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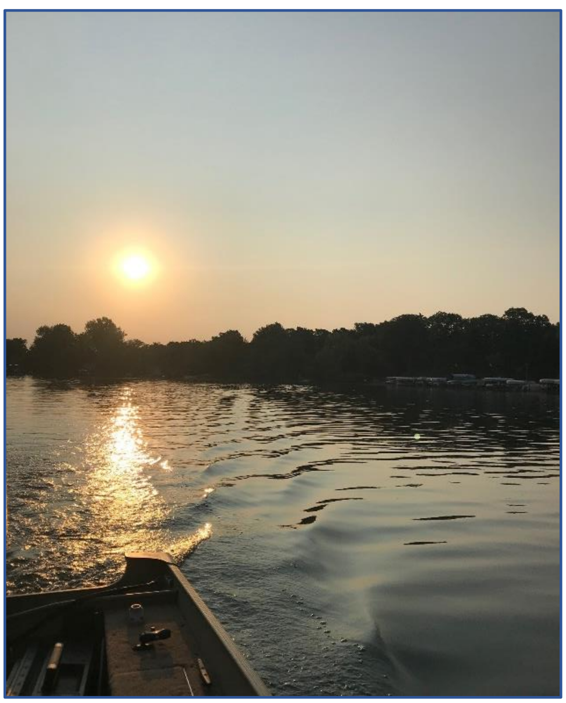

2021 Summary of Water Quality Results Paw Paw Lake

January 5, 2022

Prepared For:
Paw Paw Lake Special Assessment Advisory Committee

Prepared By:
Spicer Group
1400 Zeeb Drive
St. Johns, MI 48879
www.spicergroup.com

With Sampling Support From:
GEI Consultants of Michigan, P.C.
230 N. Washington Square
Lansing, MI 48933
www.geiconsultants.com

Summary:
This document is intended to summarize recent Paw Paw Lake water quality monitoring efforts.

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EXECUTIVE SUMMARY

Paw Paw Lake exhibits water quality characteristics typical of a Michigan inland lake. Dissolved oxygen, pH, temperature, specific conductivity, and chlorophyll-*a* measured in Paw Paw Lake are near the USGS Michigan inland lakes dataset median. Paw Paw Lake's soluble reactive phosphorus, ammonia, and nitrate concentrations tend to be lower compared to Michigan's inland lakes, with the exception of samples collected in the deepest part of the middle lake zone. Occasionally, bottom samples collected in the middle part of Paw Paw Lake had much higher concentrations of these nutrients compared to the median, and previous years on Paw Paw Lake.

Total phosphorus and water clarity have tended to be higher and lower, respectively, compared to other Michigan inland lakes. Despite total phosphorus being elevated, most of the phosphorus in the water column of Paw Paw Lake is not readily available for plant and algae uptake, as exhibited by low soluble reactive phosphorous concentrations. Soluble reactive phosphorus is the form of phosphorus that is readily available for uptake. Nevertheless, there should still be an effort to reduce total phosphorus within Paw Paw Lake.

While an increase in water clarity in Paw Paw Lake is desirable, it does not come without tradeoffs. Paw Paw Lake tends to have more nutrient-rich water towards the bottom of the lake and has nutrient rich sediment. If sunlight can access deeper depths of the lake where nutrients are higher, this can lead to more aquatic plant and algae growth, as these organisms need nutrients and sunlight for photosynthesis and growth. Water clarity should be at a balance where excess plant and algae growth does not take place, but visibility is not hindered.

Paw Paw Lake is considered a mesotrophic lake, based on its total phosphorus, chlorophyll-a, and Secchi depth levels. A mesotrophic lake has a moderate level of nutrients and are typically clear with submerged aquatic plants. Algae populations tend to be less diverse, the lake supports a warmwater fishery and walleye. It is a good goal for Paw Paw Lake to maintain a mesotrophic status.

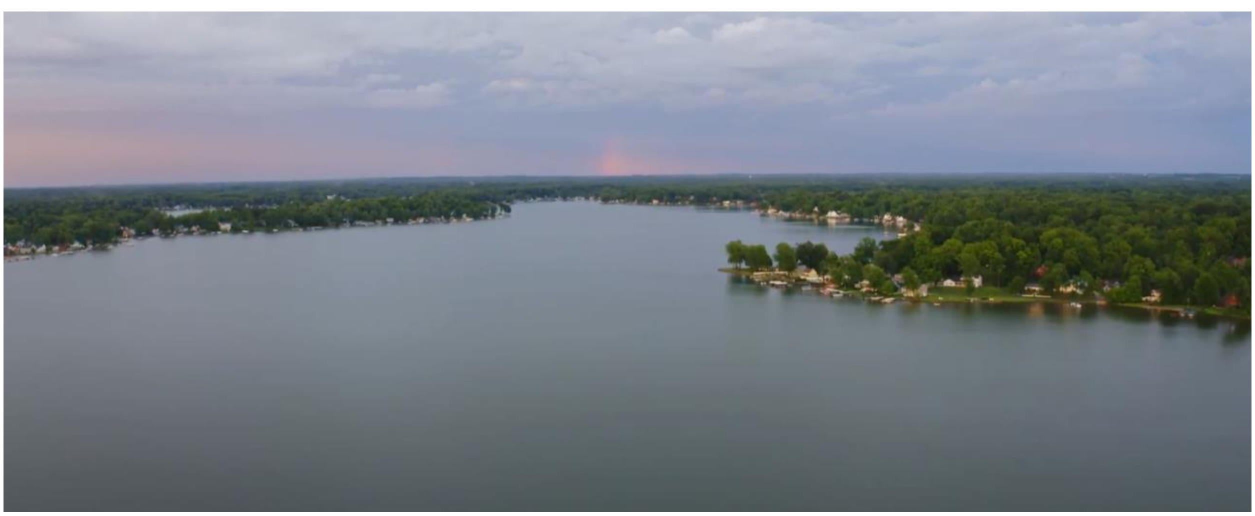

Figure 1 - Paw Paw Lake after a rainstorm on June 26, 2021. Source: Cody Krieger

INTRODUCTION

Paw Paw Lake is an approximately 900-acre lake located in northern Berrien County, Michigan in the townships of Coloma and Watervliet. Combined, there are a total of 8,087 people who reside in Coloma and Watervliet Townships according to the 2020 census. Paw Paw Lake's watershed is 9,248 acres. Within the watershed, the land has many uses, including farmland, residential, and forestland. Soils within the Paw Paw Lake basin and watershed are fine loamy sand. The lake's outlet is located on the east side of the south basin, which ultimately flows into the Paw Paw River. The Paw Paw River then flows into the St. Joseph River, and finally into Lake Michigan at St. Joseph, Michigan.

Originally inhabited solely by indigenous people, specifically, the Potawatomi (Neshnabék), the Paw Paw Lake area saw an influx of European immigrants in the early 19th century (Source: Pokagon Band of Potawatomi, History). Through the mid- 19th century, the land was used for timber and farming. By the 1890's the lake was starting to be used recreationally by local people from Coloma and Watervliet, and largely by visitors from Chicago. Resorts and cottages began popping up around the lake as tourism from Chicago steadily increased and became more fashionable. By 1929, there were 47 resorts, hotels, cottages, and inns around the lake (Source: Paw Paw Lake, R. L. Rasmussen).

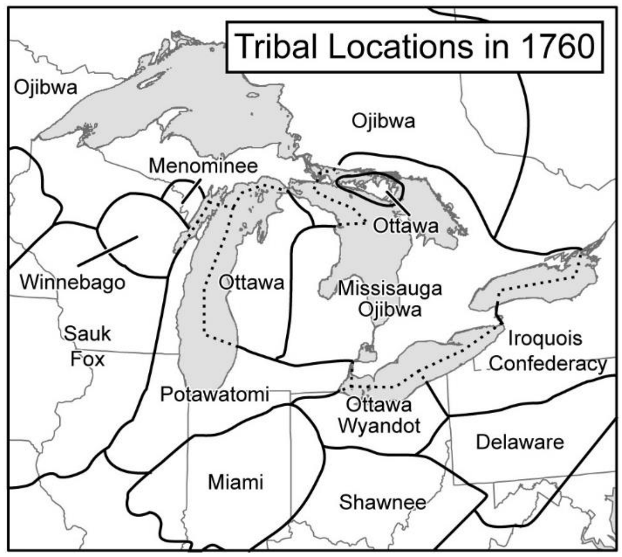

Figure 2- Tribal Lands, Great Lake's basin, 1760's. Source: Michigan State University.

As time passed, land was parceled out and sold to families as a place to build summer cottages. To this day, many properties around the lake have remained within the family for decades.

Figure 3- Steamer Margaret at Woodward's Paw Paw Lake, Michigan. Source: Coloma-Watervliet Chamber of Commerce.

Paw Paw Lake has been utilized for recreation and enjoyed by people for years. The goal is to ensure that it remains a beautiful place where generations of people continue to come for relaxation and time on the water. There are a variety of ways to ensure that this goal can be met, including water quality monitoring. Monitoring Paw Paw Lake's water quality provides insight on how the lake changes over time, the impact that improvement activities have on the lake, and how environmental factors or invasive species make an impact on the lake. Additionally, with historical water quality data, better, more educated decisions can be made on which improvement activities to prioritize or abandon. The following report outlines the most recent water quality data collected in 2021 and compares it to previous years' results, as well as State of Michigan water quality regulatory criteria and Michigan inland lakes data collected on 729 inland lakes by the United States Geological Survey (USGS) and the Michigan Department of Environment, Great Lakes & Energy (EGLE, formerly DEQ).

Sample Site Locations

Various sample sites have been utilized for water quality monitoring through the years around the lake. However, in 2015, there was an effort to standardize sample site locations with the purpose of reducing variables when comparing data from year to year. Starting in 2015, there were 12 sample sites on the lake, with six sites being located in the "northern lobe" of the lake and six being located in the "middle lake" area. Samples were collected at the surface at each location (called "surface samples"), as well as within 1 – 2 feet of the bottom of the lake (called "deep samples"). Samples were (and continue to be) collected at different depths of the lake as water quality can vary widely depending on how deep it is collected.

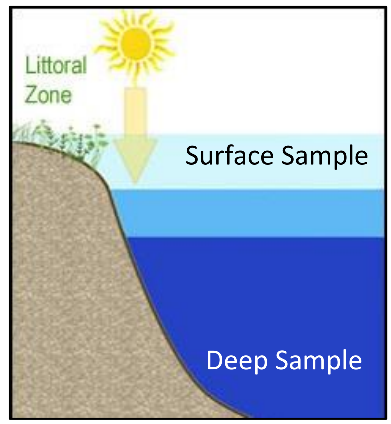

Figure 4 - Sample collection depths.

Beginning in 2016, five algae sample sites were selected to provide spatial coverage across the lake, including along the eastern shore where algal blooms may be more likely to be detected due to prevailing westerly winds. Algae and water quality monitoring sites (2015 – 2020) are depicted in the figure below.

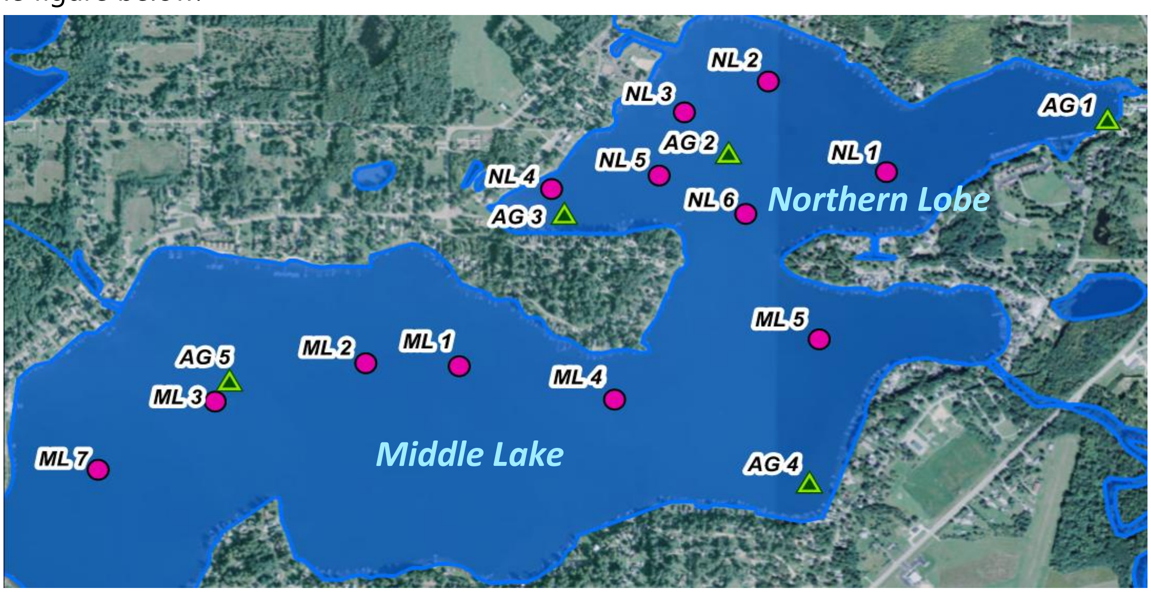

Figure 5 - Paw Paw Lake water quality and algae sample sites 2016 - 2020. Water quality samples were collected at sample sites ML 1, ML 2, ML 3, ML 4, ML 5, ML7, NL 1, NL 2, NL 3, NL 4, NL 5, and NL 6. Algae samples were collected at sites AG 1, AG 2, AG 3, AG 4, and AG 5.

Prior to the 2021 monitoring season, the water quality data was reviewed, and some sites were eliminated from the water quality monitoring program to save on the expense of monitoring yet still maintain a high-quality dataset to inform future management directions. 2021 water quality monitoring sites are shown in the figure below.

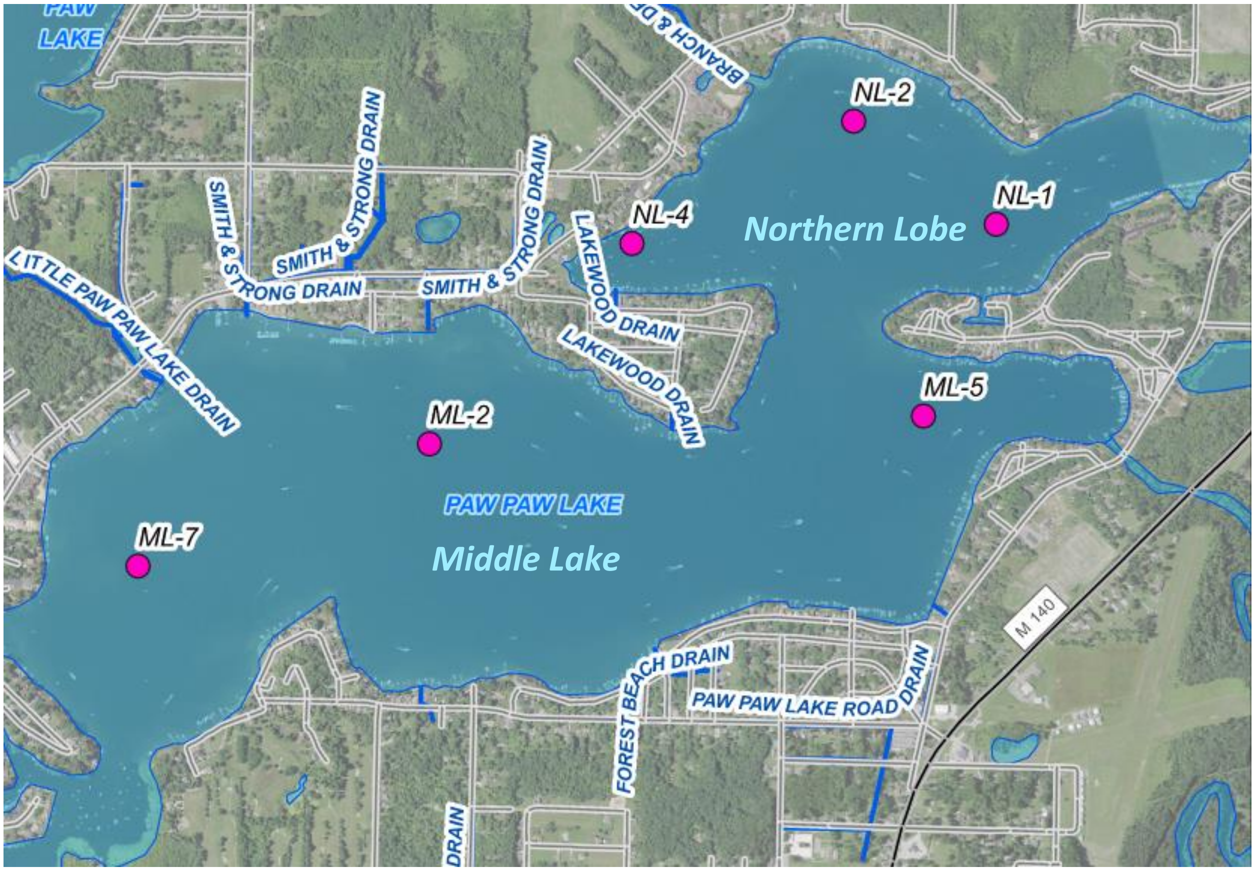

Figure 6 - 2021 Water quality monitoring sample sites. Note - algae sample sites (not pictured) remained the same as 2016 - 2020.

Parameters Monitored

Parameters monitored on Paw Paw Lake during 2021 (and years previous) include:

- Total phosphorus (TP)
- Orthophosphate, also referred to as soluble reactive phosphorus (SRP)
- Nitrate
- Ammonia
- Dissolved Oxygen (DO)
- Temperature (Temp)
- Specific Conductivity (SpC)
- pH
- Secchi Depth, also referred to as water clarity
- Chlorophyll-a
- Algal Identification and Enumeration (measured at algae sites "AG" only)
- Microcystins (measured at algae sites "AG" only)

Total suspended solids (TSS) was monitored for years prior to 2021, however was removed from the analytical suite given TSS results were almost always below the reporting limit (aka "not detected) of the test used to measure the concentration of TSS in the water.

Phosphorus, orthophosphate, nitrate, ammonia, chlorophyll-a, algal ID and enumeration, and microcystins were analyzed/performed by a NELAP certified laboratory. Dissolved oxygen, temperature, specific conductivity, pH and Secchi depth (i.e., water column visibility) measured in the field using a calibrated Hydrolab Quanta Multi-Probe Meter.

Standard methods utilized to analyze and measure the concentration of each parameter are listed in the table below.

Parameter	***Standard Method***
Total Phosphorus	EPA 0365.3
Orthophosphate	EPA 0300.0
Nitrate	EPA 0300.0
Ammonia	SM 4500-NH3 G-2011
Chlorophyll-a	SM 10200 H
Algal ID and Enumeration	All algae and cyanobacteria are identified, enumerated and biovolumes are calculated by a phycologist.
Microcystins	US EPA Method 546 and Ohio EPA DES 701.0
Dissolved Oxygen	Quanta – Table 4500-O found in the 19th Edition of Standard Methods for the Examination of Water and Wastewater.
Temperature	Quanta
Specific Conductivity	Quanta – Table 3 in ISO 7888-1985 Water Quality – Determination of Electrical Conductivity.
pH	Quanta
Secchi Depth	Quanta

Table 1 - Standard methods utilized by the laboratories to measure the concentration of each parameter. Some parameters were measured in the field using a Hydrolab Quanta multi-parameter probe.

Results

Secchi Depth (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 through filtering of particulate matter in the water and allow for more light to hit the bottom of the lake, thus increasing the growth of aquatic plants.

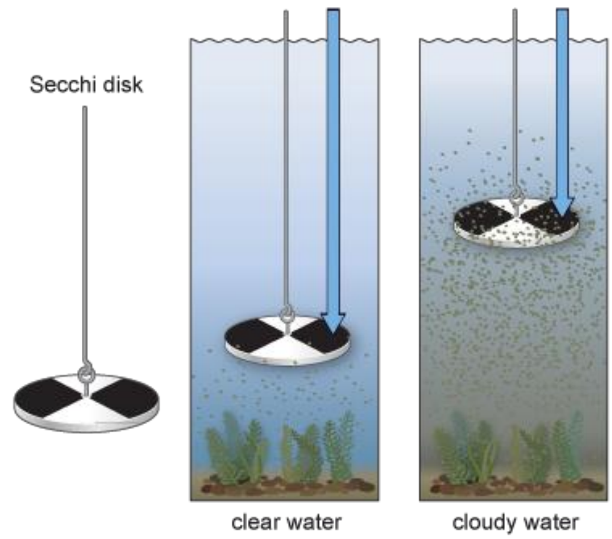

Figure 7 - Secchi disk. Secchi depth is measured using the Secchi disk. The disk is dropped into the water out of the sunlight. The depth at which the disk is no longer visible is the Secchi depth. Sunglasses cannot be worn while taking the Secchi Depth.

Water clarity can also influence the fish community and angler success through direct and indirect mechanisms including, but not limited to fish feeding success (visual predatory fish can "see" more fish to pursue as prey when water clarity increases), changes in ultraviolet light (which can be harmful to fish), changes in the abundance and density of aquatic plants, and alterations to fish reproductive behavior and success. Source: Bunnell et al, 2021 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 8 - Paw Paw Lake October 2021.

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.

Additionally, Secchi data collected on 729 inland lakes around the state of Michigan by the United States Geological Survey (USGS) and the Michigan Department of Environment, Great Lakes & Energy (EGLE) was compared to Paw Paw Lake's data set. Spring and summer Secchi depth medians of the inland lakes data set are slightly higher than Paw Paw Lake's Secchi depths. This means that Paw Paw Lake's water tends to have less clarity than other inland lakes in Michigan. Again, this is not necessarily a bad thing, as each inland lake in Michigan is unique and reduced water clarity can be beneficial in some cases (e.g., less predation pressure on young fish due to decreased water column visibility). Paw Paw Lake Secchi depths are depicted in the figure below.

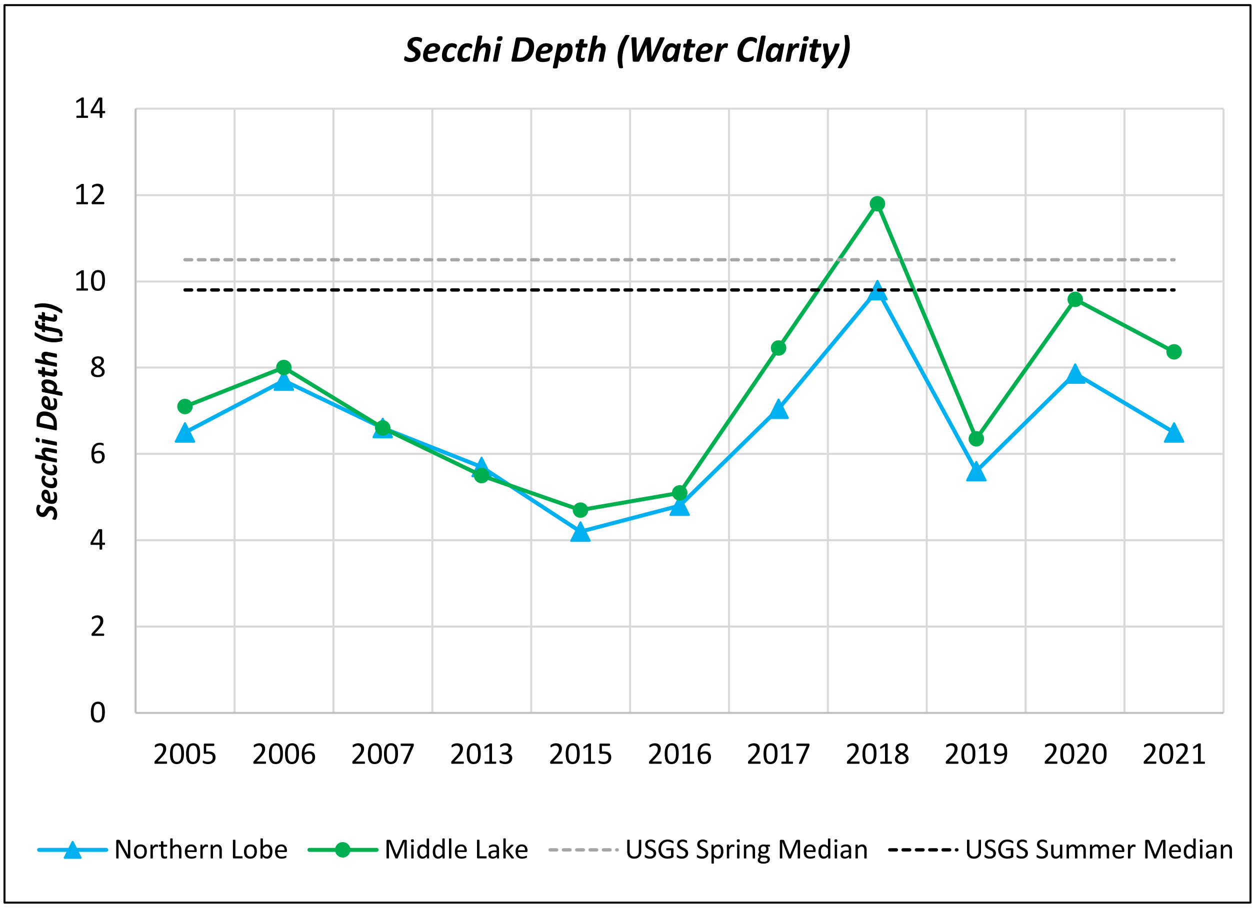

Figure 9 - Secchi depth measured in Paw Paw Lake over time.

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.

Total Phosphorus

Phosphorus is an element that is a major component in all lifeforms. Every living thing, from a human being to green algae has phosphorus in it. 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. Total phosphorus is the measurement of all types of phosphorus (both organic and inorganic) within the water.

The main concern with phosphorus regarding inland lakes is that too much phosphorus can lead to excess algal and aquatic 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.

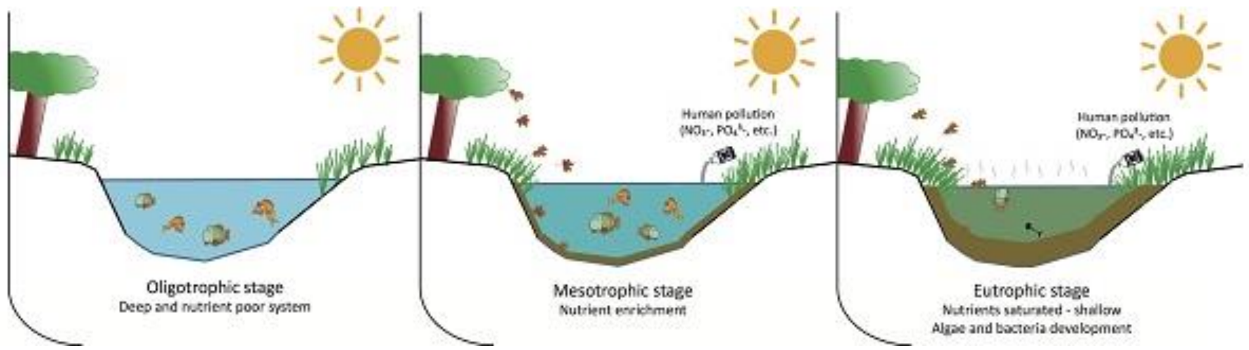

Figure 10 - Eutrophication of a water body over time.

Phosphorus is a key factor for plant and algal growth because it is the limiting nutrient for their growth. A limiting nutrient is defined as a component that limits the amount of the product that can be formed or its rate of formation, because it is present in small quantities. Too much phosphorus in a lake year after year can lead to hastened aging of a lake, or "eutrophication."

Reducing total phosphorus in the water column is one of the goals noted in Paw Paw Lake's Lake Improvement Plan, as historically TP concentrations have been elevated compared to other Michigan inland lakes. The figure below shows how TP concentrations in Paw Paw Lake have changed over time. TP has been measured in the four distinct Zones of Paw Lake:

- Middle Lake – surface
- Middle Lake – deep (within 2 feet of bottom of the lake)
- Northern Lobe – surface
- Northern Lobe – deep (within 2 feet of the bottom of the lake)

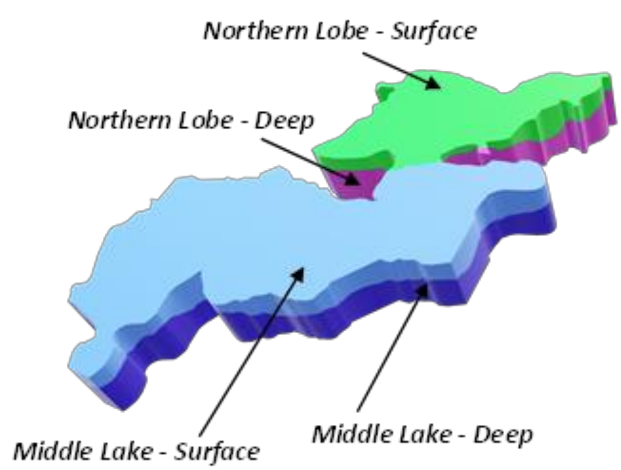

Figure 11 - Paw Paw Lake sample collection zones.

Paw Paw Lake TP data have also been compared to median concentrations of TP measured in 729 inland lakes around the state of Michigan. The data was collected by the United States Geological Survey (USGS) and EGLE. Currently in the state of Michigan, there is not a surface water quality standard for total phosphorus that applies to inland lakes and streams.

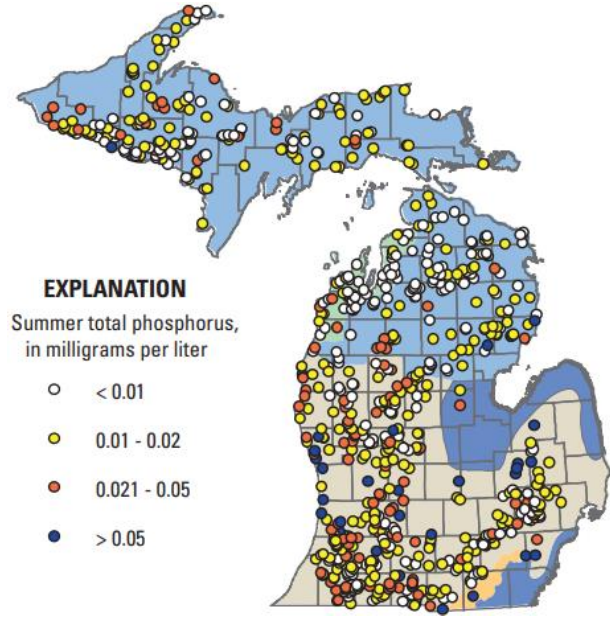

Figure 12 - Summer total phosphorus concentrations measured in Michigan inland lakes. Concentrations are measured inn milligrams per liter (mg/L). Source: USGS

In Paw Paw Lake, there has been a downward trend in surface TP concentrations over time in the last 10+ years. Concentrations remain higher than the state of Michigan inland lakes median for summer. Samples collected near the bottom of Paw Paw Lake have had tended to increase in the last 10+ years, with the exception of a sharp drop in TP concentration during the 2019 and 2021 monitoring seasons. On average, bottom samples are approximately 25 – 55% higher in concentration than the median of Michigan inland lakes bottom samples. The highest concentrations of TP were measured near the bottom of the lake in the Middle Lake basin, where samples were collected at depths of approximately 80 feet in some places.

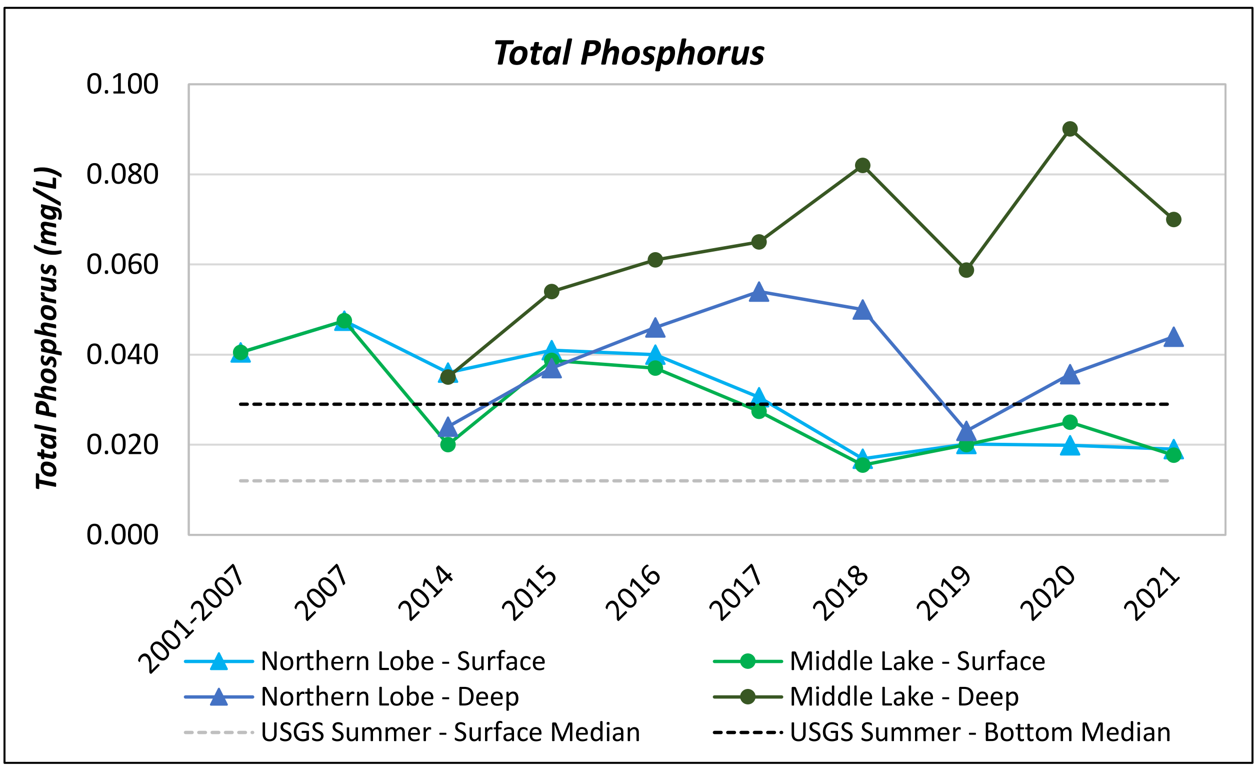

Figure 13 - Total phosphorus concentrations measured in Paw Paw Lake over time.

Total phosphorus may increase 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. Phosphorus may decrease 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. Aeration has been utilized in Paw Paw Lake (Summer of 2015) as a means to help control internal loading of phosphorous from bottom sediments. While the oxygen from aeration can help reduce internal loading of phosphorus, aeration can also have some adverse effects in a stratified lake. The aeration can cause mixing in the stratified water column, leading to more nutrient-rich, dense, cold water from the bottom of the lake to be brought to the surface, and warmer surface water drawn to the bottom. Higher concentrations of nutrients at the surface are then available for algae and other microorganisms to uptake, which can potentially lead to algae blooms depending on lake conditions.

Soluble Reactive Phosphorus

Orthophosphate, also known as soluble reactive phosphorus (SRP), is a main constituent in fertilizers used for agriculture and residential purposes. SRP is a form of phosphorus that is readily available for plant, algae, and other biota use. SRP can be introduced into a lake or stream via runoff, animal waste, and plant and animal decomposition. SRP is included in the measurement of total phosphorus, since it is a form of phosphorus, therefore SRP concentrations should never be higher than TP concentrations.

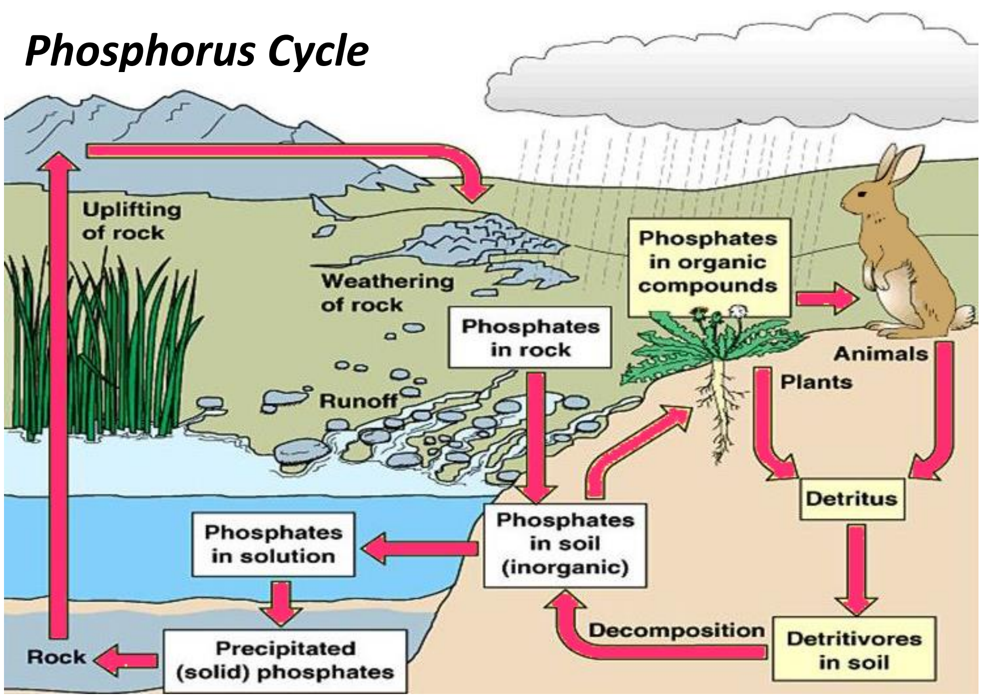

Figure 14 - Phosphorus cycle. The figure depicts inputs of phosphorus from both organic and inorganic, soluble and insoluble phosphorus into a water system. The figure also shows the cycle of phosphorus out of a water system and back into inorganic and organic forms.

The figure below depicts SRP concentrations measured in Paw Paw Lake over time.

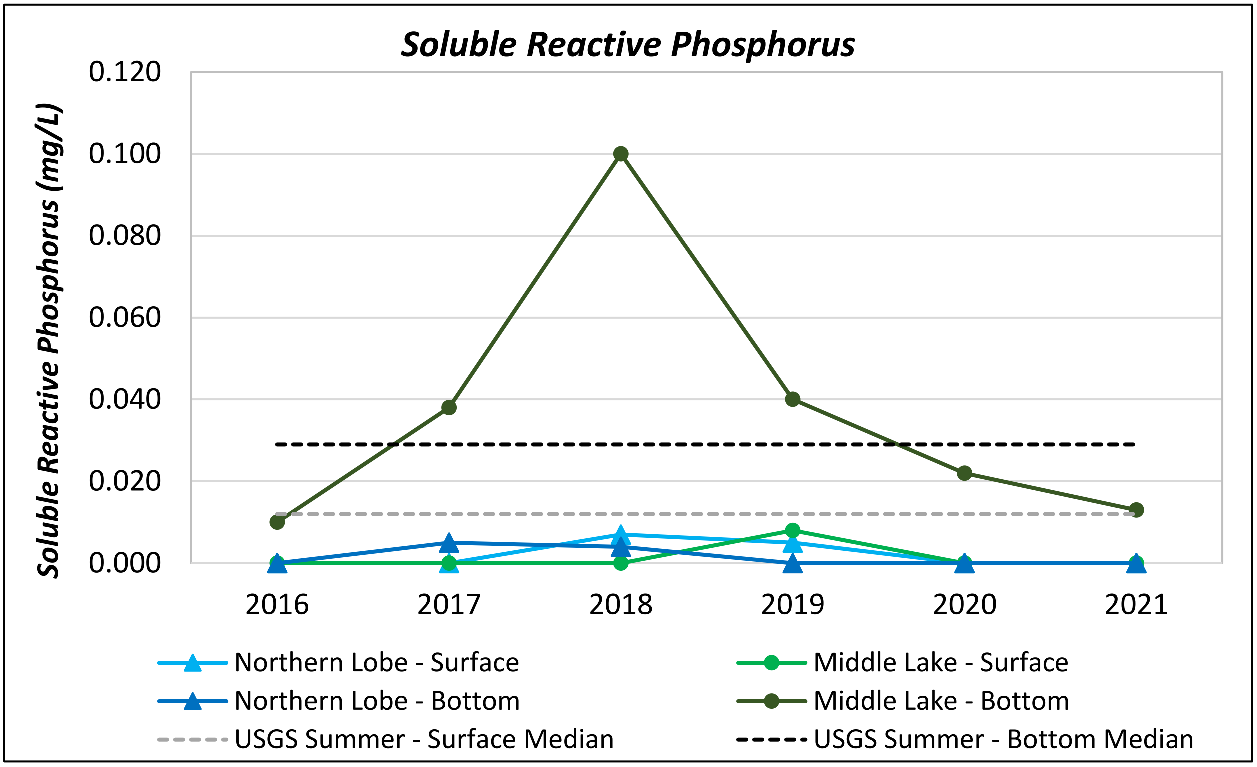

Figure 15 – Average soluble reactive phosphorus (orthophosphate) measured in Paw Paw Lake over time. Note – The laboratory results from 8/23/2018 had the following qualification for SRP samples: "Analyte is found in the associated method blank as well as in the sample." This means that there could have been some cross-contamination within the laboratory biasing the sample results high for SRP on 8/23/2018.

Concentrations of SRP were generally very low (i.e., at or below laboratory detection limits (0.05 mg/L of SRP)) in Paw Paw Lake., especially at the lake's surface. Having low concentrations of SRP in the surface water of the lake is conducive for keeping algae blooms to a minimum, as the algae have little to no phosphorus available for immediate uptake and growth. SRP levels have been consistently detected in the deepest part of the lake (Middle Lake – Bottom samples). Sunlight cannot reach depths of 50+ feet in Paw Paw Lake, so while SRP is available for plant uptake at the bottom of the lake, there is no sunlight available for any plants or algae to photosynthesize. This means that plants and algae cannot survive at this location in the lake. Compared to other Michigan inland lakes, Paw Paw Lake has SRP concentrations lower than the surface median and bottom median, except for at the bottom, Middle Lake zone.

NITRATE

Nitrate is a form of nitrogen that is naturally found in aquatic and terrestrial ecosystems. However, nitrate may be introduced into the environment at unnatural levels by sewage, fertilizers, and manure used as fertilizer. Nitrate may also become incorporated into an aquatic ecosystem by atmospheric deposition. According to USGS "more than 3 million tons of nitrogen are deposited in the United States each year from the atmosphere, derived either naturally from chemical reactions or from the combustion of fossil fuels, such as coal and gasoline." (Source: USGS Water Science School, [Nitrogen and Water](#))

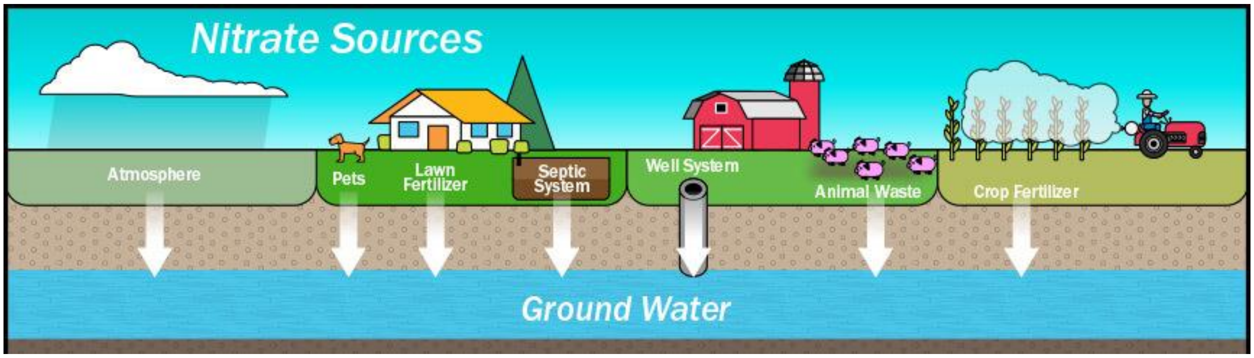

Figure 16 - Nitrate sources to groundwater and surface water. Source: Aquasana, Nitrates in Drinking Water – Reasons to Avoid Nitrates.

When at excessive levels, nitrate leads to eutrophication of a water body, much like phosphorus. The presence of nutrients like nitrogen and phosphorus can lead to excessive algae growth, which can deplete dissolved oxygen in the water and severely harm water quality. At its most severe, this process can even lead to anoxic "dead zones," such as those found in the Gulf of Mexico and Lake Erie. Dead zones refer to areas that are completely depleted of oxygen that cannot support the majority of aquatic life.

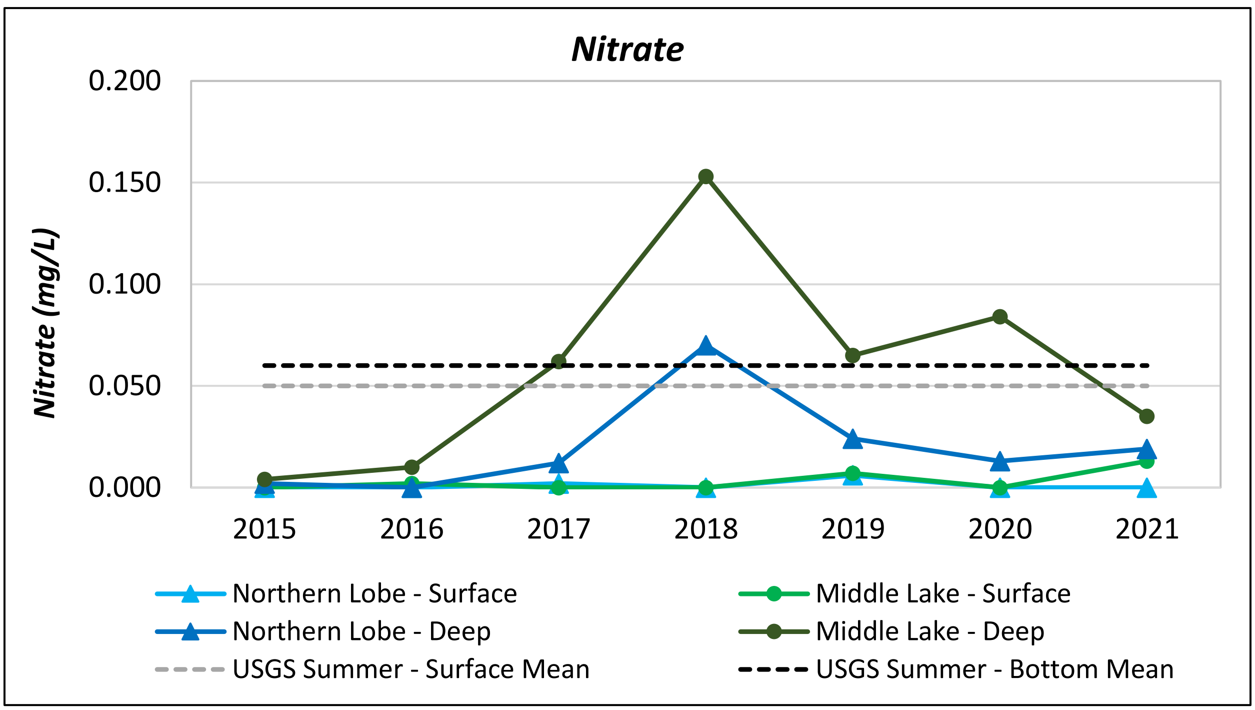

Figure 17 - Nitrate measured in Paw Paw Lake over time.

In general, Paw Paw Lake's nitrate concentrations are much lower than the Michigan inland lakes mean. Nitrate concentrations are higher the deeper samples are collected in the lake.

AMMONIA

Ammonia is another form of nitrogen that exists naturally in an aquatic environment. Natural sources include the decomposition of organic material and vegetation, gas exchange with the atmosphere, forest fires, animal and human waste, and the nitrogen fixation process. Just like nitrate, SRP, and TP, ammonia levels can become too high in the environment due to human influence. Unnatural sources of ammonia include commercial fertilizer, industrial applications, and wastewater treatment plant effluent.

Unlike other forms of nitrogen, which have indirect effects on aquatic life due to the over enrichment of water, ammonia causes direct toxic effects on aquatic life. When ammonia is present in water at high enough levels, it is difficult for aquatic organisms to sufficiently excrete the toxicant, leading to toxic buildup in internal tissues and blood, and potentially death. Environmental factors, such as pH and temperature, can affect ammonia toxicity to aquatic animals. (Source: United States Environmental Protection Agency, Aquatic Life Criteria – Ammonia)

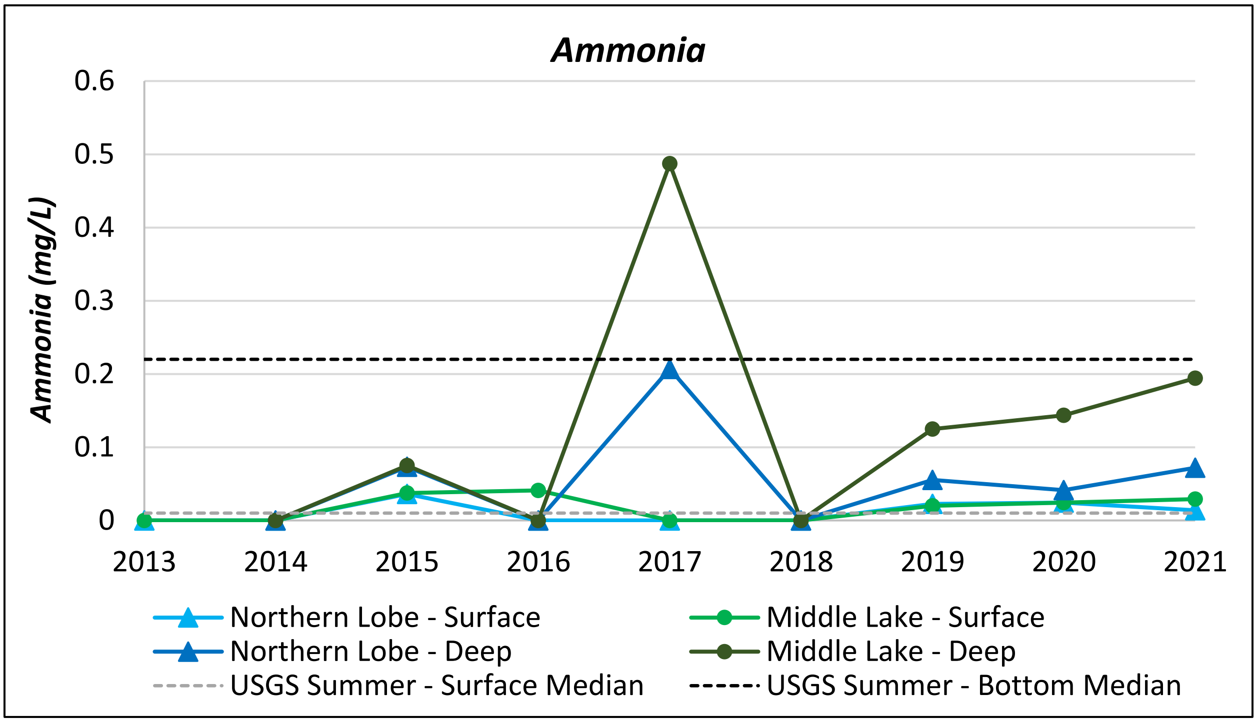

Figure 18 - Ammonia concentrations in Paw Paw Lake over time.

Ammonia levels on Paw Paw Lake are typically well below the median for Michigan inland lakes for bottom samples and are slightly higher than the median for surface samples (Figure 15). Ammonia in Paw Paw Lake is also well below recommended EPA water quality criteria. EPA recommends an acute criterion magnitude of 17 mg Total Ammonia Nitrogen (TAN) per liter at pH 7 and 20°C for a one-hour average duration, not to be exceeded more than once every three years on average. EPA recommends a chronic criterion magnitude of 1.9 mg TAN/L at pH 7 and 20°C for a 30-day average duration, not to be exceeded more than once every three years on average.

Dissolved Oxygen

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 and subsequent decay, water that's too warm, and an increase in oxygen demand from aerobic bacteria, and minimal wave action. Dissolved oxygen may be increased by increased wave action, cooler temperatures, and more photosynthetic activity from aquatic plants and macrophytes. Paw Paw Lake is considered a warm water fishery with an applicable dissolved oxygen water quality standard of 5 mg/L.

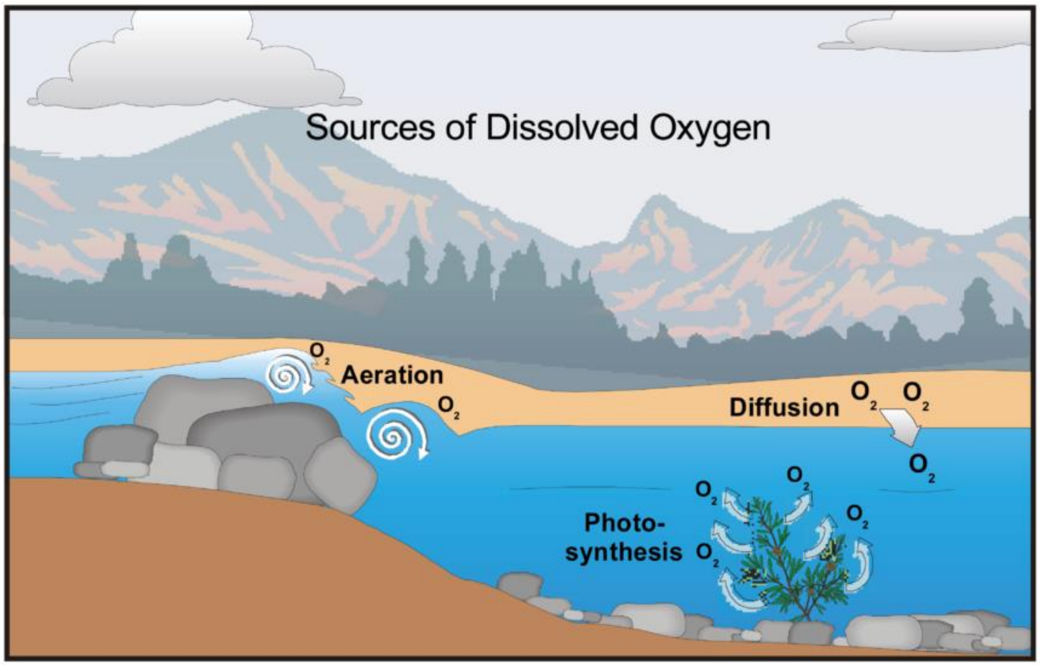

Figure 19 - Sources of dissolved oxygen in surface water. Source: Vernier Experiments, Biochemical Oxygen Demand.

Paw Paw Lake tends to have oxygen levels well above the warmwater fishery standard at its surface down to about 15 – 20 feet of water. Towards the bottom of the lake, dissolved oxygen levels drop to near zero mg/L of oxygen. This is fairly common for inland lakes in Michigan that are stratified in the summertime. A stratified lake has three distinct layers of thermal stratification:

- Epilimnion: Shallowest layer that is warm and near the surface. This layer interacts with wind and sunlight and has the highest concentrations of dissolved oxygen.
- Metalimnion: Middle layer and transition zone between the warm upper layer and cold lower layer. This is where the thermocline, the greatest temperature and density difference in water, is located.
- Hypolimnion: The deepest and coldest layer. This water is more dense than the epilimnion and does not have any interaction with wind or sunlight. This layer typically has minimal or no dissolved oxygen in the water.

Paw Paw Lake's dissolved oxygen concentrations over time are shown in the figure below.

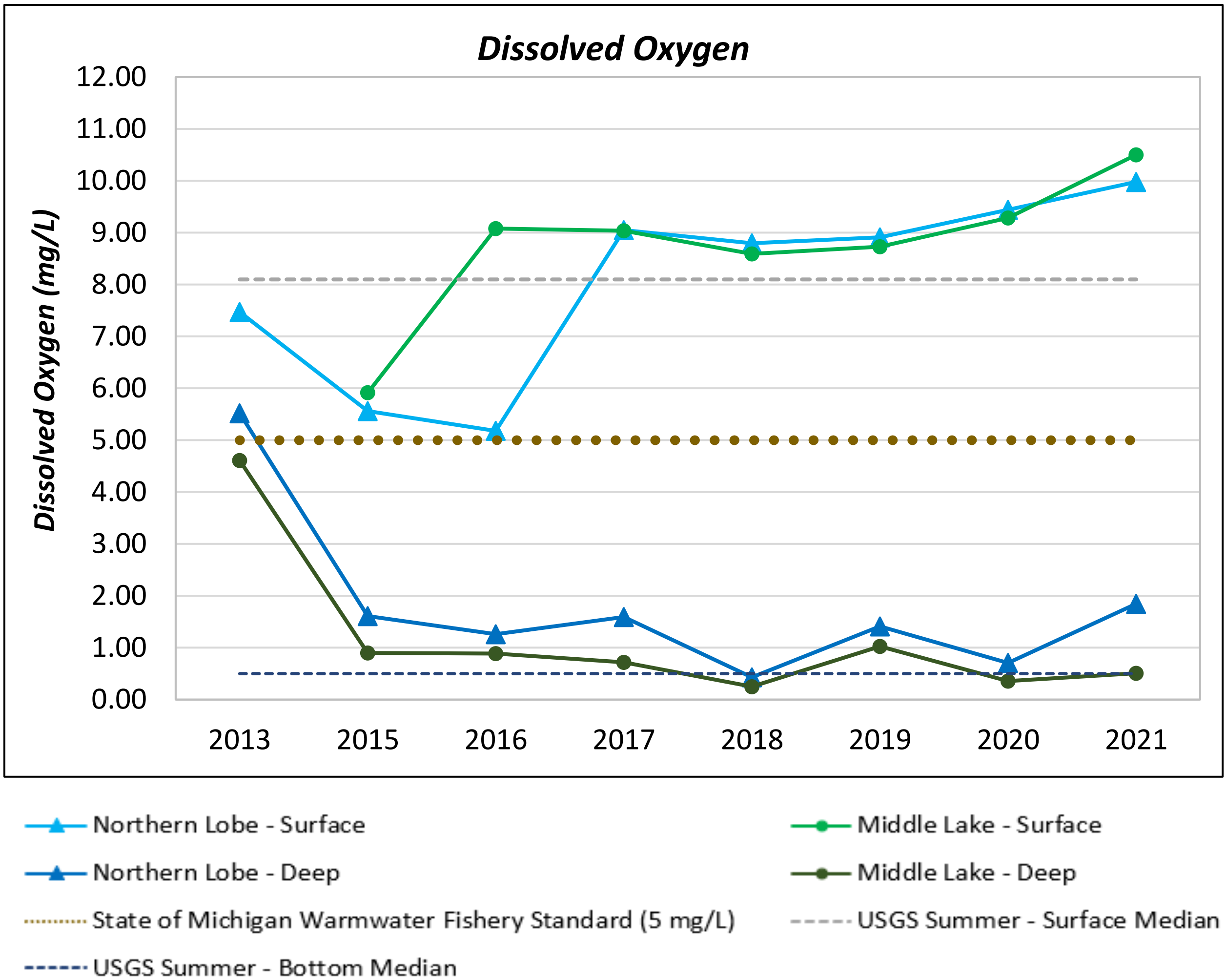

Figure 20 - Dissolved oxygen measured in Paw Paw Lake over time. Note that 2013 data is biased in that there was only one sample event for the year. The sample event took place in mid-June. DO concentrations at the bottom of the lake tend to be higher earlier in the year (May, June).

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

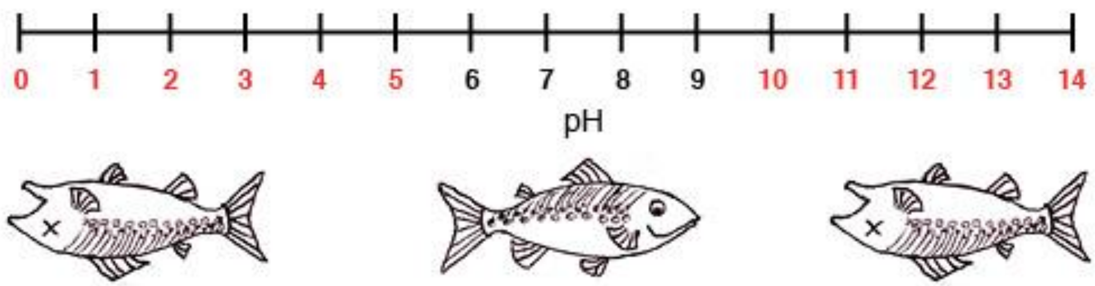

Figure 21 - Range of pH where fish are happy.

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). 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. Paw Paw Lake tends to be slightly more basic than other Michigan inland lakes but is within the pH range required for a healthy fish community.

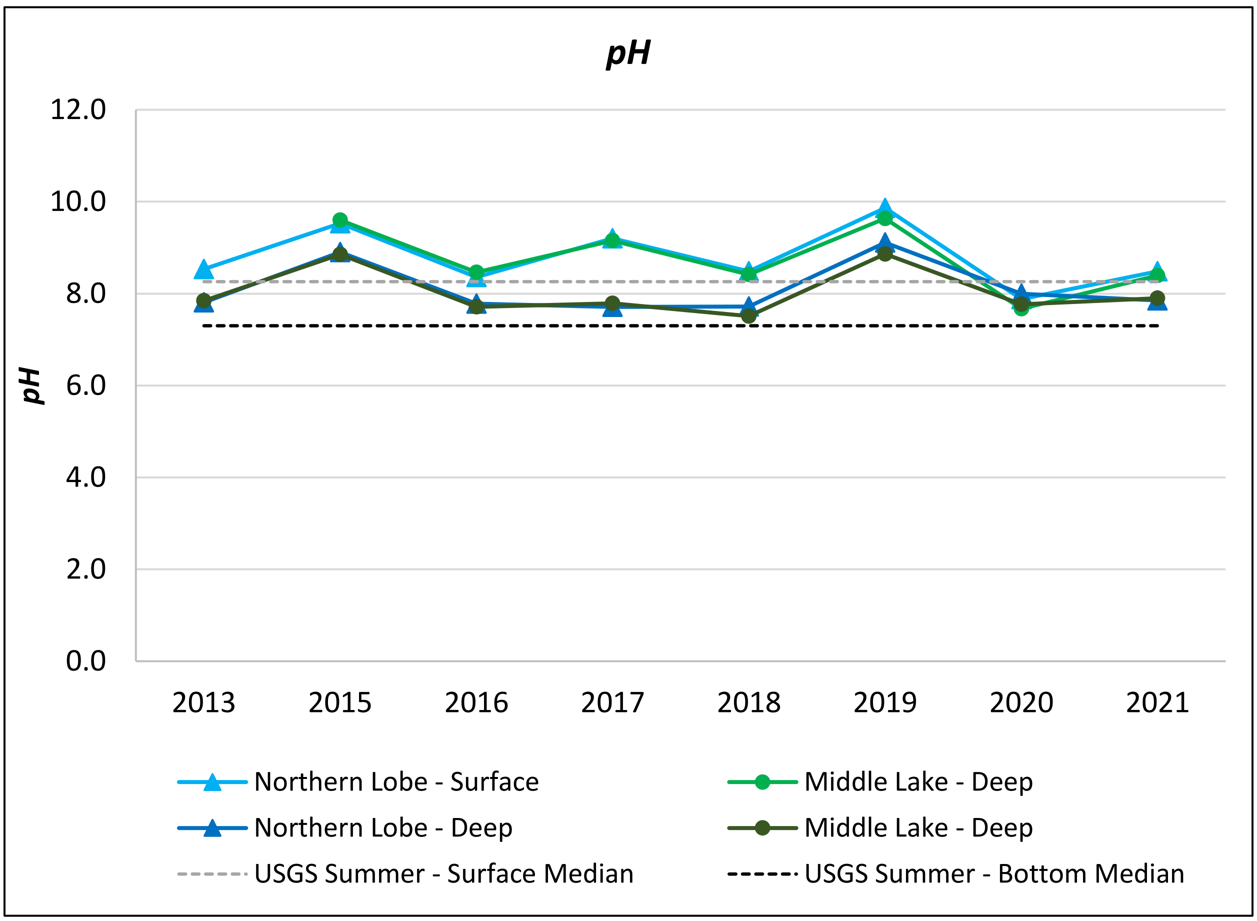

Figure 22 - pH measured in Paw Paw Lake over time. Annual values were calculated by taking the geometric mean of values in each monitoring zone.

Temperature

Water temperature in a lake can greatly impact its water quality, biological activity, and growth. Warmer water holds less dissolved oxygen, a component which is critical to the survival of aquatic species, and cooler water holds more dissolved oxygen.

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

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. Paw Paw Lake falls within the normal range of surface and bottom temperatures of Michigan inland lakes. Water temperatures over time are shown in the graph below.

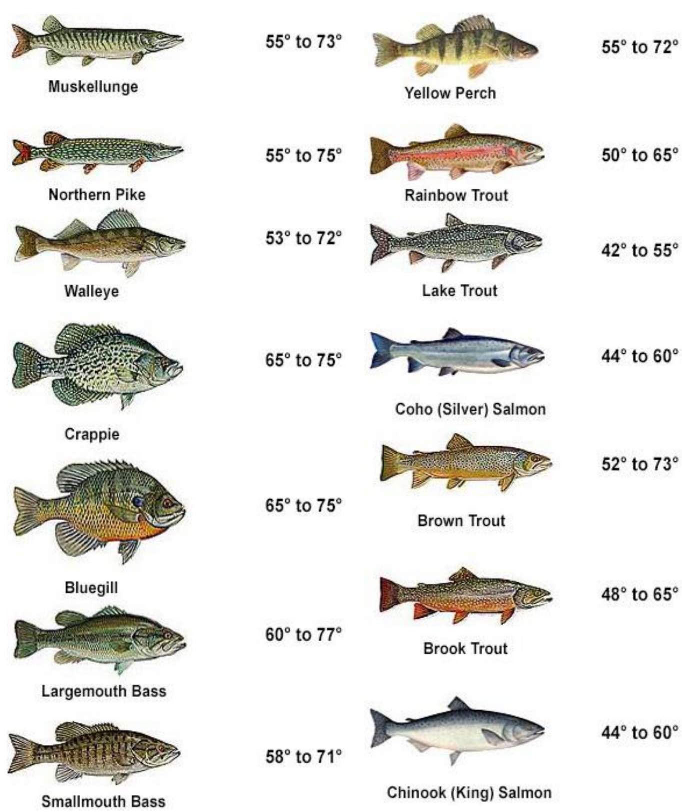

Figure 23 - Favored temperature range for freshwater fish. Paw Paw Lake supports a warmwater fishery. Fish in a warmwater fishery include pumpkinseed, largemouth bass, and bluegill. Source: Bass Pro Shops.

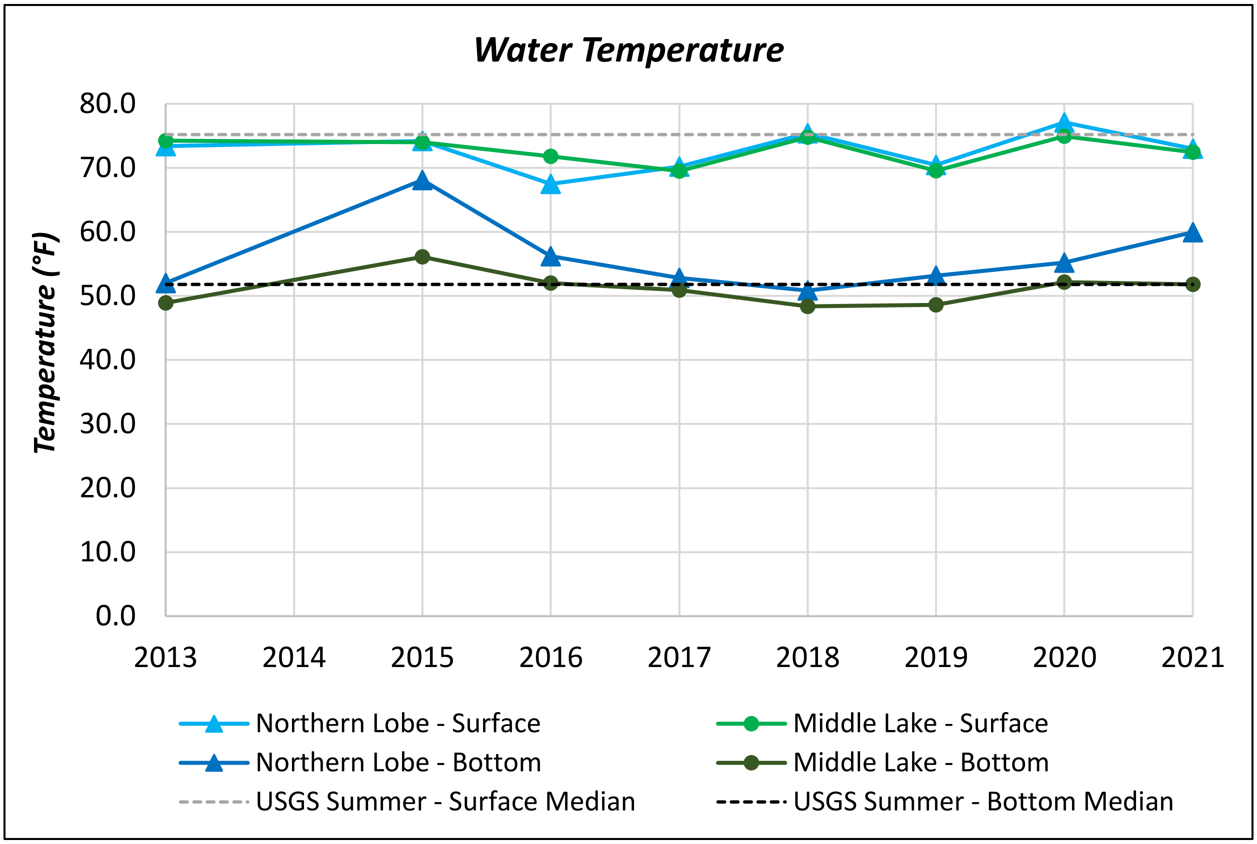

Figure 24 - Water temperature measured in Paw Paw Lake over time. Note the temperature change within the northern lobe deep sample zone in 2015. During the summer of 2015 aeration was utilized in the northern lobe and not the middle lake area. The middle lake area did not see as large of an increase in bottom temperature.

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. 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

Type of Water	***Specific Conductivity (mS/cm)***
Distilled Water	0.0005 - 0.003
Melted Snow	0.002 - 0.042
Tap Water	0.05 - 0.8
Potable Water in the US	0.03 - 1.5
Freshwater Streams	0.1 - 2.0
Industrial Wastewater	10
Seawater	55

Table 2 - Specific conductivity measured in various types of water. Source: Fondriest

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.

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, which consequently means more ions are dissolved in the water. Specific conductivity within the lake has remained relatively consistent in recent years. Any variable leading to an increase or decrease in specific conductivity has uniformly impacted specific conductivity in the entire lake – top, bottom, north lobe and middle lake zones.

For inland lakes in the State of Michigan, there is not a set water quality standard for specific conductivity. However, there is comparison criteria derived from the USGS and EGLE study of Michigan inland lakes. Summer surface and bottom specific conductivity medians are depicted on the figure below and provide a comparison for Paw Paw Lake data.

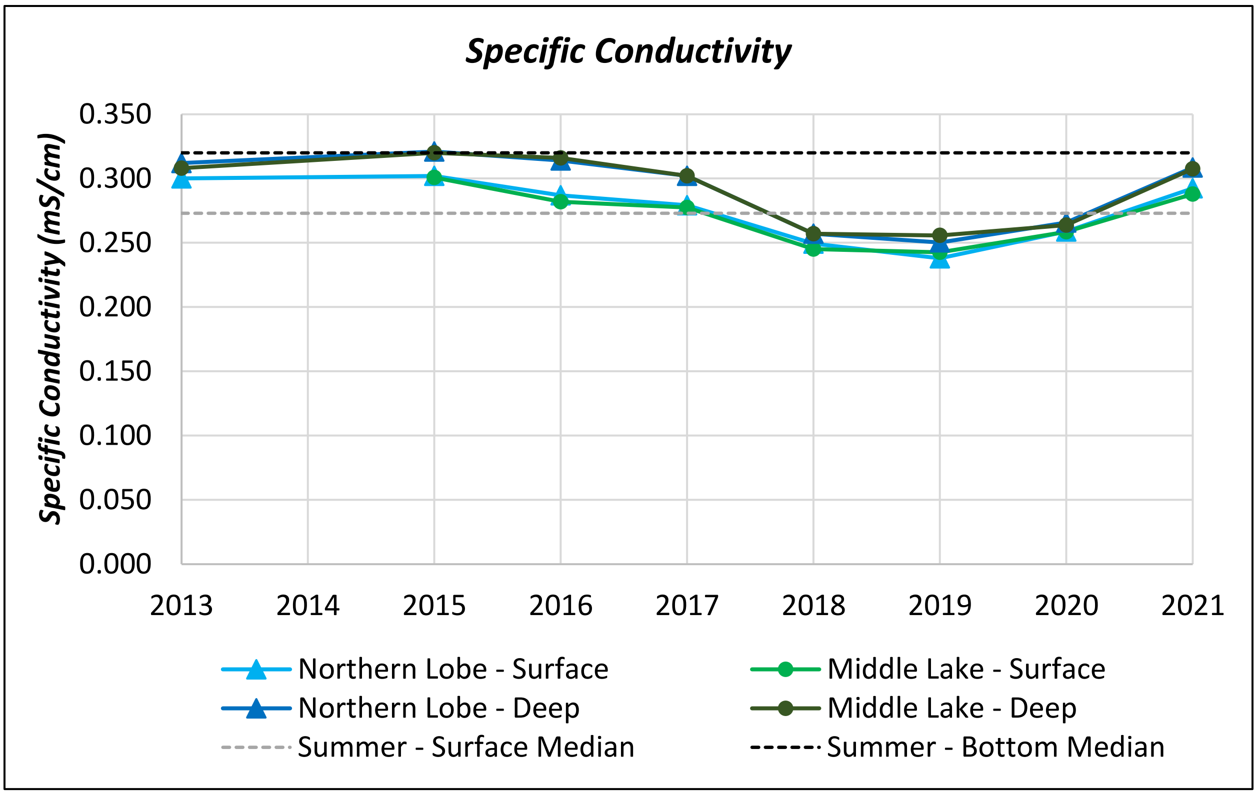

Figure 25 - Specific conductivity measured in Paw Paw Lake over time. Annual values were calculated by taking the geometric mean of specific conductivity measurements in each monitoring zone.

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.

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). While this measurement does not give an exact concentration of how many algal cells are present within the water, it does serve as an indication of how much is in the water. Ideally, chlorophyll-a concentration should be low enough to provide balance in the aquatic ecosystem. A chlorophyll-a sample is collected only in the surface water of the lake, as chlorophyll is a green pigment found in plants, algae, and phytoplankton used to absorb sunlight to provide energy for photosynthesis. Chlorophyll-a is not measured at the bottom of the lake, as sunlight does not penetrate down that far. Therefore, organisms with chlorophyll in their tissues do not live at the bottom of the lake, as they would not survive without the sunlight necessary to produce energy to live.

Chlorophyll-a concentrations increase due to an increase in phytoplankton and algae in the water column. If phytoplankton and algae populations decrease, so does Chlorophyll-a concentrations. Chlorophyll-a has decreased in Paw Paw Lake over the last few years due in part to the filter feeding zebra mussel. Zebra mussels significantly increase water clarity and reduce chlorophyll-a since their diet is primarily composed of phytoplankton. Zebra mussels are capable of filtering about one liter of water per day while feeding primarily on algae. (Source: USGS Nonindigenous [Aquatic Species, Dreissena polymorpha]). The figure below represents a basic food web in a lake that has zebra mussels. Note that zebra mussels disrupt the lower levels of the food web by eating algae and plankton, which would otherwise be eaten by fish and other native mussels.

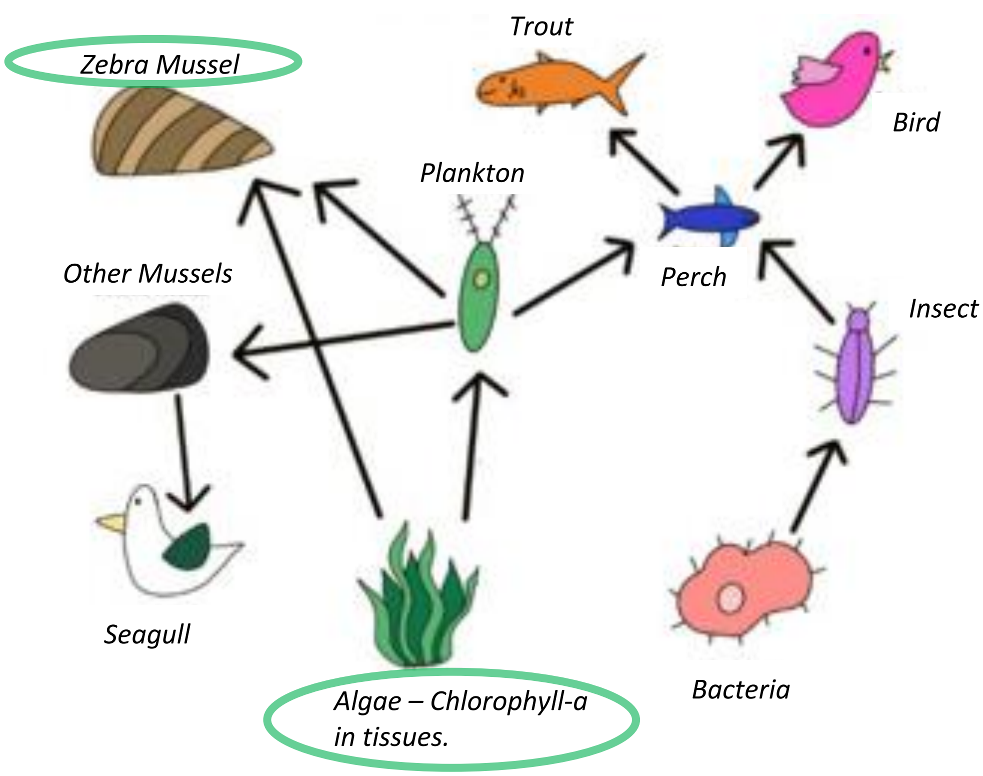

Figure 26 - Zebra mussel in the food web within the Great Lakes region (simplified). Zebra mussels eat algae, which contain chlorophyll-a. Source: Teacher Pay Teacher.

The State of Michigan does not have a water quality standard for Chlorophyll-a, however, the USGS Michigan inland lakes study and report did quantify median concentrations of chlorophyll-a in the spring and summer within Michigan inland lakes. Since 2018, Paw Paw Lake has had chlorophyll-a levels near Michigan inland lakes spring and summer median concentrations as shown in the figure below.

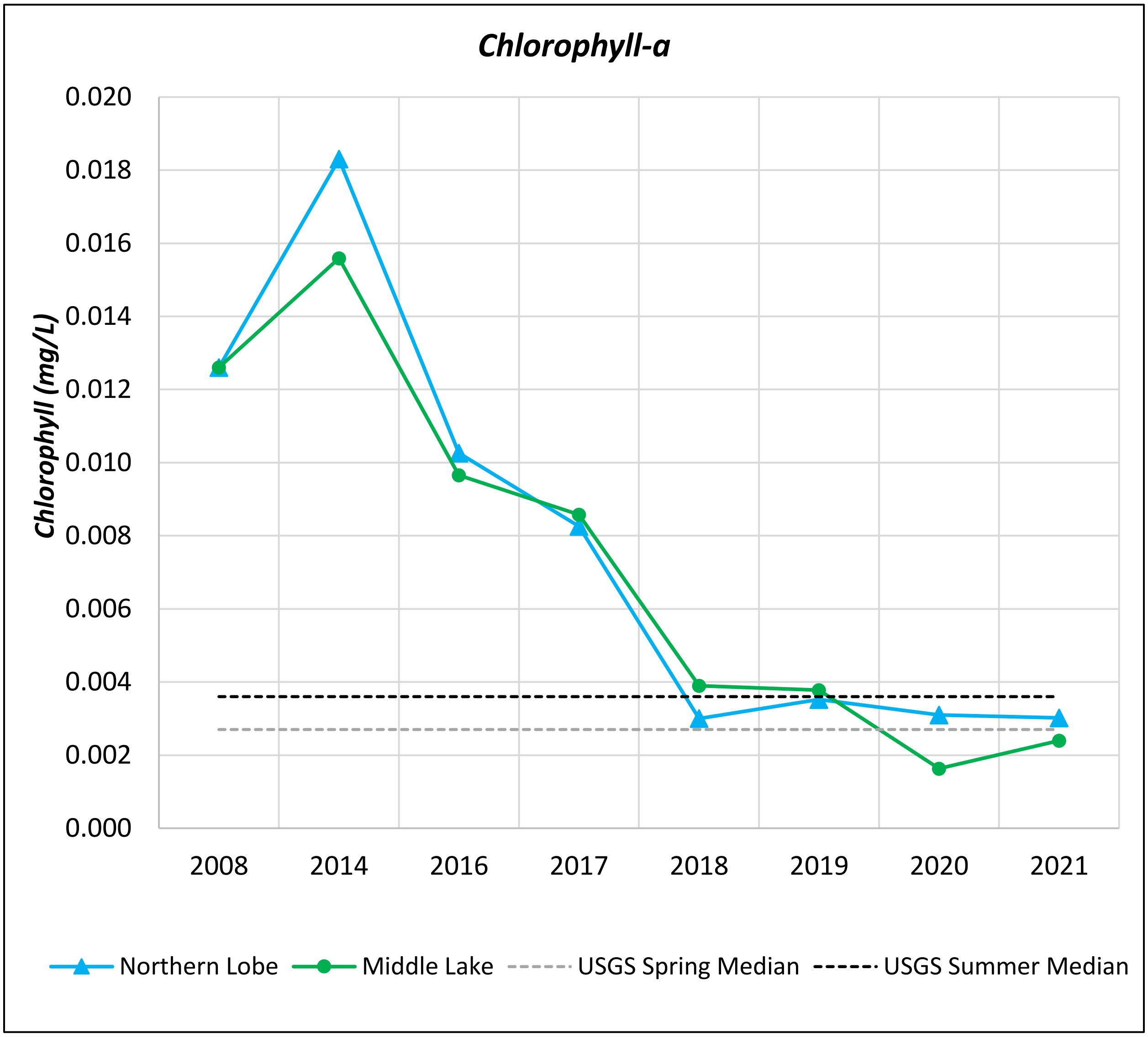

Figure 27 - Chlorophyll-a measured in Paw Paw Lake over time. Annual values were calculated using the geometric mean.

TROPHIC STATE INDEX

The Trophic State Index is a classification system designed to rate a body of water based on the amount of biological productivity taking place in the water. Productivity within a lake is defined as a lake's ability to support plant and animal life. The rating scale is from 1 – 100, with the least productive body of water being a "1" and the most productive body of water being a "100." Specific ratings are correlated to classes of lakes, for example:

- <u>*<30: Oligotrophic Lake*</u> – Clear water, oxygen throughout the year in bottom of lake.
- <u>*40 – 50: Mesotrophic Lake*</u> – Water moderately clear; increasing chance of reduced dissolved oxygen in bottom of lake.
- <u>*50 – 60: Eutrophic Lake*</u> – Anoxic hypolimnia, excess plant and algal growth possible.
- <u>*70 – 80: Hypereutrophic Lake*</u> – Light limited productivity. Dense algae and aquatic plants.

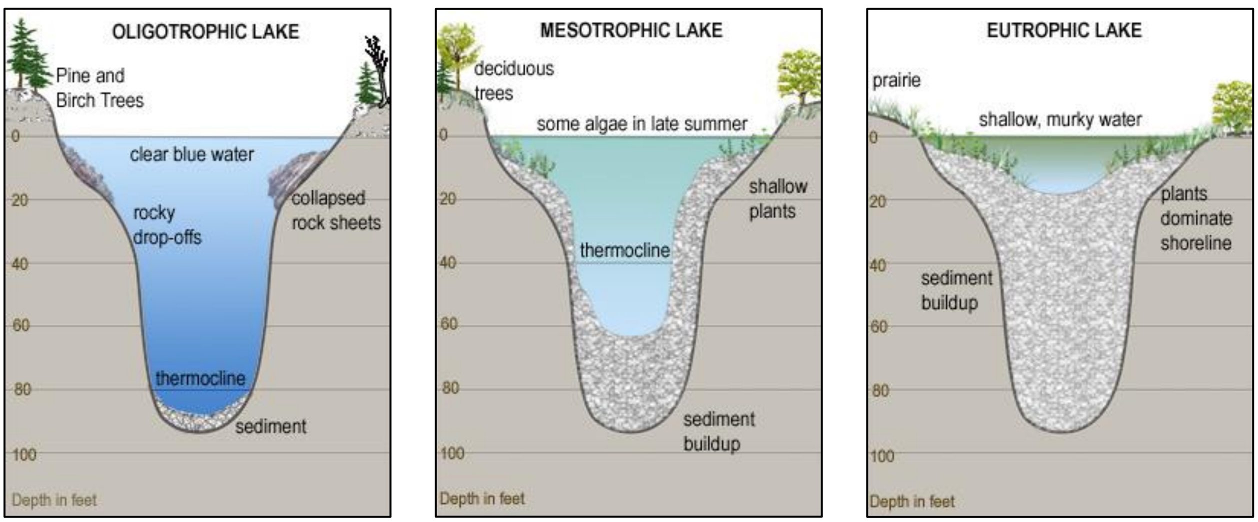

Figure 28 - Trophic states of lakes and associated characteristics. Source: RMB Environmental Laboratories, Inc.

Trophic State ratings are calculated by using three different variables using three different calculations. The variables are Secchi Depth, chlorophyll-a, and total phosphorus.

Trophic State Index Calculations (Source: Carlson 1977):

<u>***Secchi Depth***</u>

$$TSI(SD) = 10\left[6 - \frac{\ln SD}{\ln 2}\right]$$

<u>***Chlorophyll-a***</u>

$$TSI(CHL) = 9.81\ln(CHL) + 30.6$$

<u>***Total Phosphorus***</u>

$$TSI(TP) = 14.42\ln(TP) + 4.15$$

The table below outlines each trophic state, general condition of a lake with that trophic status, and a range of Secchi depth, chlorophyll-a, and total phosphorus concentrations within each state.

Trophic Status	**TSI**	**Chlor-a (mg/L)**	**Secchi (ft)**	**TP (mg/L)**	**Fisheries and Recreation**
Algal scums, few aquatic plants.	>80	>0.1550	<0.8	0.192 – 0.384	Rough fish dominate; summer fish kills possible.
Hypereutrophic – Light limited productivity. Dense algae and aquatic plants.	**70 – 80**	0.0560 – 0.1550	0.8 – 1.6	0.096 – 0.192	-
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.
Eutrophic – 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.
Mesotrophic – 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.
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.
Oligotrophic– Clear water, oxygen throughout the year in bottom of lake.	**<30**	<0.00095	>26	<0.006	Salmonid fisheries dominate.

Table 3 - Trophic status and associated parameter concentrations, associated environmental characteristics. Paw Paw Lake is considered a mesotrophic lake according to TSI calculations.

Between the three methods of calculating trophic status, Paw Paw Lake has historically fallen in the categories "eutrophic" and "mesotrophic." In recent years, the lake has tended to be more mesotrophic than eutrophic. This may be due in part to recent improvement work on tributaries to Paw Paw Lake, including the Branch & Derby Intercounty Drain. Improvement work includes the construction of an in-line detention basin, bank stabilization, erosion prevention, and drain clean out. All of these improvement activities reduce the nutrient load going into the lake.

The trend towards a mesotrophic status may also be due to property owners within the watershed being more aware of how landuse effects water quality. Meaning that less fertilizer may be used on lawns and farmland, buffer strips could have been installed adjacent to drains and the lakefront, and lawn clippings and other organic waste may not have been dumped into the lake or a tributary drain. While all these actions may seem small and inconsequential on their own, collectively it makes a big impact on water quality if many landowners partake in responsible land management.

Finally, zebra mussels, an invasive filter feeder, can also provide an explanation why Paw Paw Lake is moving towards mesotrophy according to the TSI calculations. Zebra mussels significantly increase water clarity and reduce chlorophyll-a since their diet is primarily composed of phytoplankton. Phytoplankton are tiny plants and algae that contain chlorophyll within their tissues. Zebra mussels are capable of filtering about one liter of water per day while feeding primarily on algae. (Source: USGS Nonindigenous Aquatic Species, Dreissena polymorpha). They are able to filter particles smaller than 1 µm in diameter, although they preferentially select larger particles (Sprung and Rose 1988). At a 90% efficiency rate, zebra mussels are much more efficient at filtering such small particles than are unionids and Asiatic clams (Noordhuis et al. 1992).

Trophic status calculations for Paw Paw Lake based on chlorophyll-a, total phosphorus, and Secchi depth are shown in the figure below. Some years do not have a TSI calculation for each parameter, as the parameter was not monitored in that given year. Also, the composite TSI score is the average of the three trophic statuses calculated from chlorophyll-a, total phosphorus, and Secchi depth.

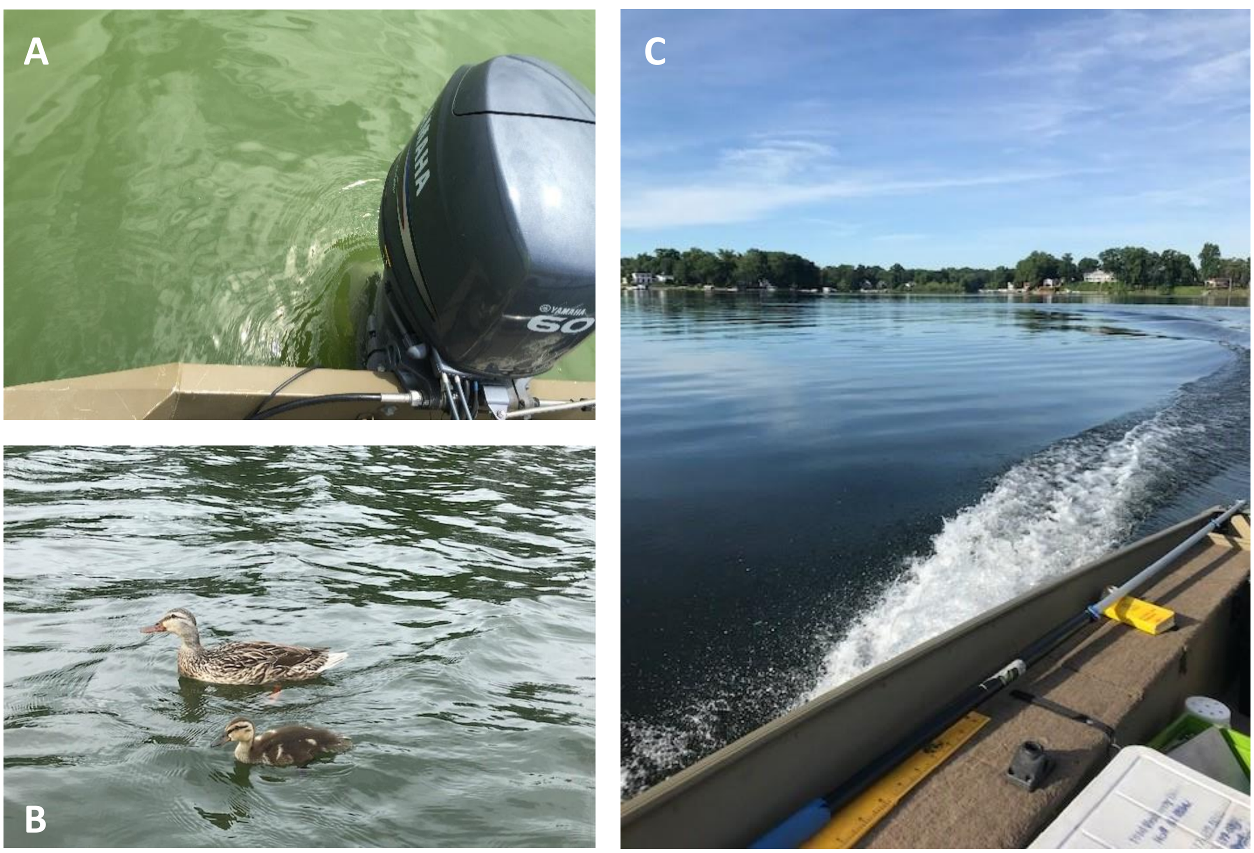

Figure 29 - Paw Paw Lake surface water through the years. A - August 2016, B - July 2021, C - July 2020. Note in 2016 the lack of clarity and green water due to an algae bloom.

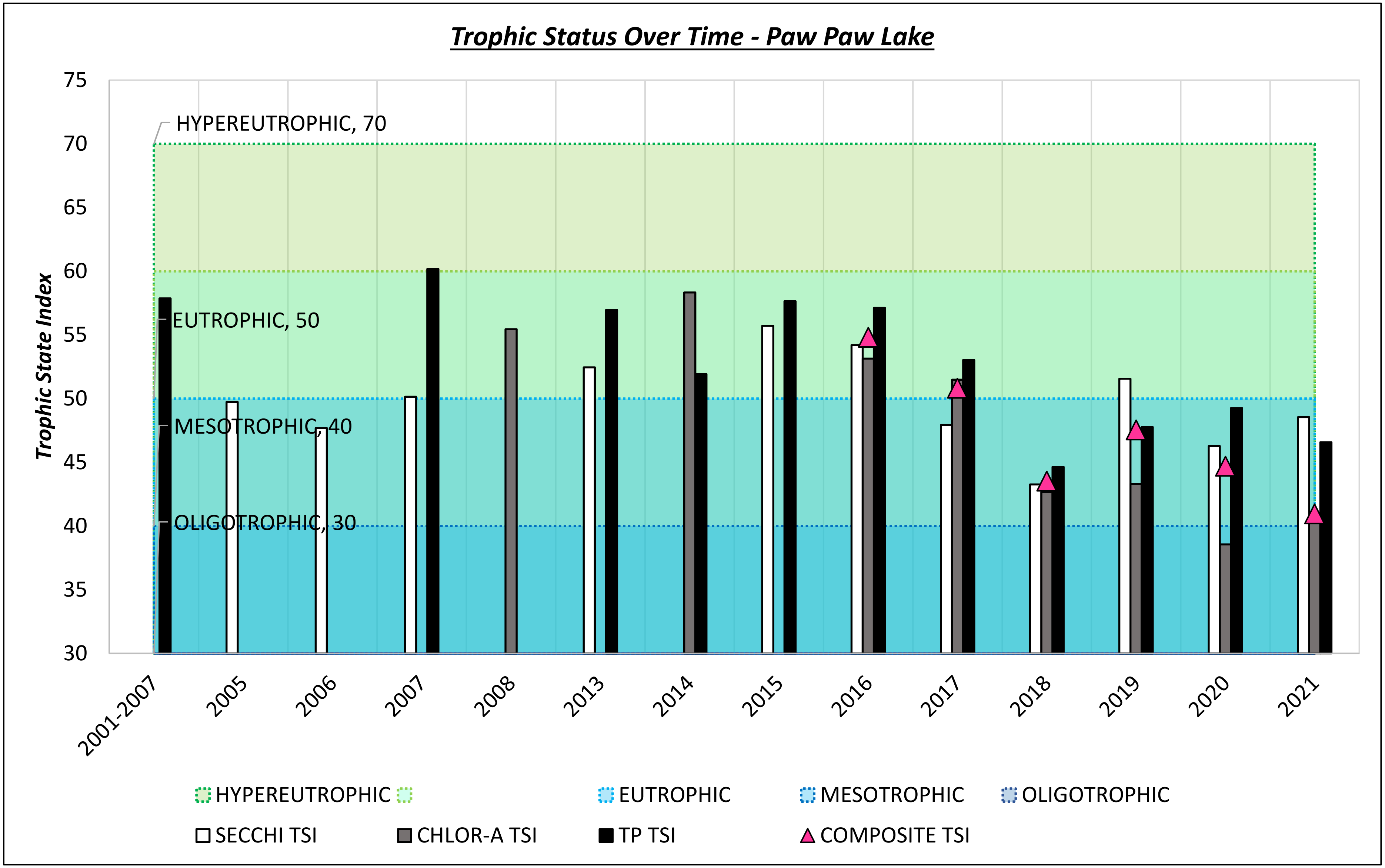

Figure 30 - Trophic status over time in Paw Paw Lake. Trophic status was calculated using chlorophyll-a, total phosphorus, and Secchi depth data. A lower TSI number is desired for Paw Paw Lake.

ALGAE ANALYSIS

While algae can lead to undesirable conditions for recreation and relaxation on a lake, algae are an important component of a lake system. They are the base of the food web for all aquatic organisms and convert water and carbon dioxide into sugar through the process of photosynthesis. Photosynthesis also generates oxygen as a byproduct, contributing to the survival of fish and other aquatic organisms (Source: Indiana Department of Environmental Management, Algal Blooms Fact Sheet).

Algae become a nuisance and an environmental issue once they grow to an excess. An algae bloom, defined as a rapid increase in the density of algae in an aquatic system, can form naturally without any human influence. However, algae blooms happen more frequently and are larger due to an excess of nutrients in a water body. Blooms also tend to happen when the weather is warm and the water is calm.

Some species of blue green-algae (cyanobacteria) have the capability to produce toxins. An example of a harmful algae bloom (HAB) that lead to human and environmental impacts was in August of 2014 in the western Lake Erie basin. A cyanobacteria bloom took place, and the algae produced microcystin, which is a liver toxin. This resulted in the shutting down of Toledo, Ohio's water supply. Currently, research is being conducted in the western Lake Erie basin and other water bodies within the Great Lakes region in order to understand why these blooms happen and what conditions lead the algae to produce toxin(s).

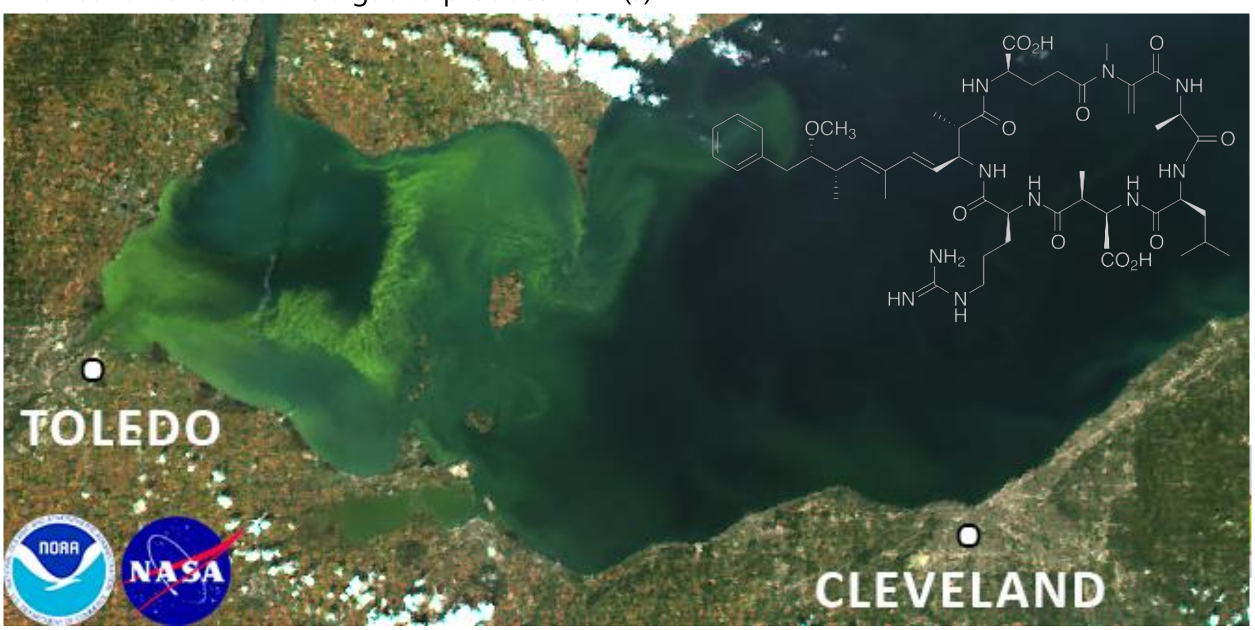

Figure 31 - Algae bloom in western Lake Erie and microcystin variant LR chemical structure. Source: Great Lakes Today

In Paw Paw Lake, algae has been monitored since 2016 in response to concerns expressed by property owners and recreational users of Paw Paw Lake. Analysis run on the samples include algal identification and enumeration, and analysis for microcystins. These tests show which species of algae are living in Paw Paw Lake during the time of sample collection, and relative abundance of different types of algae in each sample. Microcystin testing tells if there has been any microcystin toxin produced by the algae, and if there is microcystin toxin present is it at a level that is considered potentially harmful to humans.

When analyzed, algae samples showed that the algal community within Paw Paw Lake is primarily composed of cyanobacteria. Some species of blue-green algae can produce toxins. These algae are referred to as "potentially toxigenic cyanobacteria" or "PTOX" for short. During analysis of the water samples, the PTOX cyanobacteria were counted separately from the other cyanobacteria cells. This is because PTOX cyanobacteria is of special concern for water quality, and if just cyanobacteria were enumerated, it would be difficult to assess how much risk the lake has for a harmful algae bloom. For example, on August 30, 2016, 61% of the algae identified at sample site AG 4 was non-PTOX cyanobacteria and 8% was PTOX cyanobacteria. In total, the algae identified in the sample was 69% cyanobacteria (includes both PTOX and non-PTOX). Even if 100% of the cells identified in the algae sample were PTOX cyanobacteria, this does not necessarily mean that there will be toxins in the water, as the algae produce toxins only some of the time depending on environmental conditions. Research is still being conducted on PTOX cyanobacteria with the intent to understand why they produce toxins and under what conditions. The figures below depict Paw Paw Lake algae analysis results over time.

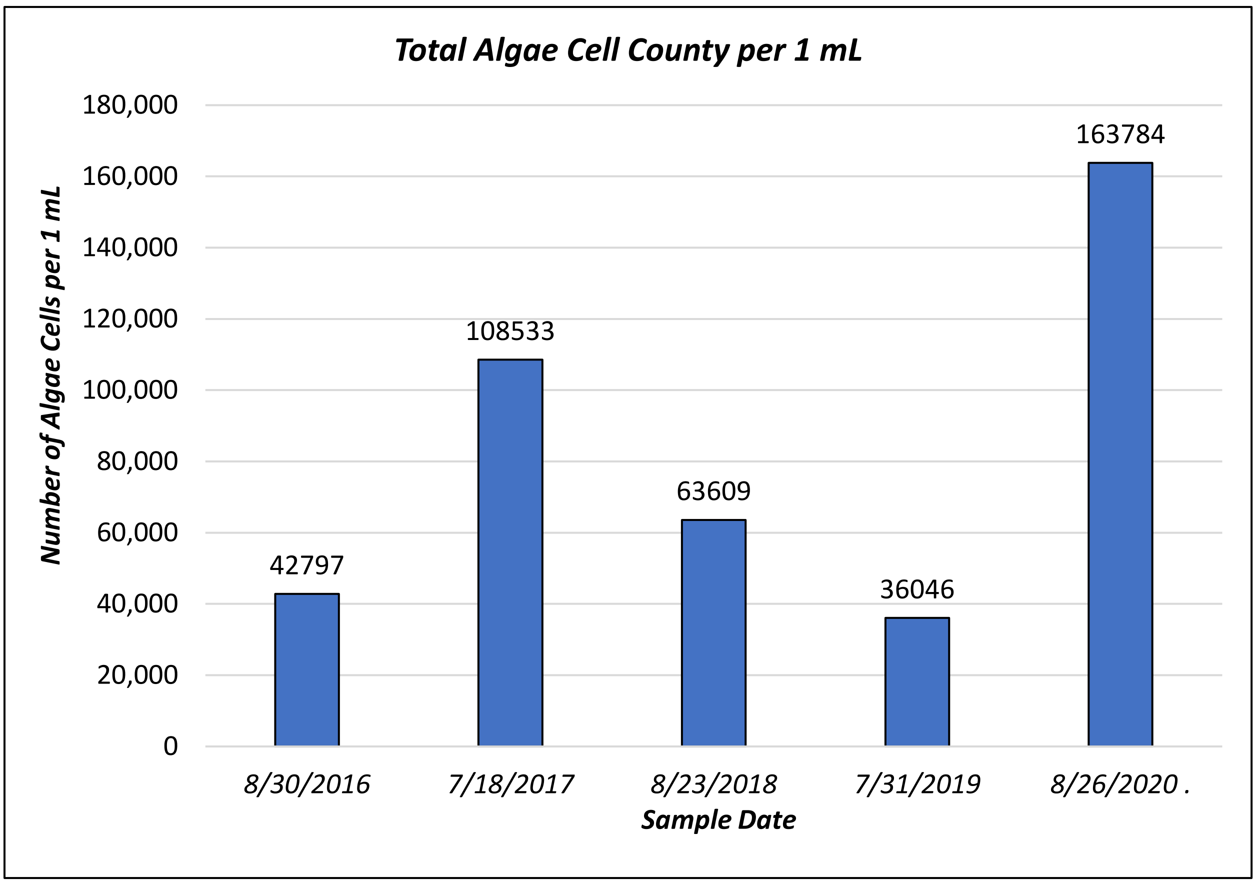

Figure 32 - Number of algae cells per milliliter (mL) measured over time.

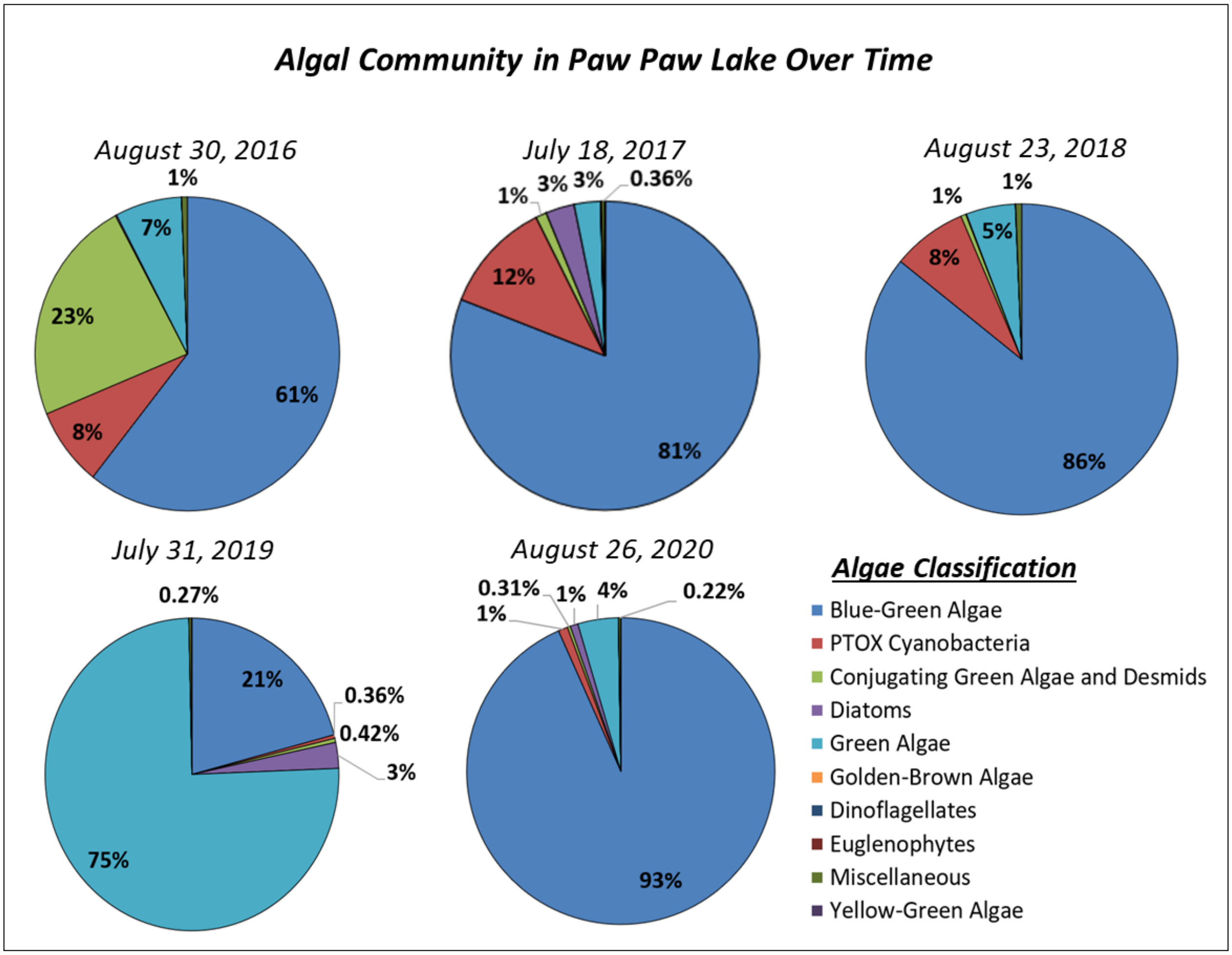

Figure 33 – Make up of algal community over time in Paw Paw Lake. Blue-green algae tend to dominate the algal community.

Though several types of algal toxins have been analyzed for in Paw Paw Lake, microcystin was determined to be the most relevant and became the focus of algal toxin analysis beginning in 2018.

Toxins were only detected once in Paw Paw Lake since 2016,, and in all cases algal toxins were well below levels that could be of concern to human health. On August 23, 2018, two microcystin variants were detected in all three samples collected. The variants were LA and LR, and the sample sites were AG 2, AG 4, and AG 5. Samples were collected at the lake's surface. Levels were very low, 0.05 – 0.10 ng/L for total microcystins. EGLE defines a harmful algal bloom as: "An algal bloom in recreational waters is harmful if microcystin levels are at or above the 20 ug/L World Health Organization non-drinking water guideline, or other algal toxins are at or above appropriate guidelines that have been reviewed by EGLE." All other sample events tested below the reporting limit of the test for toxins. Algal toxin data is shown in the tables below.

Four Toxin Scan					
Date	*Sample Site Location*	*Microcystin*	*Anatoxin-a*	*Cylindrospermopsin*	*Saxitoxin*
8/30/2016	AG 1	ND	ND	ND	ND
	AG 2	ND	ND	ND	ND
	AG 3	ND	ND	ND	ND
	AG 4	ND	ND	ND	ND
	AG 5	ND	ND	ND	ND
7/18/2017	AG 1	ND	ND	ND	ND
	AG 3	ND	ND	ND	ND
	AG 4	ND	ND	ND	ND

Table 4 - Four toxin scan results from 2016 and 2017 sample events. ND = No detection of toxin.

Date	**Sample Site Location**	**Microcystin Variants and Nodularins (ng/mL)**														
		[DAsp^3] RR	*RR*	*NOD-R*	*YR*	*HtYR*	*LR*	*[DAsp^3] LR*	*[Dha^7] LR*	*HilR*	*WR*	*[Leu^1] LR*	*LA*	*LY*	*LW*	*LF*
8/23/2018	*AG 2*	ND	ND	ND	ND	ND	0.01	ND	ND	ND	ND	ND	0.04	ND	ND	ND
	AG 4	ND	ND	ND	ND	ND	0.02	ND	ND	ND	ND	ND	0.04	ND	ND	ND
	AG 5	ND	ND	ND	ND	ND	0.03	ND	ND	ND	ND	ND	0.07	ND	ND	ND
7/31/2019	*AG 1*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	AG 4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	AG 5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	AG 6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8/26/2020	*AG 1*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	AG 4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	AG 5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10/8/2021	*AG 1*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	AG 4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	AG 5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 5 - Microcystin and nodularin testing results from 2018 – 2021. ND = no detection of toxin.

Summary and Discussion

Paw Paw Lake exhibits water quality characteristics typical of a Michigan inland lake. Dissolved oxygen, pH, temperature, specific conductivity, and chlorophyll-*a* measured in Paw Paw Lake are near the USGS Michigan inland lakes dataset median. Paw Paw Lake's soluble reactive phosphorus, ammonia, and nitrate concentrations tend to be lower compared to Michigan's inland lakes, with the exception of samples collected in the deepest part of the middle lake zone. Total phosphorus and water clarity have tended to be higher and lower, respectively, compared to other Michigan inland lakes. Despite total phosphorus being elevated, most of the phosphorus in the water column of Paw Paw Lake is not readily available for plant and algae uptake, as exhibited by low soluble reactive phosphorous concentrations. Nevertheless, there should still be an effort to reduce total phosphorus within Paw Paw Lake.

Future actions for Paw Paw Lake should focus on lake improvement goals already outlined in the Paw Paw Lake Improvement Plan. Currently, these goals include:

- Management and Control Invasive and Nuisance Species
- Maintaining Water Quality and Clarity
- Improve Fisheries, Wildlife, Recreation, and Aesthetic Values of Paw Paw Lake
- Provide Educational Outreach
- Identify Metrics to Measure Success of the Paw Paw Lake Improvement Plan

A reasonable short-term action would be to assess the current status of those goals, including the use of water quality data summarized in this document.