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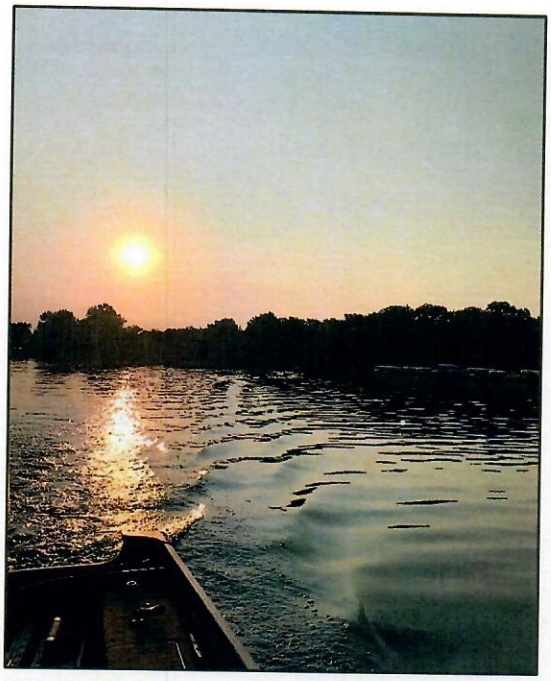

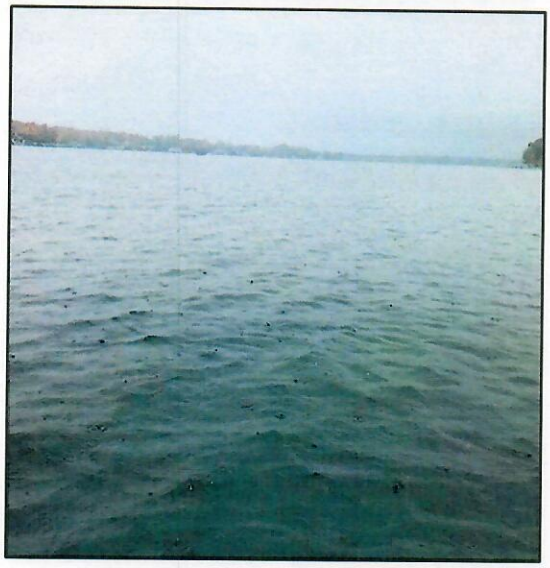

2020 Summary of Water Quality Results Paw Paw Lake

December 30, 2020

Prepared For:

Paw Paw Lake Improvement Board

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Summary:

This document is intended to concisely summarize recent Paw Paw Lake water quality monitoring efforts. The complete database of water quality results and supporting documents is maintained by Spicer Group.

PAW PAW LAKE SUMMARY OF HISTORICAL RESULTS

BERRIEN COUNTY, MI

DECEMBER 30TH, 2020

SAMPLE SITES

The following sample sites have been utilized consistently for water quality monitoring on Paw Paw Lake. There are six sample sites in the northern lobe of the lake (NL 1, NL 2, NL 3, NL 4, NL 5, and NL 6) and six sample sites in the main part of the lake, dubbed "middle lake" (ML 1, ML 2, ML 3, ML 4, ML 5, and ML 7). Algae samples are collected at sample sites AG 1, AG 2, AG 3, AG 4, and AG 5.

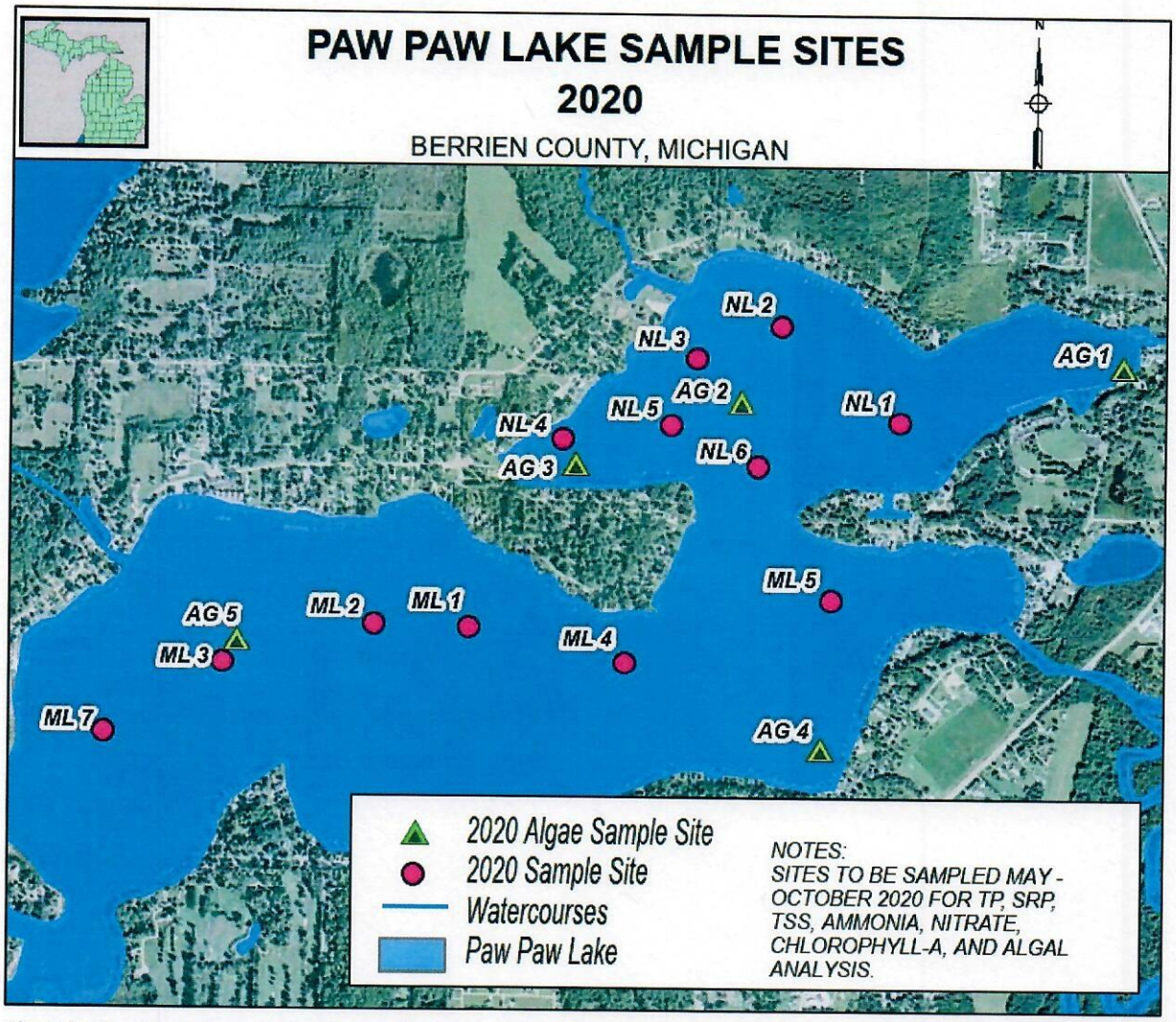

Figure 1- Paw Paw Lake water quality sample sites.

WATER CLARITY

Secchi depth is a measurement of water clarity. **The higher the Secchi depth, the higher the water clarity is.** Water clarity is often associated with "good" water quality. However, invasive species such as Dreissenid mussels (i.e., zebra and quagga mussels) can increase water clarity and allow for more light to hit the bottom of the lake, thus increasing the growth of aquatic plants. Therefore, a happy medium is desired for water clarity: not too clear to allow for excess growth of aquatic plants and not too cloudy so that the water appears dirty and does not allow for a productive, healthy lake.

Paw Paw Lake water clarity is variable. Within the course of a year, clarity is typically highest during spring and mid-fall and lowest during the late summer months.

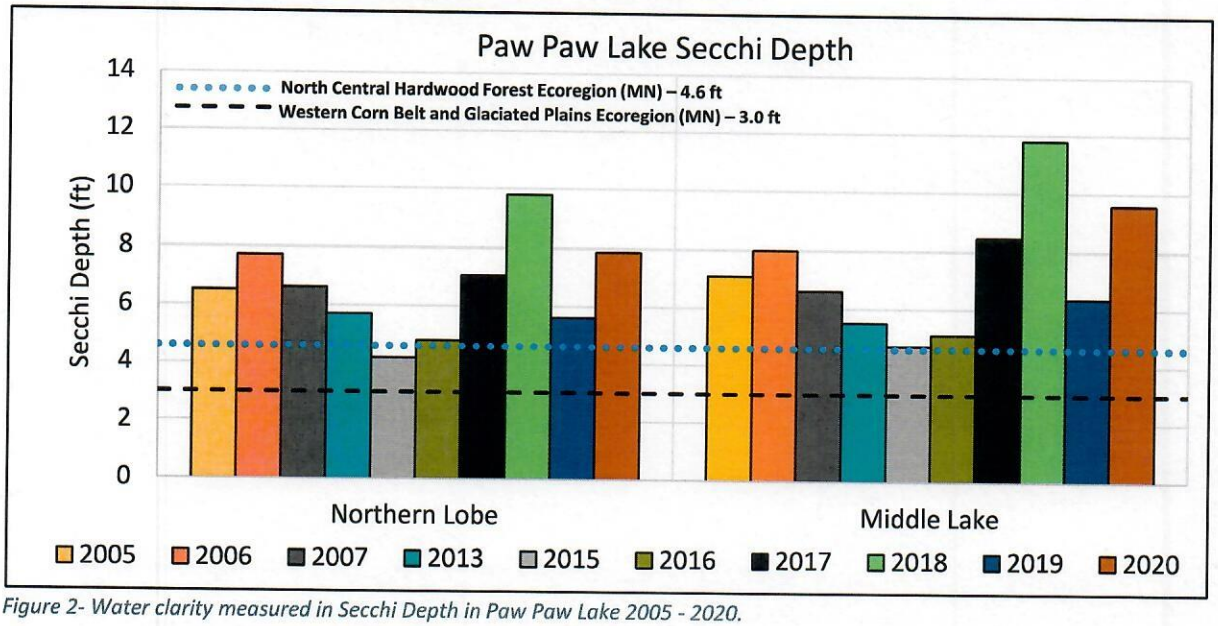

Figure 2- Water clarity measured in Secchi Depth in Paw Paw Lake 2005 - 2020.

CRITERIA FOR COMPARISON – Michigan does not have a set water quality standard for Secchi Depth. However, Minnesota has a variety of water quality standards for Secchi Depths on different water bodies. The most applicable criteria are:

- Lakes and Reservoirs in North Central Hardwood Forest Ecoregion: **Not to be below 4.6 ft.**
- Lakes and Reservoirs in Western Corn Belt Plains and Northern Glaciated Plains Ecoregion: **Not to be below 3.0 ft.**

WHY DOES IT INCREASE AND DECREASE? –

- **Increase and Decrease in Water Clarity –** An increase in Secchi depth is caused by the reduction of particulate matter suspended in the water column and reduction of algae blooms, phytoplankton and zooplankton. Conversely, a decrease in Secchi depth is due to an increase in particulate matter suspended in water, algae, phytoplankton and zooplankton. An increase in particulate matter can be caused by more runoff and boat traffic, and an increase in algae blooms, phytoplankton, and zooplankton can be due to excess nutrients in the water.
- **The Secchi Depth this year is similar to the 2017 measurement. The increase in Secchi Depth during 2020 may be linked to an increase in zebra mussel density, a reduction in boat traffic or a reduction in algal blooms.**

pH

pH is a measurement of how many hydrogen ions are in the water and thus, **is a measurement of how acidic (pH ranging from 0 – 7) or basic (pH ranging from 7 – 14) the water is.** Michigan tends to have more basic water due to the large amount of limestone present in the bedrock.

In inland lakes, pH may also be indicative of how productive a lake is and how much photosynthesis is occurring within a body of water. The pH will be higher if the lake is very productive and there is a lot of plant growth. Ideally, the pH of Michigan water bodies should **be within a range of 6.5 – 9.0.**

CRITERIA FOR COMPARISON –

MDEQ Rule 53 of Michigan Water Quality Standards (Part 4 of Act 451)

- **pH: 6.5 – 9.0**

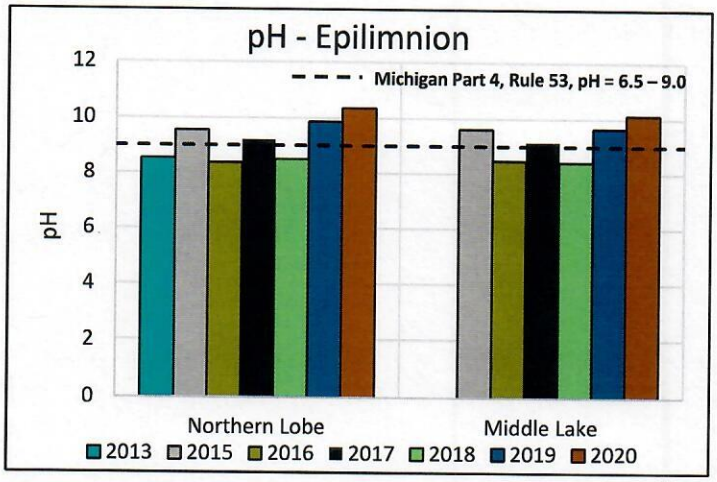

Figure 3- pH measurements in the epilimnion (surface level) of Paw Paw Lake 2013 - 2020.

WHY DOES IT INCREASE AND DECREASE?

- **Increase in pH –** pH can increase due to an increase in dissolved oxygen concentration, an increase in photosynthetic activity of aquatic plants and algae in the water, and an increase in the hardness of the water (i.e. higher calcium and magnesium concentrations in the water).
- **Decrease in pH** – pH can decrease due to a reduction in dissolved oxygen concentration, and an increase in carbon dioxide concentration in the water. This is why the pH is lower in the bottom of the lake versus the top of the lake.

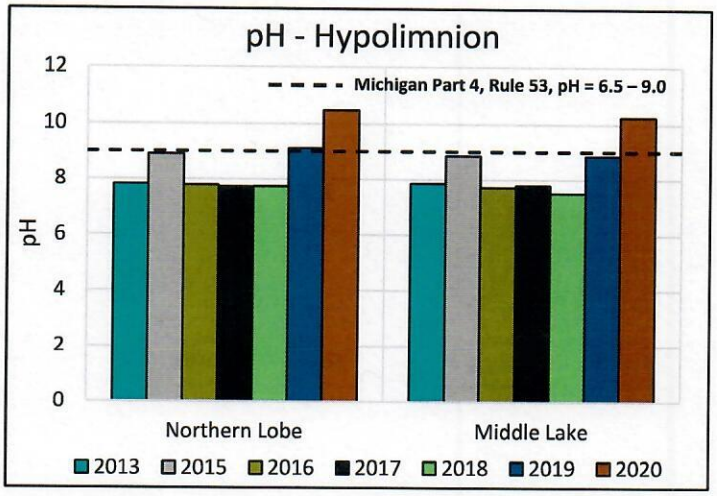

Figure 4- pH measurements in the hypolimnion (bottom) of Paw Paw Lake 2013 - 2020.

- **In 2020, there was an increase in pH in both the epilimnion, hypolimnion, and northern lobe and middle lake.** The increase in pH could be due to the changes in photosynthetic activity or if water quality monitoring was conducted only a short time after a weed treatment. However, readings seemed exceptionally high, so the pH probe was tested with standards that have a known pH. The standards read higher than what they are, so the high pH may be attributed to equipment failure. Therefore, the pH readings are likely much less (approximately 1.5 units) than what was being measured in the field.

DISSOLVED OXYGEN (DO)

Dissolved oxygen is a measurement of **how much oxygen gas is dissolved in the water** and is typically measured in milligrams per liter (mg/L). It is important to have high enough dissolved oxygen concentrations within the water to support fish, macroinvertebrates, and other aquatic life.

Dissolved oxygen can be reduced by excess algal growth, water that's too warm, and minimal wave action. Dissolved oxygen may be increased by increased wave action, cooler temperatures, and non-invasive aquatic plants. The State of Michigan has developed water quality standards for dissolved oxygen. Paw Paw Lake is considered a "warm water fishery," as it is below the geographically designated line that extends horizontally from a point near Alma, Michigan that separates the cold-water fisheries from the warm water fisheries. **The warm water fishery standard for dissolved oxygen is 5.0 mg/L.**

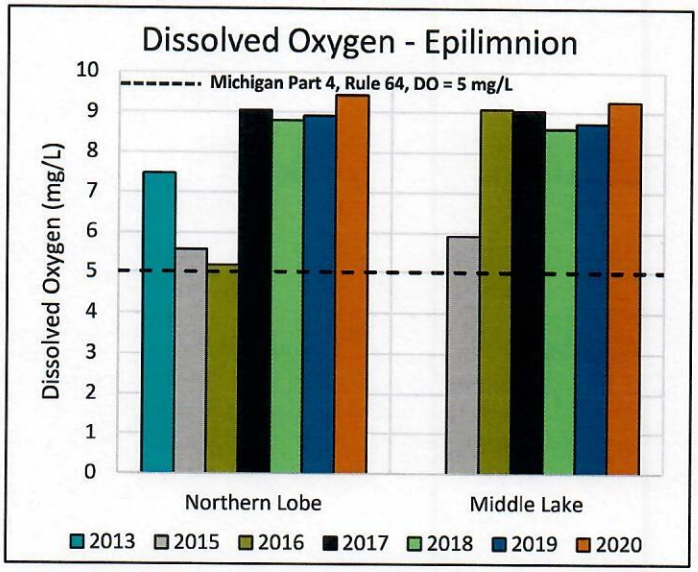

Figure 5- Dissolved oxygen measurements in epilimnion (surface level) of Paw Paw Lake 2013 - 2020.

CRITERIA FOR COMPARISON –

MDEQ Rule 64 of Michigan Water Quality Standards (Part 4 of Act 451) –

- **Dissolved Oxygen (DO): 5 mg/L**

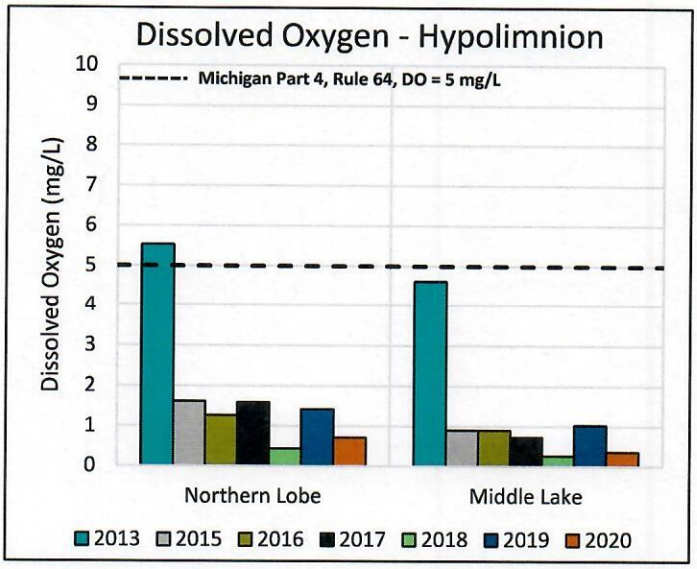

Figure 6- Dissolved oxygen measurements in hypolimnion (bottom) of Paw Paw Lake 2013 - 2020.

WHY DOES IT INCREASE AND DECREASE?

- **Increase –** Dissolved oxygen increases due to more wave action, lower water temperatures, and more photosynthetic activity from aquatic plants and macrophytes.
- **Decrease** – Dissolved oxygen decreases due to the decay of organic material, such as aquatic plants and algae, the increase of oxygen demand from bacteria that use oxygen to respire and break down organic material, and warmer water temperatures.
- **The DO in 2020 is similar to DO levels from 2017 through 2019.**
- The bottom of Paw Paw Lake is anoxic, or lacking in oxygen, once it is stratified in the summer. 2013 has elevated DO, as there was only one sample event for the year earlier in the season.

TOTAL SUSPENDED SOLIDS (TSS)

Total suspended solids are small particles that consist of organic material, clay, and other **particulate matter suspended in the water** and are measured in milligrams per liter (mg/L). Often times, TSS carries other types of contaminants including nutrients, metals, and hydrocarbons (which is more common in urban areas). While TSS occurs naturally in some waterways, an over-abundance of TSS can lead to a decrease in visibility and an increase in other undesired contaminants previously mentioned, in addition to smothering fish eggs and other aquatic wildlife. Therefore, **low concentrations of TSS are desired.**

TSS can be introduced into Paw Paw Lake via incoming streams and rivers or by the stirring up of bottom sediments. The State of Michigan does not have a numerical standard for TSS. Instead, the State has defined a narrative standard, meaning that the waters of the state should not have un-natural characteristics attributed to TSS (i.e. excessive cloudiness, films, foams, etc.). Typically, water bodies with a TSS value of less than 20 mg/L are considered to be "clear."

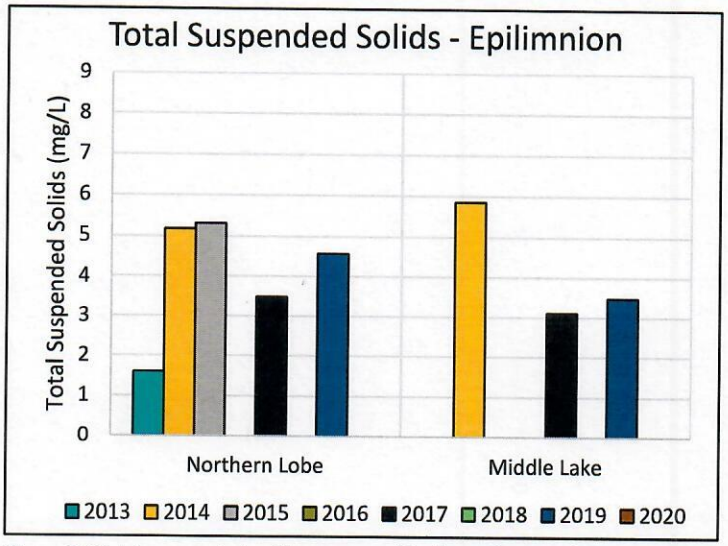

Figure 7- Total suspended solids measured in the epilimnion (surface level) of Paw Paw Lake 2013 - 2020.

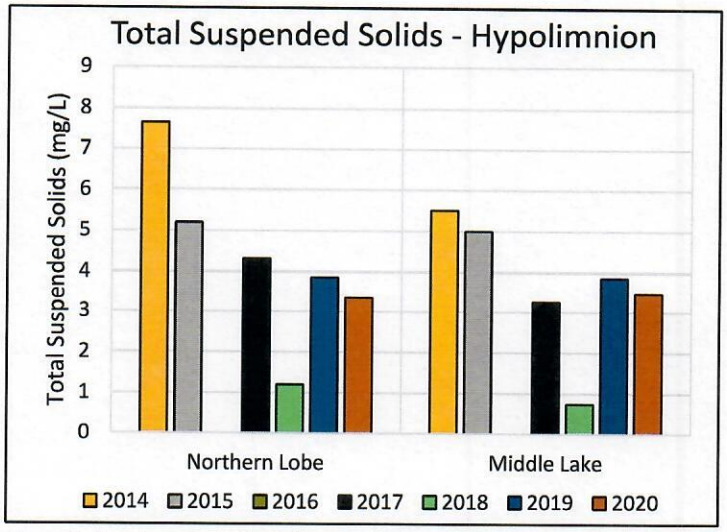

Figure 8- Total suspended solids measured in the hypolimnion (bottom) of Paw Paw Lake 2014 - 2020.

CRITERIA FOR COMPARISON –

MDEQ Rule 50 of Michigan Water Quality Standards (Part 4 of Act 451):

- **TSS = Narrative standard stating that water should not have unnatural physical characteristics**

WHY DOES IT INCREASE AND DECREASE?

- **Increase and Decrease of TSS –** TSS increase due to more particulate matter, such as clay, organic material, and algae being suspended in the water column. These materials can get stirred up in a lake when there is a large amount of boat traffic, or when there is an increased amount of runoff from tributary drains. Alternatively, TSS can decrease if these materials settle out, there is little boat traffic, and minimal runoff.
- **In 2020, TSS in the epilimnion is similar to 2016 and 2018. TSS in the hypolimnion is similar to 2017 and 2019.**

TOTAL PHOSPHORUS (TP)

Phosphorus is an element that is a major component in all lifeforms, including everything from a human being to green algae. In fact, after calcium, phosphorus is the second most abundant mineral in the human body. Phosphorus can also be found in inorganic forms like in rocks. Therefore, total phosphorus is the measurement of all types of phosphorus (both organic and inorganic) within the water and is measured in milligrams per liter (mg/L). **Low TP concentrations that provide a balanced environment for aquatic wildlife are desired.**

The main concern regarding inland lakes and phosphorus is **too much phosphorus can lead to excess algal and plant growth.** Excess algal growth can lead to reduced dissolved oxygen, reduced clarity, unpleasant odors/discolored water, and many more undesirable water quality issues. Excess aquatic plant growth can be an issue for motorboats, as it can become tangled in propellers. Phosphorus causes such a large impact on plant and algal growth because it is the limiting nutrient for plant and algal growth. Reducing total phosphorus in the water column is one of the goals noted in Paw Paw Lake's Lake Improvement Plan.

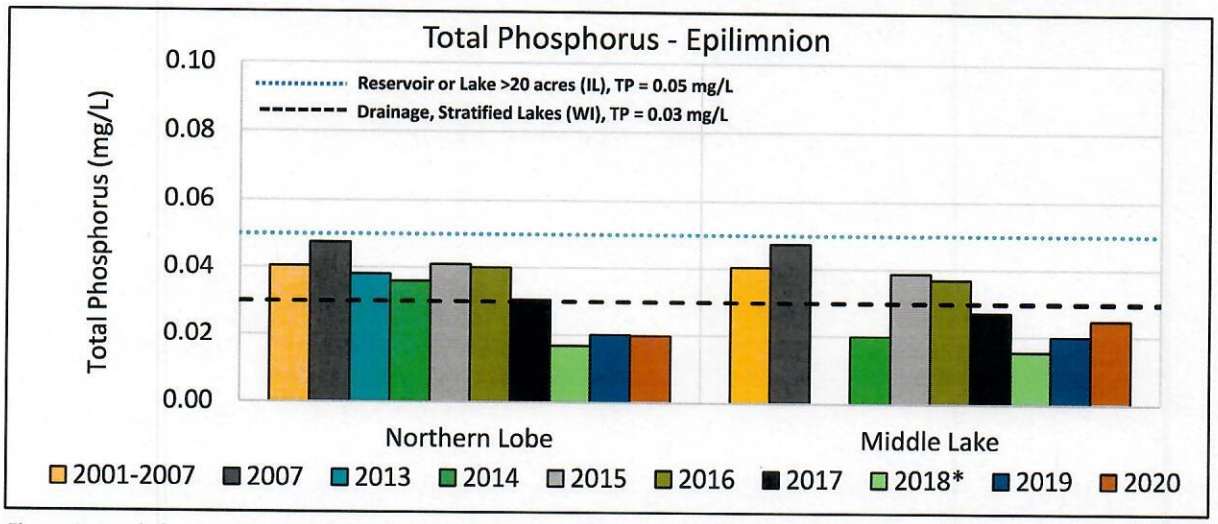

Figure 9- Total phosphorus measurements in the epilimnion (surface level) of Paw Paw Lake 2001 - 2020.

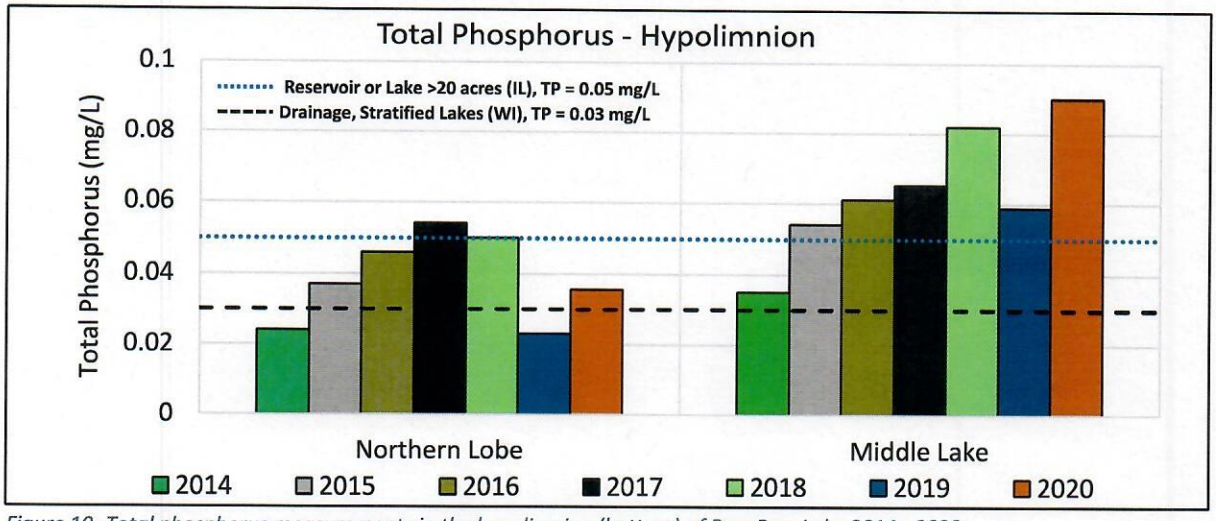

Figure 10- Total phosphorus measurements in the hypolimnion (bottom) of Paw Paw Lake 2014 - 2020.

TOTAL PHOSPHORUS (TP), CONTINUED

CRITERIA FOR COMPARISON:

Michigan does not have numeric water quality standards for inland lakes but is in the process of creating them. However, Wisconsin and Illinois both have water quality standards for total phosphorus:

- Wisconsin standard for drainage, stratified lakes: **0.030 mg/L**
- Illinois standard for a reservoir or lake with a surface area of >20 acres: **0.050 mg/L**

WHY DOES IT INCREASE AND DECREASE? –

- **Increase in Total Phosphorus –** An increase in total phosphorus may be due to an increase of external inputs of TP into the lake from lawns, soil erosion, or runoff from tributary drains. Additionally, phosphorus can be released from bottom sediments if dissolved oxygen is very low near the surface of the sediment and when temperature is elevated.
- **Decrease in Total Phosphorus –** A decrease in TP may be due to the reduction in runoff and other external sources of TP. TP can also be reduced when dissolved oxygen levels are higher, and temperatures are lower near the surface of bottom sediment.
- TP in 2020 was similar to previous years. **In comparison to 2019, TP levels increased at all locations except for the Northern Lobe epilimnion, where it remained the same.** The increase could be explained by increased external inputs of TP, as well as the decrease in DO levels and increase in temperature in the hypolimnion resulting in TP release from bottom sediments.

CHLOROPHYLL-A

Chlorophyll-a is used as a measurement to determine the **relative amount of algal presence** within the water and is measured in milligrams per liter (mg/L). Ideally, **chlorophyll-a concentration should be low enough to provide balance in the aquatic ecosystem.**

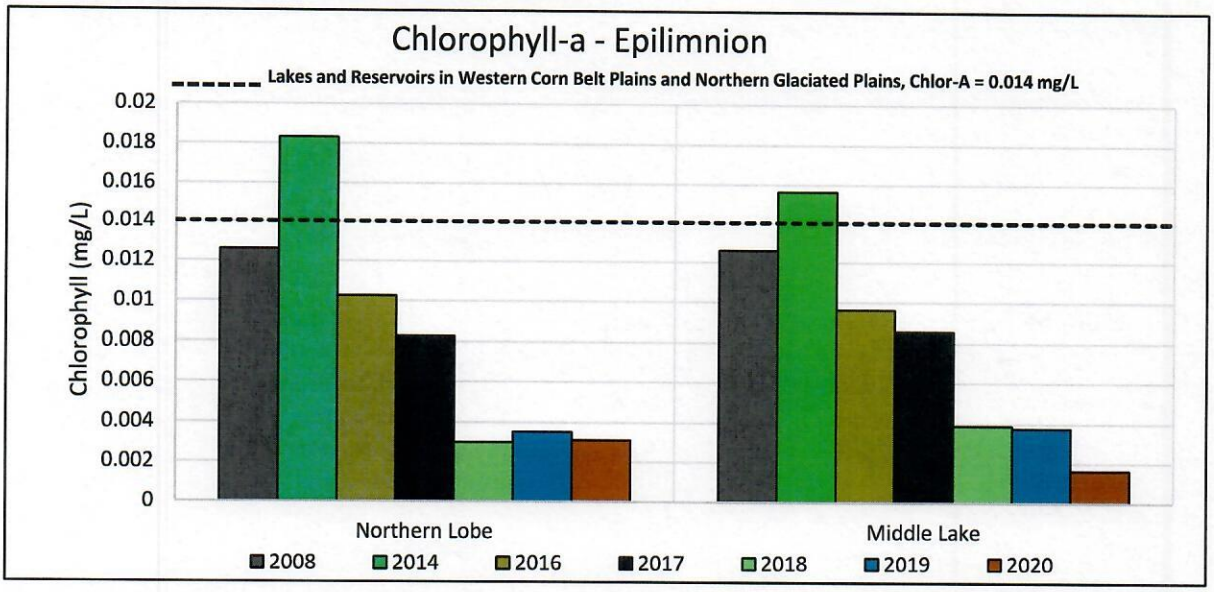

Figure 11- Chlorophyll-a measured in the epilimnion (surface level) of Paw Paw Lake. Chlorophyll-a is not measured at the bottom depths of the lake, as minimal to no sunlight reaches the bottom of the lake. Chlorophyll-a is found in plants and algae that need sunlight to survive.

CHLOROPHYLL-A, CONTINUED

CRITERIA FOR COMPARISON: Michigan does not currently have a water quality standard for chlorophyll-a. However, the state of Minnesota does have water quality standards for a variety of waterways:

- Lakes and reservoirs in North Central Hardwood Forest Ecoregion: **0.014 mg/L**
- Lakes and reservoirs in Western Corn Belt Plains and Northern Glaciated Plains Ecoregions: **0.022 mg/L**

WHY DOES IT INCREASE AND DECREASE? –

- **Chlorophyll-a increases and decreases** based on how much phytoplankton and algae are present in the water column. If chlorophyll-a is higher, there is likely more phytoplankton and algae, and if it is lower, there is less.
- **Chlorophyll-a levels were similar from 2018 to 2020.** The drop in chlorophyll-a from 2017 – 2020 is likely due to increased filtration by zebra mussels, effects from weed management, or lower phosphorus levels. Lower phosphorus concentrations will lower the ecosystems productivity, resulting in decreased algal population and growth.

Figure 12- Algal bloom observed on Paw Paw Lake during the August 9, 2016 sample event.

TEMPERATURE

Water temperature in a lake can greatly impact its water quality, biological activity, and growth. Temperature controls which organisms can survive in the waterbody. If a waterbody increases or decreases in temperature too greatly, the number of organisms that can survive in the ecosystem become less diverse. Additionally, warmer water holds less dissolved oxygen, a component which is critical to the survival of aquatic species, and cooler water holds more dissolved oxygen.

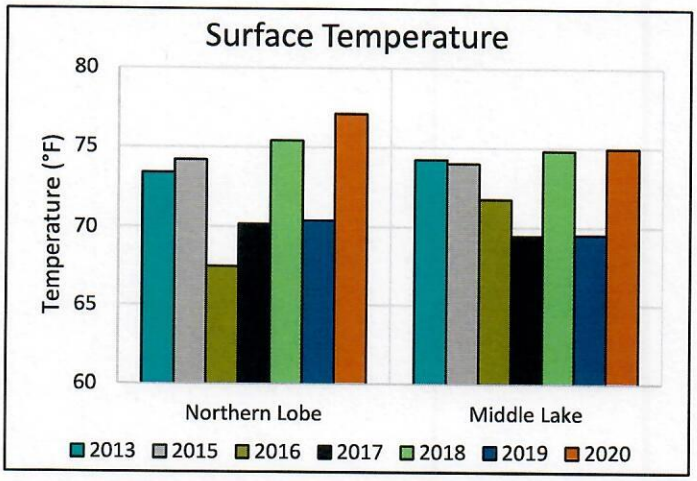

Figure 13- Surface temperature measured in Paw Paw Lake 2013 - 2020.

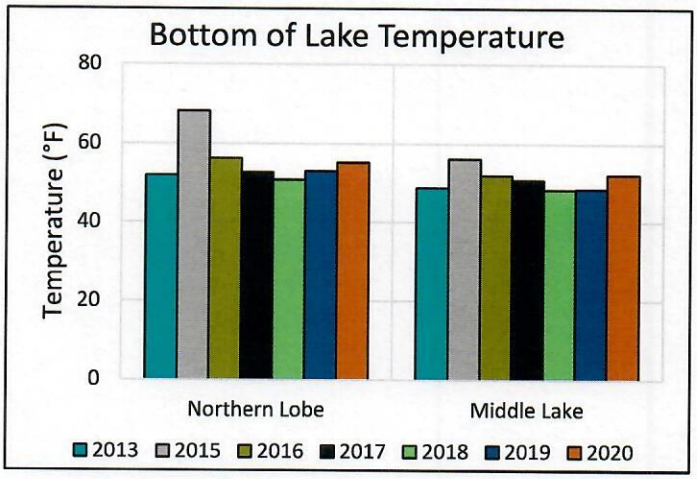

Figure 14- Temperature measured at the bottom of Paw Paw Lake 2013 - 2020.

CRITERIA FOR COMPARISON: The State of Michigan has the following water quality standards for temperature in inland lakes, according to MDEQ Part 4 Water Quality Standards (R 323.1072, Rule 72): Inland lakes shall not receive a heat load which would:

- Increase the temperature of the thermocline or hypolimnion or decrease the volume thereof.
- Increase the temperature of the receiving waters at the edge of the mixing zone more than 3 degrees Fahrenheit above the existing natural water temperature.
- Increase the temperature of the receiving waters at the edge of the mixing zone to temperatures greater than the following monthly maximum temperatures:

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
45	45	50	60	70	75	80	85	80	70	60	50

WHY DOES IT INCREASE AND DECREASE? –

- Temperature will increase if there is an increase in impervious surfaces (pavement, roadways, roofs) in the watershed. These surfaces increase in temperature when the sun warms them, and when it rains, the stormwater absorbs the heat from these surfaces, and flows into a lake, river, or stream, thus elevating the temperature. Temperature will also increase if there is a higher concentration of suspended solids. These solids absorb energy from sunlight, thus increasing the temperature of the waterbody that they are suspended in.
- Temperature in waterbodies naturally increase and decrease seasonally as atmospheric temperatures increase and decrease.

SPECIFIC CONDUCTIVITY

Conductivity is a measure of the ability of water to pass an electrical current. Conductivity will increase or decrease depending on the quantity of positively or negatively charged ions (chloride, nitrate, sulfate, phosphate, sodium, magnesium calcium, iron, aluminum, etc.) dissolved in the water. Conductivity is also temperature-dependent, so specific conductivity corrects the conductivity measurement to 25°C.

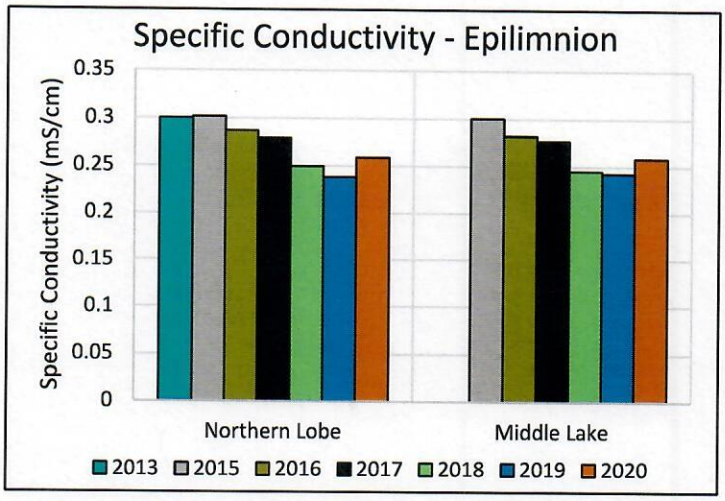

Figure 15- Specific conductivity measured in the epilimnion (surface level) of Paw Paw Lake 2013 – 2020.

In Paw Paw Lake, specific conductivity tends to be higher in the bottom of the lake and lower at the surface of the lake. This may be attributed to the breakdown of bottomland sediment and detritus. Specific conductivity at the lake's bottom has also remained relatively consistent the past five years, where the concentration at the surface has seen a 19 – 21% reduction in concentration.

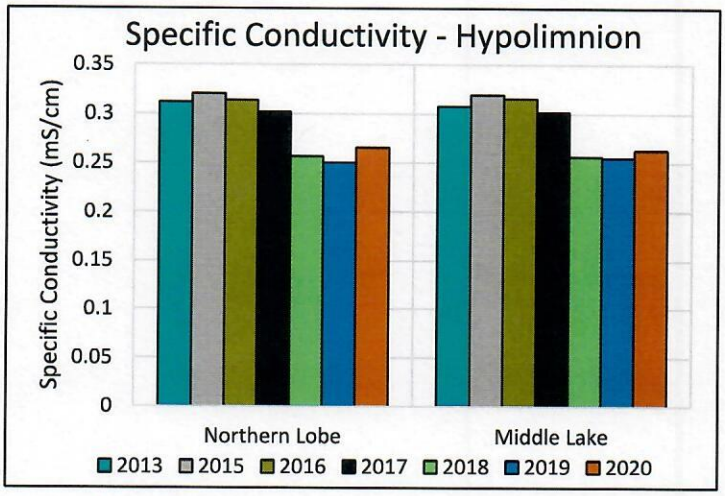

Figure 16- Specific conductivity measured in the hypolimnion (bottom) of Paw Paw Lake 2013 – 2020.

CRITERIA FOR COMPARISON:

For inland lakes in the State of Michigan, there is not a set water quality standard for specific conductivity.

A good rule of thumb is that the higher in concentration specific conductivity is, the more dissolved ions there are. A higher concentration doesn't necessarily mean that the water quality is poor, and a low concentration doesn't mean that the lake is healthy. Just like temperature, the lake needs the right balance of ion concentrations to maintain its health.

WHY DOES IT INCREASE AND DECREASE? –

Specific conductivity is impacted by geology of the area. For example, lakes with a large amount of limestone in the surrounding area will have a higher specific conductivity due to dissolved carbonate ions. Specific conductivity will also increase if the watershed is larger, as there is more land surface area that is being drained and contributing ions to the runoff water that feeds the lake. Pollutants such as fertilizers, pesticides, road salts, and wastewater from septic fields will increase specific conductivity.

Specific conductivity will be reduced if pollutant inputs to the lake are reduced and evaporation is minimized, among other pathways.

TROPHIC STATUS INDEX (TSI)

Overall, Paw Paw Lake exhibits water quality characteristics typical of developed, inland lakes in lower Michigan. According to its 2020 trophic status index, Paw Paw Lake classifies as a mesotrophic lake, at a composite TSI of 44.7. The trophic status of Paw Paw Lake has decreased from the previous year, which had an average TSI of 47.5, again classifying the lake as mesotrophic. The calculations used to determine the trophic status of Paw Paw Lake take chlorophyll-a, Secchi depth, and total phosphorus measurements into consideration. In general, trophic status is a measurement of how productive a water body is, with oligotrophic being the least productive and eutrophic being the most productive.

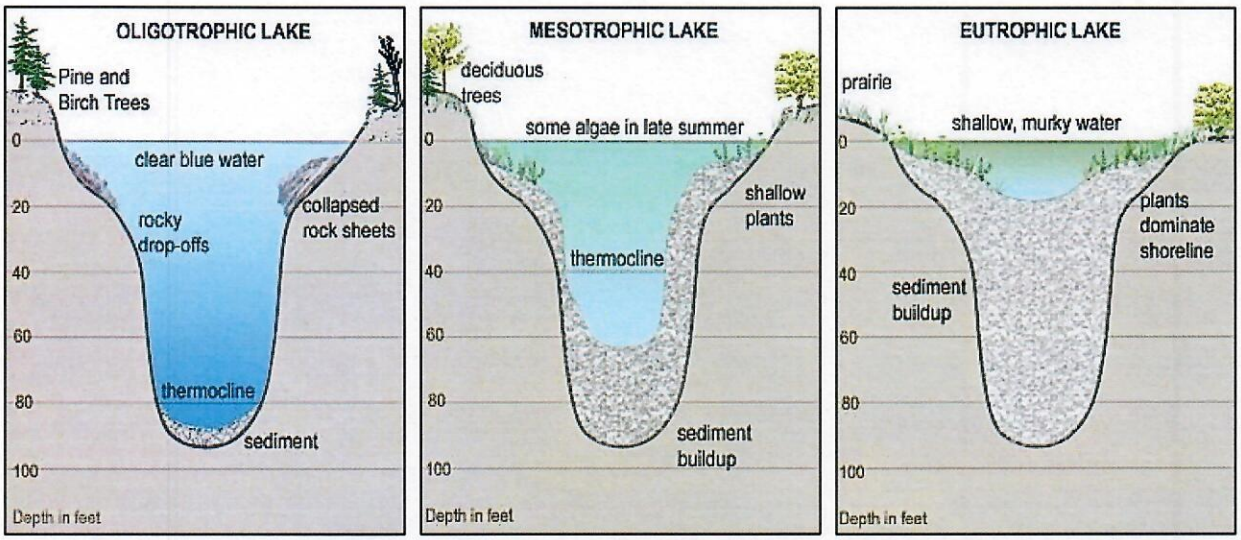

Figure 17- Trophic status of lakes. Oligotrophic is least productive, meaning that it has the least capability to support plant and animal life. Low productive oligotrophic lakes are generally deep and clear with little aquatic plant growth. High productive eutrophic lakes are generally shallow, turbid, and support abundant aquatic plant growth – these lakes can typically only support warmwater fish such as pike and bass. (Source: Michigan State University's Inland Lakes Partnership)

For the past three years, Paw Paw Lake's Trophic Status Index has maintained mesotrophic status. Prior to 2018, the lake shifted from eutrophic to mesotrophic, meaning that there are less nutrients available, there is less chlorophyll-a, clarity has increased, and the lake is less productive. There was a slight decrease in TSI in 2020. Generally, the "older" a lake gets, the more eutrophic it becomes, and the more algae, aquatic plants, and productive it becomes. A lake that is extremely eutrophic, or hypereutrophic, will have excessive nutrients, minimal clarity, and will not be conducive for a variety of recreational activities. The shift of Paw Paw Lake from a eutrophic to mesotrophic status may due to factors such as the influence of zebra mussels, improvement projects implemented around the lake and within the watershed, and/or lakefront landowners managing their waterfronts using environmentally-friendly methods. The figure below shows Paw Paw Lake's TSI over time based on Secchi depth, chlorophyll-a, total phosphorus, and all three components (titled "Composite TSI").

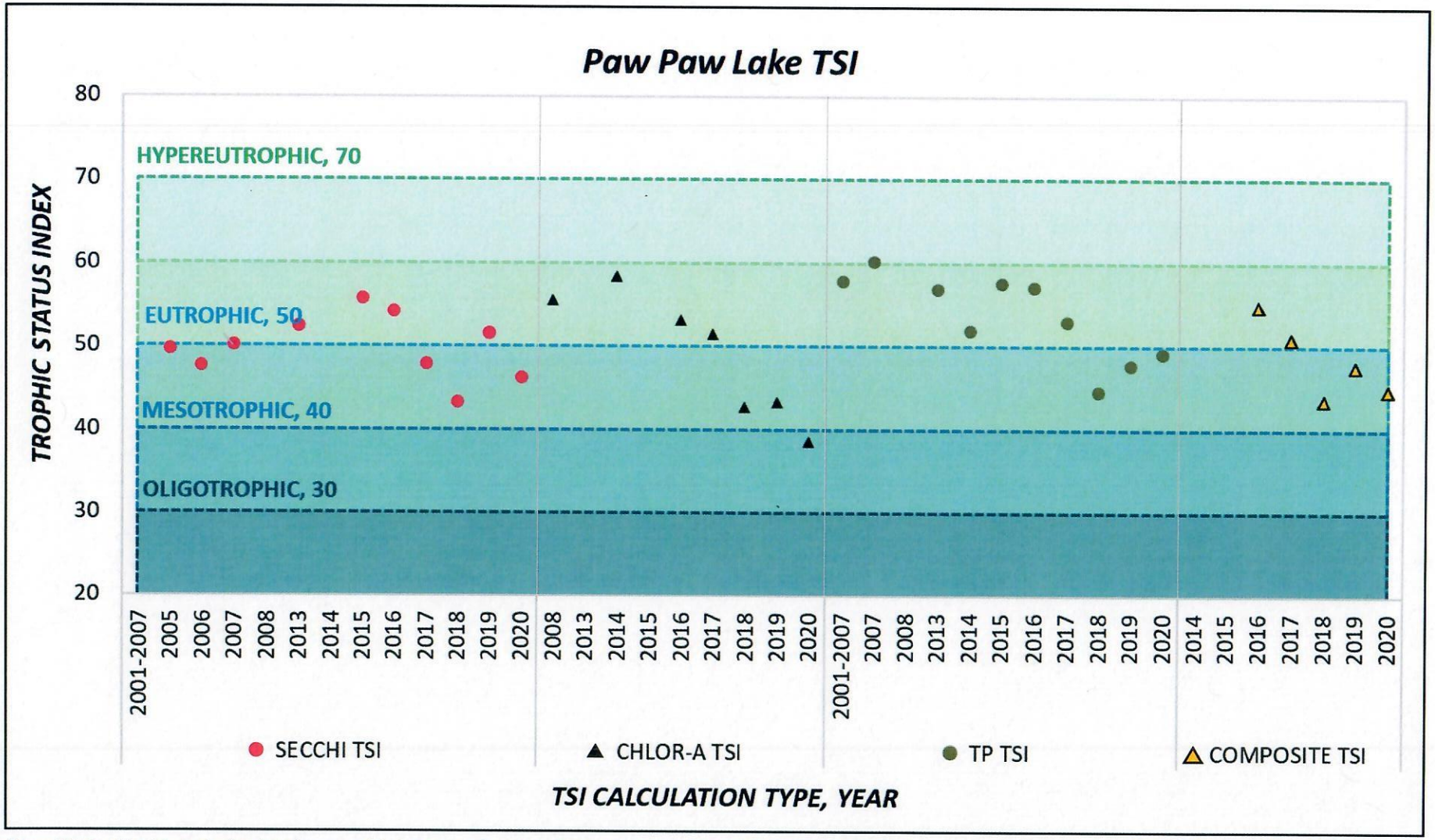

Figure 18- Trophic status calculated and measured in Paw Paw Lake 2005 - 2020. Trophic status may be calculated using only one parameter, such as Secchi depth (clarity), chlorophyll-a, or total phosphorus. This is useful when minimal data is collected on a lake – for example, a lake may only measure Secchi depth and temperature annually. However, the best and more accurate calculation of Trophic Status takes into account three parameters: Secchi depth, chlorophyll-a, and total phosphorus. Historical trophic status was calculated using Secchi depth or total phosphorus measurements. However, in more recent years (2016 – 2020) TSI has been calculated using all three parameters.

TROPHIC STATUS INDEX, CONTINUED:

The table below summarizes levels of trophic statuses and their environmental and ecological conditions:

TROPHIC STATUS	TSI	CHLOR-A (MG/L)	SECCHI (FT)	TP (MG/L)	FISHERIES AND RECREATION
Oligotrophy – Clear water, oxygen throughout the year in bottom of lake.	**<30**	<0.00095	>26	<0.006	Salmonid fisheries dominate.
Bottom of shallower lakes may become oxygen depleted.	**30 – 40**	0.00095 – 0.0026	13 – 26	0.006 – 0.012	Salmonid fisheries in deep lakes only.
Mesotrophy – Water moderately clear; increasing chance of reduced dissolved oxygen in bottom of lake.	**40 – 50**	0.0026 – 0.0073	7 – 13	0.012 – 0.024	Hypolimnetic anoxia results in loss of salmonids. Walleye may predominate.
Eutrophy – Anoxic hypolimnia, excess plant and algal growth possible.	**50 – 60**	0.0073 – 0.0200	3 – 7	0.024 – 0.048	Warm-water fisheries only. Bass may dominate.
Blue-green algae dominate, algal scums and aquatic plant problems.	**60 – 70**	0.0200 – 0.0560	1.6 – 3	0.048 – 0.096	Nuisance plants, algae, and low transparency may discourage recreation.
Hypereutrophy – Light limited productivity. Dense algae and aquatic plants.	**70 – 80**	0.0560 – 0.1550	0.8 – 1.6	0.096 – 0.192	-
Algal scums, few aquatic plants.	**>80**	>0.1550	<0.8	0.192 – 0.384	Rough fish dominate; summer fish kills possible.

ALGAE MONITORING

In recent years (2016 – 2020), the algal community has been monitored on Paw Paw Lake to determine dominant types of algae present and the extent to which toxin-producing algae are present. The Paw Paw Lake algal population, as measured by the total number of algae cells per milliliter of lake water, has varied substantially as seen in Figure 17. Variability in algal communities is common in inland lakes due to variable weather patterns and changes in nutrient levels that influence algae communities.

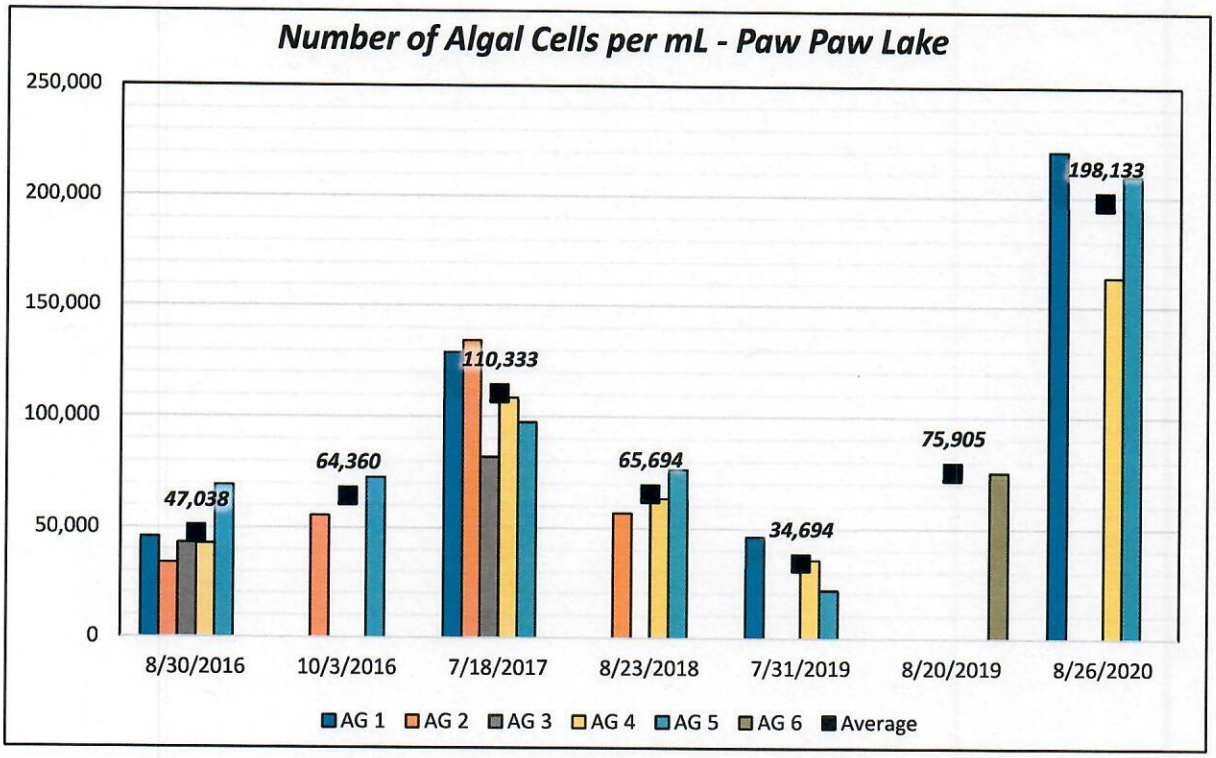

Figure 19- Number of algal cells per milliliter measured in Paw Paw Lake. Algae sample sites are named AG 1, AG 2, AG 3, AG 4, AG 5, and AG 6.

Blue-green algae, which are classified as cyanobacteria, have consistently been the dominant species of algae in Paw Paw Lake samples collected 2016-2020. Some cyanobacteria blooms are able to produce toxins, known as cyanotoxins, which can be harmful to humans and wildlife. Algae samples collected from Paw Paw Lake have been analyzed for toxin-producing bacteria (called PTOX for short) and the toxins they produce. Concentrations of toxin-producing bacteria have always been low, or in some cases, not detected at all. Similarly, the toxins produced by the bacteria have been measured at levels of non-detection or at very low, non-harmful concentrations. This is demonstrated by the pie charts depicted in Figure 18 that show the proportions of algae during multiple sample dates over time. Consistently, blue-green algae dominates the community and potentially-toxic bacteria represent a small proportion of the cells in the sample. This pattern has generally been observed in Paw Paw Lake algae samples collected in 2016 – 2020. Continued monitoring of the algal community is warranted given the variability observed and the potential presence of toxin-producing algae.

ALGAE MONITORING, CONTINUED:

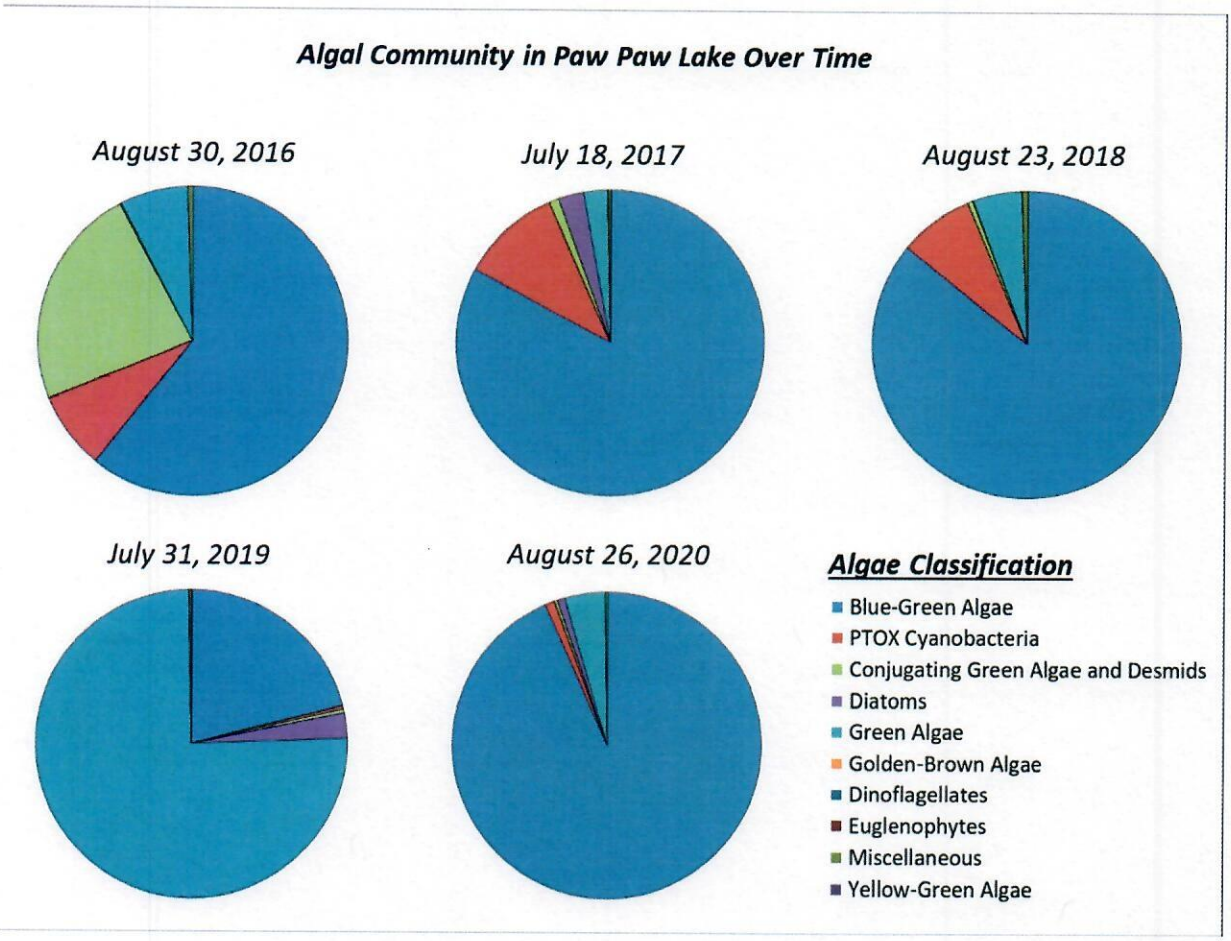

Figure 20- Algal community observed within Paw Paw Lake from 2016 - 2020. The data shown is representative of all sample sites monitored on the various sample dates shown above. During almost all sample events, blue-green algae is the dominant algae present in the water samples.