmospheric deposition to the nutrient budget of the lake and it probably would make an important contribution. As a side note, most of the mercury that lands on the watershed and lake comes from fossil fuel power plant emissions. Mercury is converted from elemental mercury to methyl mercury, allowing uptake by bacteria and it then moves up the food chain to fish and man. Most large, non-fatty fish, like largemouth bass, black crappies, and northern pike would have high concentrations, unlike PCBs (polychlorinated biphenyls) which accumulate in fatty fish, like large channel catfish or common carp. A contaminant study was done during 1997 (see History). Read the MDNR guidelines for consumption of fish in the fishing guide for directions on eating fish.

6. **Riparians**. In the war against preventing P from entering Hess Lake, the riparians can be a positive influence and help curtail P entry by several activities (see Appendix 1). Lawn fertilization should be curtailed or eliminated and replaced with native vegetation, water gardens, or green belts where possible. Leaves should be disposed of outside the watershed, and never burned. The amount of impermeable surfaces (driveways, tennis courts, etc. should be

minimized). Septic tanks should be eliminated by supporting sewers, but barring that, they should be pumped every 1-2 years.

Macrophytes are sparse or non-existent along most shores and the lake is dominated by algae. The fish population is degraded (13 species collected) with the invasive common carp being common and a non-native species, the channel catfish seemingly abundant. There do not appear to be very many large bluegills, pumpkinseed, or yellow perch in the lake. Northern pike are reported to be present, but we caught none, so they must be scarce in the lake. Undoubtedly northern pike are stressed, since they are cool-water species that require adequate dissolved oxygen and cool temperatures during the summer stratification period. Conditions are not conducive to high survival during this period, since temperatures are very warm and sometimes there is little or no dissolved oxygen on the bottom (see Fish Squeeze – Fig. 3). In addition, they like many other fish species that require good light to see, are inhibited by the low water transparency in the lake.

Hess Lake's "vital signs" are mostly detrimental (Table 10). Algal blooms are extensive and the worst possible outcome, since they are dominated by blue-greens, which can fix their own nitrogen and are not edible by zooplankton or benthos. The dominant species is *Microcystis*, the culprit in Lake Erie that shut down water intakes. This species produces toxins which can be detrimental to pets and humans that ingest it. Zooplankton were an exception, since *Daphnia* composed 45-81% of the zooplankton community at the deep station during July and August and 20-56% of their community at the shallow station; their presence is a surprise and an excellent sign. *Daphnia* are the most efficient zooplankters that eat algae and reduce turbidity in the lake due to algal blooms. None were eaten by fish we sampled, however, which is unfortunate. The dissolved oxygen concentrations are indications of the degradation of Hess Lake, one of the inevitable consequences of time's effect on lakes: eutrophication - nutrient enrichment. The lake has had some anoxia (dead zones) in the summers of 2018 (Progressive AE 2018) and 2019 (our study). The water chemistry data were the most damaging among the parameters we measured during our 2019 study. Total P on the bottom was almost 3-fold higher than the maximum criterion for eutrophic status. Ammonia was surprisingly high (over 2 mg/L) on the bottom as well at one station. Concentrations this high would be toxic to fish and eventually would be converted to nitrates and fuel algal blooms. Water transparency was and has been for many years, very low (ca. 2.5 ft), which as we have noted, is due to the dense algal blooms. High turbidity has many consequences, including degraded zooplankton communities, smothered and damaged benthic (insects) communities, inability of larval fish to find critical zooplankton prey because first, they are not abundant nor the species/sizes required for survival, and second, they would be difficult to find in the turbid water column. Residents are on septic systems, which seep into the ground water and since some of the soils around the lake are sand, it could be that nutrients from this practice are reaching the lake at an even faster rate. In addition, there is a large drain, Wheeler Drain plus five other creeks, that run into Hess Lake. Wheeler Drain had almost 1 mg/L nitrate when we measured it during 23 July 2019; it will be much worst during rain events and the spring runoff period. Chloride, indicators of contamination from septic tanks and road salting activities, was lower than we expected, ca 15 mg/L.

The rise in phosphorus and to a lesser degree, nitrogen, in Hess Lake needs to be addressed by shutting down all possible corridors of phosphorus input. There are many studies that document how P is the limiting nutrient in lake eutrophication problems, so our focus should be on this nutrient. We listed above what we think are the major sources of P coming into Hess Lake. These include: 1.) internal loading (phosphorus regenerated from sediments, then resuspended during fall and spring overturn), 2. Wheeler Drain and the other drains that enter the lake, 3.) Septic tanks, 4.) Waterfowl, and 5.) riparian inputs from lawn fertilization, car washing, and other phosphorus pollution on lawns or the streets (e.g., burning of leaves or grass in the watershed). Riparians need to reduce their impact on the lake by practicing good conservation measures on their property (see Appendix 1).

These findings suggest some major actions and some minor actions need to be done; otherwise conditions will continue to get worse.

<u>Major actions:</u>

1. **Diversion of the Wheeler Drain.** This has been suggested before and would require MDNR, riparian, Brooks Lake, and other entity buy ins. Much has been done already to ameliorate the input of sediments and nutrients (dams, bank stabilization, seeding erosion sites, and sediment basin), but more needs to be done.

2. **Get on sewers**. This too has been suggested and turned down by riparians.

3. **Dredge Hess Lake**. A massive project requiring money, place to dispose of dredge spoils, and support.

4. **Winter drawdown**. Very complex and complicated action. It would require acceptance by riparians, MDNR, and other entities, may endanger fish with a dissolved oxygen sag during a winter with much snow (this may happen anyway during a bad year) and could cause winterkill of fishes. If done, it should start small (perhaps 1 ft drawdown) and increase as experience dictates (adaptive management). It will consolidate sediments, and dry out the nearshore exposed zone, and kill any Eurasian milfoil (and other macrophytes) in the exposed zone. This has had good success in other lake applications.

<u>Minor actions:</u>

1. **Well sampling**: Some representative wells (at least 20 spread over the whole lake's riparian owners) should be sampled around the lake in the four geographical sectors. Water should be taken BEFORE the water softener and tested for several parameters including chlorides and nutrients. Data will be kept confidential and inform us of how

or if the groundwater is contaminated with nutrients, such as nitrates. If findings show high concentrations this is more support for sewers.

2. **Control common carp**: Continue current efforts to reduce carp through contests and inform public that they should be disposed of if caught. A. Consider trammel netting (very effective) during the spawning runs in spring. B. Consider putting a weir or trap net in Wheeler Drain during the spawning season; fish would be harvested once inside the weir/net.

3. **Riparian responsibilities**: Lakeside dwellers need to: reduce their impacts on Hess Lake by eliminating or reducing lawn fertilization, disposing of leaves outside the watershed, planting greenbelts, pump septic tanks often, and avoid high P soaps and detergents (see Appendix 1). They also should slow down with the watercraft and large boats should stay in open water away from shore to reduce re suspension of sediments (no wake zone).

4. **Practice catch and release**: Largemouth bass and northern pike, but not channel catfish, should be released back into the lake to reproduce.

5. **Curtail invasive species:** Obey the new law in Michigan which is trying to stop invasive species from entering inland lakes. You do not have zebra mussels yet and do not want them. Clean off all aquatic plants from boats and treat any water left in the boat with chlorine or dry them, when they come back into Hess Lake. No bait dumping; try to rely on bait obtained from the lake.

6. **Restore native macrophytes**: What few native macrophytes that are left should be protected and not treated with herbicides. Further, consider cordoning off a bay (suggest the bay by station B) that would be off limits to large boats and declared a no-wake zone, to see if macrophytes can become re-established there.

Positive and Negative Attributes of Hess Lake

It may be useful to list the positive and negative conditions of Hess Lake to focus our attention on what needs to be done (see Table 10 for an attempt at this). First, it should be realized that Hess Lake is a unique lake for several reasons. It would be classified as a highly eutrophic lake based on water clarity being low, anoxia, dense blue-green algae blooms, high TP and ammonia generated on the bottom, and a warm-water fish community. Here are positive attributes:

Positive attributes:

1. Large lake, providing many different and diverse habitats
2. Some sandy nearshore zones: good for fish spawning and sensitive benthic species
3. Northern pike: in low abundance but present
4. Sensitive benthic species: small mayflies, caddisflies, the amphipod *Hyalella*
5. Presence of some native macrophyte species (lily pads) in patches around the lake

6. Low chloride concentrations
7. Great abundance of the zooplankter *Daphnia*, which eat algae and are excellent fish prey
8. Good to adequate largemouth bass fishery

Negative attributes include:

1. Anoxia (dead zone) on the bottom of the lake: leads to exclusion of fish from the hypolimnion and release of phosphorus and other deleterious substances (e.g., ammonia, carbon dioxide) from the sediments
2. High concentrations of total phosphorus and ammonia on the bottom
3. Presence of three known invasive species: Eurasian milfoil, curly-leaf pondweed, common carp
4. Low abundance of sport fishes, especially northern pike and large panfish
5. Dominated by blue-green algae blooms; low abundance of native macrophytes
6. Wheeler Drain and other creeks bring in large amounts of sediment and nutrients
7. Common carp increase turbidity
8. Channel catfish are non-native, will disrupt the fish community, and compete with native predators
9. Riparians: People can have negative (or positive) effects on lake condition through their behavior in developing their property (paving roads, putting in tennis courts, cutting down vegetation), having septic tanks, fertilizing their lawns, burning or letting leaves decompose on their property; watercraft re-suspend sediments increasing nutrients during times when plants are nutrient-limited

Management Recommendations

Hess Lake is a eutrophic lake, which develops anoxia (no dissolved oxygen) on the bottom during summer stratification, which leads to two potential problems: 1. It stresses cool-water fishes, which are forced to survive in a thin layer of optimal water (fish squeeze- Fig. 3), and 2. It promotes P and ammonia release from bottom sediments, which enrich and fuel algae and macrophyte growth.

Studies like the one we did are short-term snapshots of the chemical environment and biological community of Hess Lake designed to flag any potential problems and provide data to identify these problems and warn of future threats to the ecological integrity of the lake ecosystem. We have a rich history of prior studies which we summarized in the History section above on which we have leaned heavily to ascertain detrimental changes, inform us of potential problems, and elaborate on the history of the lake, so we can identify any trends that may be different from long-standing conditions in the lake. Our study is certainly limited by not having seasonal data and sometimes not enough fish to provide the whole spectrum of lengths or replication required for the best possible outcomes. With these caveats, we will proceed to document some of the changes and concerns we identified with this study.

This study was initiated because of a series of observations made by residents regarding declining water quality, increasing algae blooms, and a degraded fish community. It is an effort to understand better the water quality and food web of Hess Lake. To address this, we mounted a study to examine the critical components of the environment and the food web (water chemistry, algae, zooplankton, and fish). The other important components (aquatic plants) were incorporated into the study by personal observations, while on the lake and during seining. The 2019 data were compared with past data. There appear to be some dramatic changes to the water quality, the macrophytes and algae, and the fish populations, which will be elaborated on below:

More extensive discussion will follow each item.

Problem Areas:

1. No Dissolved Oxygen (Anoxia)/Dramatic Increases in TP and Ammonia on the Bottom/domination of the Lake by Algae

As we noted, there is no dissolved oxygen on the bottom of Hess Lake during summer stratification during some periods, which has resulted in lack of fish access during summer and it promotes nutrient (phosphorus and ammonia) release from decomposition of bottom sediments termed internal loading. In addition, several other parameters are indicating degradation of the water quality of the lake, including low water clarity, high conductivity, and dense blue-green algae blooms. **Recommendations**: Reduce nutrient input, especially phosphorus, to the lake. We believe there are many major sources of nutrients: anoxia, generating increased internal loading, Wheeler Drain and the other drains entering Hess Lake, septic tank effluent entry into the groundwater and thence into Hess Lake, atmospheric dry and wet deposition, waterfowl, and riparians, who fertilize their lawns, burn leaves near the lake, and do not have green belts. Riparians must help in reducing nutrient input to the lake by following recommendations in Appendix 1. These include no lawn fertilization and planting of greenbelts instead of lawn, no burning of leaves in the watershed, pumping septic tanks at least once every 2 years and more often if usage is high. More information is required before additional measures can be taken, but septic tanks may be a substantial part of the problem, which suggests support for sewers. Some well samples would provide the necessary information to decide how contaminated the water table may be from septic tank and agricultural nutrient pollution. Wheeler Drain needs to be diverted or more upgrades done in the watershed to cut down on the amount of sediment and nutrients that are entering Hess Lake. Even more macrophytes in the outlet to Hess Lake would help absorb nutrients entering there. Lastly, a drawdown should be examined. It would consolidate (dry) sediments and muck in those areas we slogged through doing seine hauls. Such an activity would be fraught with risk, since the current state of the deep areas now is filled with sediment, which will decompose during winter during conditions of extended snow on the lake during a long period of time. Dissolved oxygen would need to be monitored during winter to identify if this would happen and backup aerators be at the ready.

2. Fish management

Based on our fish sampling, the fish community of Hess Lake is degraded by few northern pike, an abundance of a non-native predator channel catfish, and lack of large panfish. We believe that the high turbidity is inhibiting larval, juvenile, and adult fish from seeing and catching prey. We caught no northern pike. It appears that largemouth bass are reproducing adequately, since many YOY largemouth bass appeared in our catches. In addition, common carp are flourishing. **Recommendation**: To maintain a good diversity of top predators, we believe large adults of northern pike and largemouth bass should be protected so they can reproduce, and in addition, large individuals probably have high mercury concentrations anyway (see MDNR eating guidelines in the MDNR fishing guide). We recommend catch and release of the bigger largemouth bass and northern pike in the lake. The larger panfish in most lakes rely on insects (caddisflies, mayflies, chironomids, dragonflies, amphipods) for good growth. We suspect that these important prey species are missing or at low abundances in the lake, hence, improvements to habitat (higher water transparency, more dissolved oxygen on the bottom, and promotion of more native macrophytes) would greatly increase these prey items. See recommendations provided in no. 1. We believe that the unauthorized introduction of channel catfish into the lake will do more harm than good. They are well adapted to survive under turbid conditions and feed at night. They will continue to proliferate in the lake to the detriment of native predators. Remove if caught. Lastly, common carp should also be reduced in any manner possible. The carp removal contests sponsored by the association should continue and we have two other suggestions, that could help reduce numbers, assuming the lake association and MDNR will support either or both of these efforts. First, trammel nets (commercial fishers on the Mississippi and Illinois rivers use similar nets to catch common and Asian carp) would be deployed during spring in spawning areas in the lake. Second, a weir could be temporarily placed in the far end of Wheeler Drain to concentrate common carp during the spawning season. They could be harvested from here using seines or shot with bow and arrow to remove them.

3. Invasive species

Hess Lake has three known invasive species: Eurasian milfoil, curly-leaf pondweed, and common carp. There are no zebra or quagga mussels, or bass viruses in the lake to date, which is a surprise considering the large number of residents on the lake. Keep it that way! Non-indigenous species enter lakes with a boat or other watercraft launched from another lake contaminated with these species. They can be on or in gear, bait buckets, or other items containing water. We cannot warn residents enough about the threat of additional species entering the lake, including quagga mussels, starry stonewort, Viral Hemorrhagic Septicemia, the red swamp crayfish, and recently a virus that has killed largemouth bass in southern Michigan lakes. Quagga mussels have recently been found in the first inland lake in Michigan. Eurasian milfoil and curly-leaf pondweed are detrimental to lakes, because they grow so densely. Currently, they are still in the lake but uncommon due to years of chemical control. **Recommendation**: Clean boats/gear of any clinging macrophytes; treat ballast water with chlorine or the sun. Live bait use (minnows, crayfish from outside the lake) and dumping of bait should be discouraged or banned (it is now the law) because of the threat of introduction of exotic species (e.g., goldfish, red swamp crayfish, quagga mussels, and VHS, which killed many muskies and other species in many lakes, including Lake St. Clair). Any stocking of fish by individuals should be banned for this very reason. The current presence of channel catfish is probably a result ignoring this caution. Warnings should be communicated to the lake association members to ensure contaminated watercraft or gear do not bring in parasites and diseases or non – indigenous species, that could have a devastating effect on the fish community of Hess Lake. Eurasian milfoil and curly-leaf pondweed should be controlled, with great care given to not killing native macrophytes, which under the current conditions of algal dominance in the lake, are critical to establishing ecosystem integrity to Hess Lake. Common carp control efforts are discussed in item 2 above.

SUMMARY OF RECOMMENDATIONS

Problem areas are summarized below (Table 10) and recommendations are given more concisely below:

1. **No Dissolved Oxygen (Anoxia)/Dramatic Increases in TP and Ammonia on the Bottom/domination of the Lake by Algae**
   Switch to sewers; in meantime pump septic tanks often
   Divert Wheeler Drain; in meantime strengthen erosion control, seeding, sediment basins
   Dredge Hess Lake
   Consider small drawdown; increase as experience is gained on effects
   Reduce or eliminate lawn fertilizations
   Plant green belts instead of lawn
   No leaf burning or disposal of leaves and compost in the watershed
   Reduce watercraft speeds; no wake zone in nearshore area
   Reduce common carp by contest, trammel netting, and weir on Wheeler Drain
   Initiate a well sampling program for nutrient pollution of groundwater

2. **Fish Management**
   Practice catch and release for largemouth bass and northern pike
   Reduce channel catfish abundance by removing all caught
   Foster more native macrophytes to increase water clarity and improve zooplankton, benthos, and fish habitat to increase panfish prey
   Reduce common carp (see 1)

3. **Invasive species**
   Educate lake association members to rid incoming watercraft/gear from outside lakes of clinging vegetation; treat ballast water with chlorine or dry out items
   Ban or discourage use of live bait (minnows, crayfish) from outside lake sources; no bait dumping

Table 10. A compilation of the various physical, chemical, and biological measures for Hess Lake during 2019 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. W=Wheeler, Dr. =Drain, draw= drawdown, WQ = water quality.

Condition Documented	Qualitative assessment	Problem Potential	Action to Take
Physical			
Water Clarity	-	Water clarity poor	Reduce nutrients, sewers, divert W. drain
Water Depth	-	Sediment buildup, anoxia, resuspend	Reduce nutrients
Water Temp.	0	Warms up in summer, affects pike	None now
Sediments	-	Muck, turbidity, nutrient resuspension	divertW.Dr.,sewers, dredge,draw
Chemical			
pH	0	None	None
Dissolved oxygen	-	No DO on bottom	Dredge; reduce nutrients
Chlorides	+	Low	None
Nitrates	0/-	OK Hess lk, poor W. Dr.	Monitor lake; divert Wheeler Drain
Ammonia	-	Excessive-Monitor	See Guidelines; see Sediments
SRPhosphorus/TP	-	TP Excessive-Monitor	See Guidelines/ DO; reduce P
Hydrogen sulfide	0	Moderate	Monitor
Biological			
Algae	-	High density blue-green algae blooms	See Water Clarity
Macrophytes	-	Scarce	Promote natives; control invasives
Zooplankton	+	*Daphnia*, high density	Monitor
Benthos	-	Poor diversity/scarce	Check periodically; improve WQ
Fish			
Largemouth bass	-/+	Plenty YOY; few big adults	C @ R
Bluegill	-	Few large fish in lake	Improve WQ; see Water Clarity
Yellow perch	-	Rare; no large fish caught	Improve WQ; see Water Clarity
Minnows	-/+	G. shiners -good, need more species	Improve plants/water clarity
Northern pike	-	Rare	More macrophytes, protect spawning sites, C @ R
Pumpkinseed	-	Rare	They eat mollusks, CuSO4 kills snails; cut down algae trt
Common carp	-	Common; increase turbidity	Eliminate: contests, trammel nets, weir

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LITERATURE CITED

Carey, C., K. Weathers, and K. Cottingham. 2009. Increases in phosphorus at the sediment-water interface may influence the initiation of cyanobacterial blooms in an oligotrophic lake. Verh. Internat. Verein. Limnol. 30:1185-1188.

Hindák, F. 2008. *Colour atlas of cyanophytes*. VEDA, Publishing House of the Slovak Academy of Sciences.

Laarman, P. W. 1963. Average growth rates of fishes in Michigan. Michigan Department of Natural Resources, Fish Division Pamphlet no. 1675. Lansing, MI.

Latta, W. C. 1995. Distribution and abundance of lake herring in Michigan. Michigan Department of Natural Resources, Fish Division Special Report no. 2014. Lansing, MI.

Latta, William C. 1958. Age and growth of fish in Michigan. Michigan Department of Natural Resources, Fish Division Pamphlet no. 26. Lansing, MI.

Levardsen, Norman. 1951. Aquatic plant control at Hess Lake, Newaygo County. Institute for Fishery Research Report no. 1306., Ann Arbor, MI. 6 pp.

Lindon, M., & Heiskary, S. 2007. Microcystin levels in eutrophic south central Minnesota lakes. Minnesota Pollution Control Agency, 53 pp.

Newaygo County (2011). Hess Lake Guidebook. 19 pp. Acessed from internet, 23 January 2020.

Prescott, G. W. 1962. Algae of the western Great Lakes area (No. 581.9 PRE). Dubuque: WC Brown Company.

Progressive AE. 2018. Water quality study of Hess Lake, 2018. ProgressiveAE, 1811 4 mile Road NE, Grand Rapids, MI.

Schneider, J. 2003. The 2002 fish survey of Dunham Lake. 21 pp. Institute for Fisheries Research, Ann Arbor, MI.

APPENDIX 1

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 or none at all. 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. We are experiencing silent spring all over again in recent losses of frogs, birds, and insects, critical components of our ecosystem. Don’t contribute to this continuing loss.

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. Septic systems can be substantial sources of phosphorus in inland lakes.

6. MONITOR EXISTING SEPTIC SYSTEMS. Service tanks every other year to collect and remove scum and sludge to prevent clogging of the drain field soil and to allow less fertilizers to enter the groundwater and then into the lake.

7. LEAVE THE SHORELINE AND YOUR LAWN IN ITS NATURAL STATE; PLANT GREEN BELTS. Do not fertilize lawns down to the water's edge – it is now the law. The natural vegetation will help to prevent erosion, remove some nutrients from runoff, and be less expensive to maintain. Greenbelts and water gardens 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. Ensure drains that enter the lake have erosion control, best management practices for agriculture in the watershed, and other safeguards, such as seeding erosional banks and building sediment basins to catch sediments before it enters 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.

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