Michigan's State Level Assessment of the 2012 National Lakes Assessment Project: Comparisons with National and Regional Results


Gasley Lake, Iron County, Michigan

Acknowledgements:

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Executive Summary

The 2012 National Lake Assessment (NLA) was a survey of the nation's inland lakes, ponds, and reservoirs under the National Aquatic Resource Surveys (NARS). The national surveys are designed to provide statistically valid regional and national estimates of the condition of lakes as well as statewide assessments for those states that choose to augment the NLA Survey. This report presents some background on the design of the 2012 NLA survey as well as the findings of the state-scale assessment for Michigan's lakes.

Results made for Michigan lakes include:

1) Nutrient pollution was not a widespread stressor. Lake habitat complexity, riparian vegetation cover, and mercury in lake-bottom sediment were the most widespread stressors.
2) Microcystin and chlorophyll-a concentrations, and cyanobacteria cell counts were generally lower than the levels of concern established by the World Health Organization.
3) The herbicide atrazine was detected in 13% of lakes, and concentrations never exceeded the United States Environmental Protection Agency (USEPA) level of concern for plants in freshwater or state water quality standards.
4) Based on macroinvertebrate communities, 52% of lakes were estimated to be in the most disturbed condition, compared to 17% based on zooplankton communities.

The 2012 NLA results highlight the need for programs that encourage riparian and shoreline protection, improvement, and restoration to improve and maintain inland lake water quality. Michigan currently has several programs focused on shoreline quality. The NLA also highlights the need for actions that lead to a reduction of mercury in inland lakes. Many inland water bodies in Michigan are impacted by mercury and have fish consumption advisories.

The national report showed changes observed between the 2007 NLA study and 2012 results, and the Michigan Department of Environmental Quality (MDEQ) presents both 2007 and 2012 data in this report. The next NLA Survey is scheduled for summer 2017. The MDEQ will again participate in the survey and sample 50 randomly selected inland lakes in Michigan.

Introduction

The USEPA implements a series of NARS to assess the quality of the nation's waters. The 2012 NLA was a survey of the nation's inland lakes, ponds, and reservoirs under NARS. The national surveys are designed to provide statistically valid regional and national estimates of the condition of lakes as well as statewide assessments for those states that choose to augment the NLA Survey. Consistent sampling and analytical procedures ensure that the results can be compared across the nation.

The goal of the NLA is to address the following questions about the quality of the Nation's lakes, ponds, and reservoirs (USEPA 2016a):

1) What is the current biological, chemical, physical, and recreational condition of lakes?
    - What is the extent of degradation among lakes?
    - Is degradation widespread (e.g., national) or localized (e.g., regional)?

2) Is the proportion of lakes in the most disturbed condition increasing, decreasing, or staying the same over time?

3) Which environmental stressors are most strongly associated with degraded biological condition in lakes?

Conclusions from the 2012 national survey (USEPA 2016a) included:

- Nutrient pollution is common in U.S. lakes; 40% of lakes had excessive levels of total phosphorus and 35% had excessive levels of total nitrogen. Nutrient pollution was the most widespread stressor among those measured in the NLA and can contribute to algae blooms and affect public health and recreational opportunities in lakes.
- *An algal toxin, microcystin, was detected in 39% of lakes, but concentrations rarely (< 1%) reach moderate or high levels of concerns established by the World Health Organization.*
- The herbicide atrazine was detected in 30% of lakes, but concentrations rarely reach the USEPA level of concern for plants in freshwater (<1% of lakes).
- Benthic macroinvertebrate communities were degraded in 31% of lakes, while 21% of lakes had degraded zooplankton communities. NLA exploratory analyses indicated an association between nutrients and biological condition, with lakes with phosphorus pollution likely to have a degraded biological condition.

This report presents some background on the design of the 2012 NLA survey and presents the findings of the state-scale assessment for Michigan's lakes, comparing statewide and national conclusions for chemical, recreational, biological, and physical indicators of the condition of Michigan's lakes. The structure of this report is patterned after the narrative layout of the USEPA's NLA 2012 report **(USEPA 2016a)** and results for many of the parameters are compared between national, regional, and statewide scales. In addition, the national report compared a selection of the metrics from the 2007 NLA study with 2012 NLA metrics. Changes in condition from 2007-2012 are presented in this report, but not emphasized due to the small sample size and lower level of confidence at the state level in comparison to the national level. More information on the overall NLA Survey, field methods and the assessment process, as well as the final national report, can be found at: https://www.epa.gov/national-aquatic-resource-surveys/nla.

National Lake Assessment Sampling Design and Assessment Framework

Sampling Design

Site Selection:
A total of 1,038 lakes in the continental United States were included in the 2012 NLA Survey (Figure 1). The sample population was comprised of natural and constructed freshwater lakes and reservoirs greater than 1 hectare (3 acres), at least one meter in depth. The lake selection process provided for five size class categories (Figure 2), as well as spatial distribution across the nation and nine aggregated ecoregions.

Sample sites were selected at random to represent the condition of the larger population of lakes across the nation and each ecoregion. The sampling design for the NLA Survey is a probability-based sampling site network that provides statistically valid estimates of the condition of about 112,000 lakes nationwide, with a known degree of confidence. Therefore, unless otherwise stated, all percentages reported here are relative to the larger inference population rather than the actual number of lakes sampled.

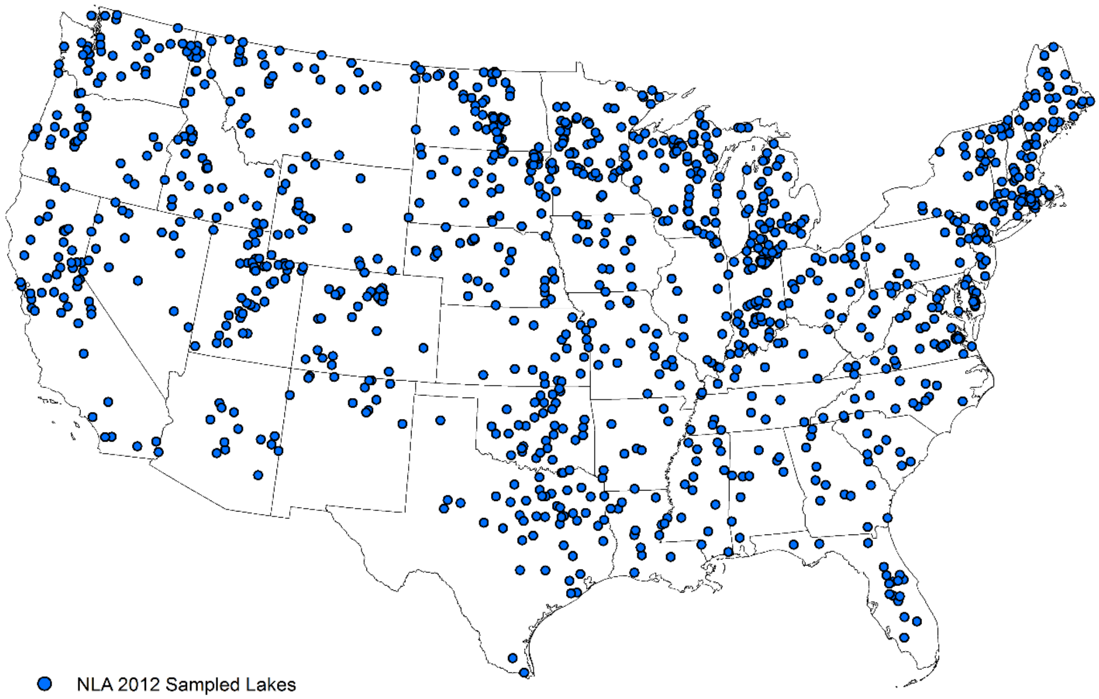

Figure 1. Lakes surveyed in the continental United States as part of the 2012 National Lake Assessment.

Michigan received 38 lakes as part of the original draw for the national survey (18 of which were also sampled in 2007). Based on the NLA Survey design, 50 randomly selected lakes was the minimum number needed to apply the results statewide with ±15% margin of error and 95% confidence level. Therefore, the MDEQ added 12 lakes to reach the 50 lakes minimum. In addition to the randomly selected lakes, two lakes in Michigan were selected as reference sites and sampled by the USEPA as part the overall NLA effort (Figure 3).

In 2007, only lakes larger than four hectares (~10 acres) were included in national site selection; however, in 2012, lakes as small as one hectare were included. Therefore, Michigan added three additional lakes that were greater than four hectares to ensure consistency between 2007 and 2012 data so data could be analyzed between years.

As part of the quality assurance plan, two lakes were sampled twice: School Lake (Lake ID: NLA12-MI-139) and Pine Lake [(Lake ID: NLA12_MI-101), Appendix A]. The results of the revisit sampling were excluded from statistical analysis so that all lakes were represented by a single sample event collected in 2012.

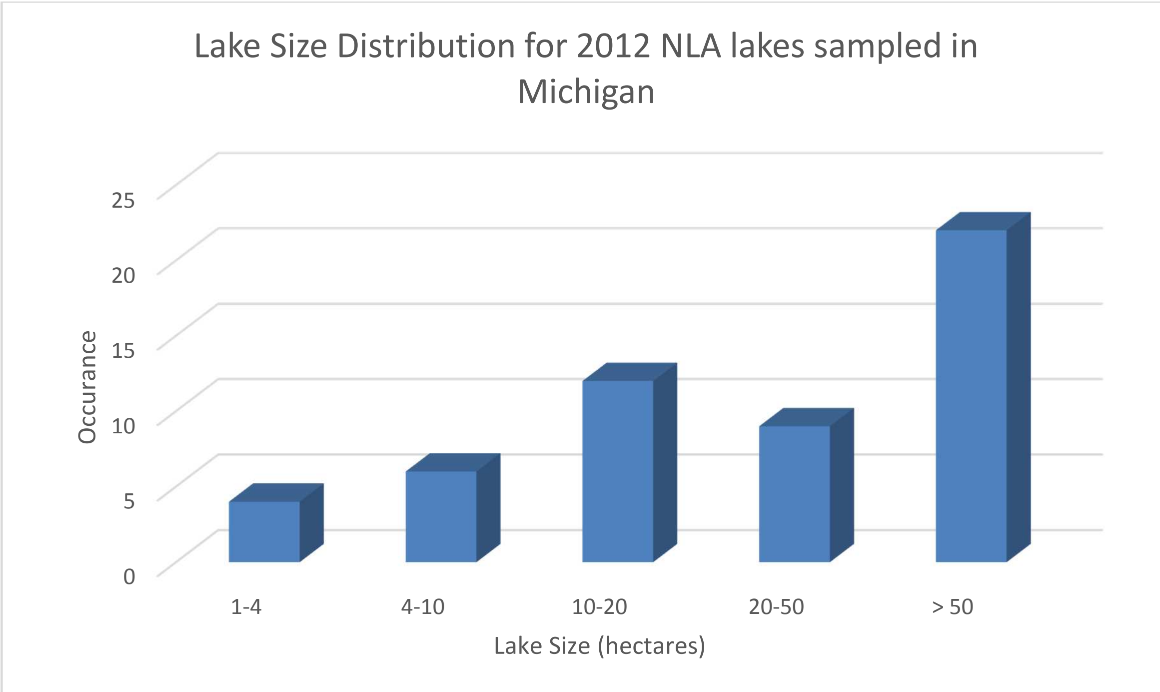

Figure 2. Size distribution of inland lakes sampled in Michigan as part of the 2012 National Lake Assessment.

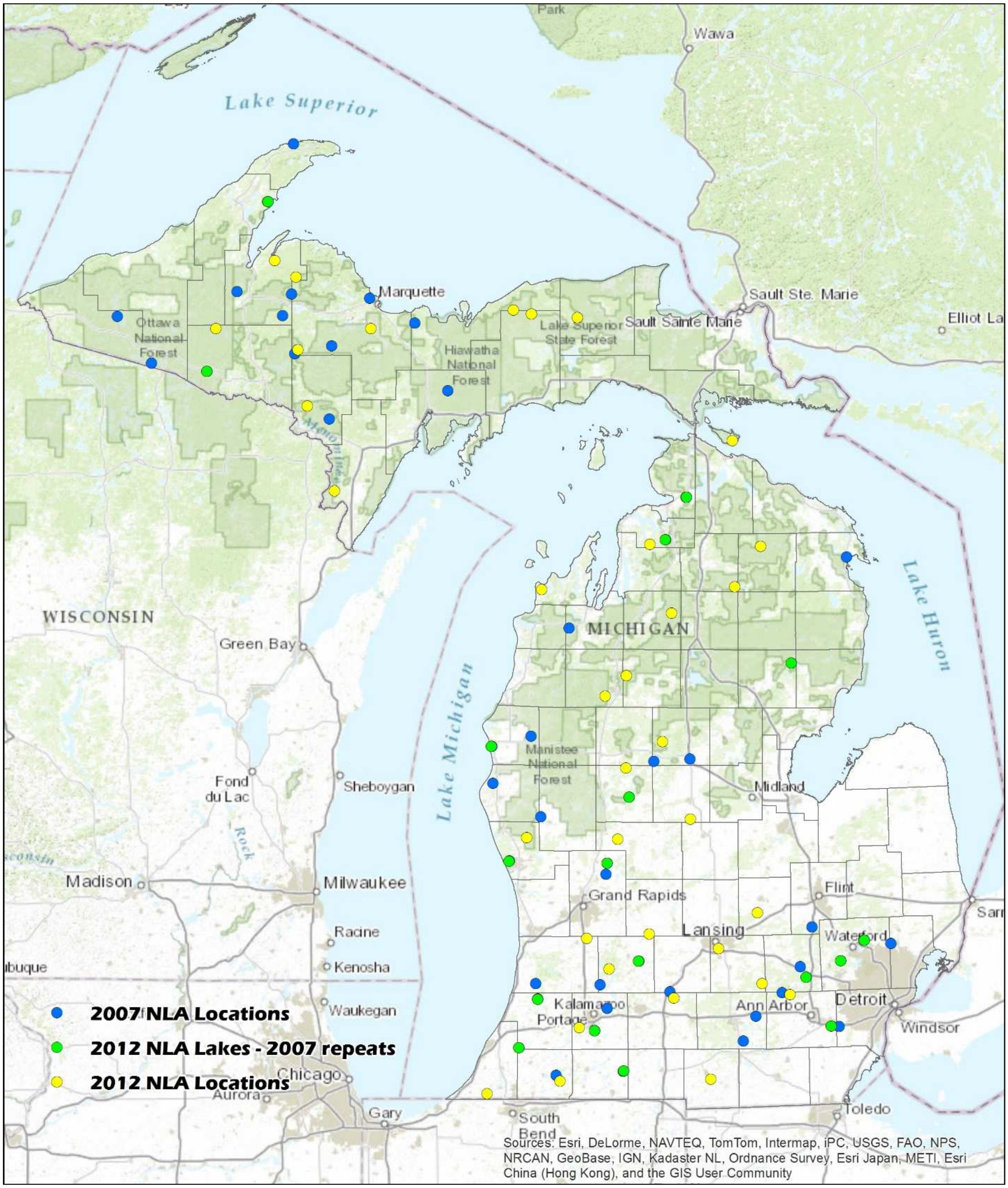

Figure 3. Locations of lakes sampled in Michigan as part of the 2012 National Lake Assessment. Latitude and longitude coordinates for 2012 stations can be found in Table 1. More information regarding the 2007 lakes can be found in Michigan's 2007 NLA report (MDEQ 2012).

Field Sampling:
Michigan's 2012 NLA field sampling effort was led by the MDEQ, with funding from a USEPA Section 106 grant. Details on methods and quality assurance may be found at: https://www.epa.gov/national-aquatic-resource-surveys/nla. To ensure consistency in collection procedures and assure the quality of resulting data, the crews participated in training, used standardized field methods and data forms, and followed strict quality control protocols (USEPA 2011).

The typical sampling effort at each lake took a full day and included a variety of water samples and measurements collected at a mid-lake index site, which was often at the deepest point in the lake. Crews took depth profiles for temperature, pH, and dissolved oxygen with a water probe. A Secchi disk was used to measure water clarity and the depth at which light penetrates the lake (the euphotic zone). Crews collected vertically integrated water samples from the euphotic zone for water chemistry, including nutrients, atrazine, chlorophyll-*a*, and algal toxins (microcystin). Field crews used a fine mesh (50 microns [µm]) and coarse mesh (150 µm) plankton net to collect a vertically integrated zooplankton sample. A sediment core sample was taken for diatom assemblage and sediment dating of natural lakes, as well as a surface sediment sample for mercury. In addition, 10 random near-shore sites were qualitatively assessed for various littoral (near-shore) and riparian (shoreline) habitat-related measures and benthic macroinvertebrate community assemblage. A visual diagram of this sampling is presented in Figure 4. Further details regarding sampling can be found in the USEPA field manual (USEPA 2011).

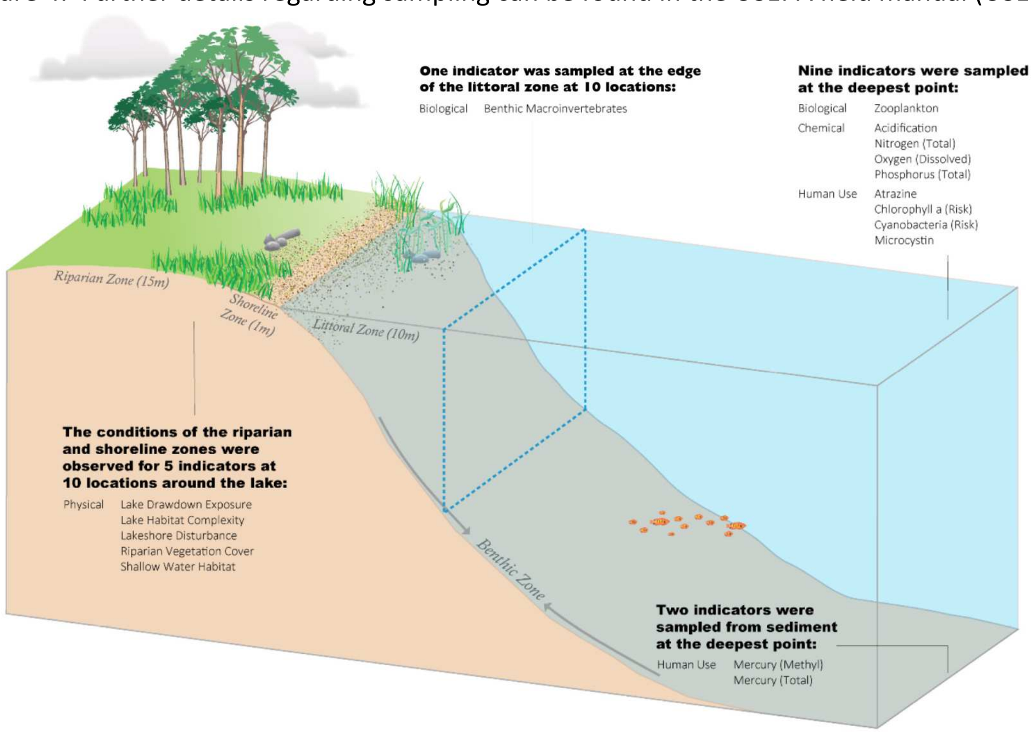

Figure 4. National Lake Assessment Sampling Location Diagram (USEPA 2016a).

Michigan also added a rapid qualitative survey of invasive species observed at each of the 10 near-shore stations. A similar survey was included in the 2007 Michigan NLA surveys (MDEQ 2014). These results were entered into Midwest Invasive Species Information Network (misin.msu.edu).

Assessment Framework:

The 2012 NLA data are summarized at the state level and compared to the national and regional results as well as the 2007 state level results. The USEPA NLA Survey results are compared regionally based on aggregated Omernik Level 3 ecoregions noted in Figure 5 (Omernik 2010). All three scales (state, regional, and national) are incorporated in this report. Nearly all lakes sampled in Michigan were sampled in the Upper Midwest ecoregion (light blue color in Figure 5). Two lakes in 2007 and one lake in 2012 were sampled in the Temperate Plains (pink color in Figure 5). When comparing state results to ecoregion results we included the lakes that were in the Temperate Plains ecoregion, because it would not change overall conclusions.

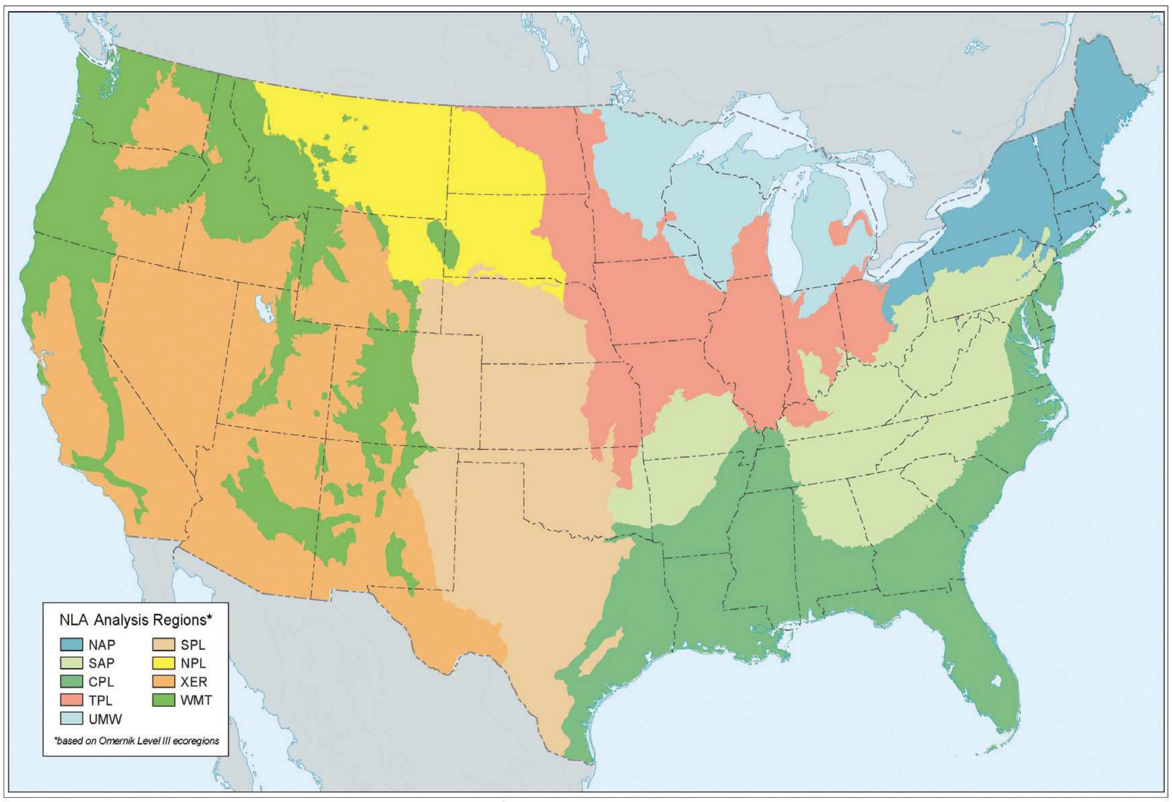

Figure 5. Aggregated ecoregions used in the 2007 and 2012 National Lake Assessments (based on Omernik Level III ecoregions; Source USEPA 2016a)

Tabulated percentile distributions of the weighted physical and chemical data and graphical illustrations of selected condition indicators are used to describe parameter distributions for Michigan, the Upper Midwest ecoregion, and the nation based on the sampled lakes. Each lake is weighted to reflect its surface area and proportion in the size-class assessment unit; this provides a balanced estimate of all lakes in the state or region (USEPA 2016b).

The national report explains that many of the measures included in the NLA are natural components of lakes. For example, nutrients like phosphorus are necessary to support lake communities, and algal toxins like microcystin occur naturally in lakes. The NLA explores whether these measures are out of balance compared to expectations or benchmark levels.

For each indicator, the USEPA divides the lakes into three condition categories – most disturbed (i.e., measures are out of balance or degraded), moderately disturbed, and least disturbed (i.e., measures are in balance or in good condition). The USEPA develops thresholds to create the condition categories using two benchmark types (Table 1) (USEPA 2016a). The first benchmark type is a fixed literature-based benchmark based on values in the peer-reviewed scientific literature. For example, a World Health Organization literature benchmark is used to classify lakes into different algal toxin risk categories for recreation in freshwaters. The second type is the NLA-derived benchmark based on the distribution (i.e., the range of values) of an indicator derived from regional reference lakes data. NLA-derived benchmarks were chosen from the range of values (i.e., the distribution) of all the reference sites in a region for a given indicator. Following established statistical approaches, the NLA uses percentiles of the reference distribution to determine benchmarks. Sites rate least disturbed when indicator scores are as good as the best 75% of the reference distribution. Sites rate most disturbed when they score worse than the worst 5% of the reference distribution. Moderately disturbed sites fall in between. The NLA 2012 Technical Report provides specific details about benchmarks (USEPA 2016b).

The NLA least disturbed, moderately disturbed, and most disturbed designations are relative to NLA 2012 benchmarks, not individual state water quality standards, and do not replace the assessment by states and tribes of the quality of lakes relative to their specific water quality standards under the Clean Water Act.

Table 1. Benchmarks used to categorize inland lakes as part of 2012 National Lake Assessment Study.

Parameter	Criteria Type	Least Disturbed	Moderately Disturbed	Most Disturbed
Turbidity (NTU)	NLA derived Regionally	< 2	≥ 2.13 to 2.89	> 2.89
Chlorophyll-*a* (µg/L)		< 6.7	≥ 6.7 to 9.6	> 9.6
Total Phosphorus (µg/L)		< 28	≥ 28 to 41	> 41
Total Nitrogen (µg/L)		< 722	≥ 722 to 920	> 941
Physical Habitat Factors		NA		
Dissolved Oxygen (mg/L)	Literature Based	≥ 5	3 to 5	≤ 3
Trophic State		See Table 2 for trophic state benchmarks		
Chlorophyll-*a* (µg/L; recreational risk)	Numeric Guidelines (World Health Organization)	< 10	10 to 50	> 50
Cyanobacterial cell counts		< 20,000	20,000 to 100,000	> 100,000
Microcystin (µg/L)		< 10	10 to 20	> 20
Atrazine (µg/L)	Literature Based	<4	NA	NA
Mercury (ng/L)	Literature Based	<180	≥180 to <1060	≥ 1060

When possible, comparisons of state-level results between 2007 and 2012 are presented. In the national 2012 NLA report, the 2007 data were reanalyzed using 2012 benchmarks so the data were comparable. The same was done with ecoregion and Michigan data. Unless otherwise noted, results presented in this report are based on results from only lakes greater than or equal to four hectares. All laboratory analyses were conducted by the USEPA, or other federal or private laboratories contracted by the USEPA to analyze the various NLA Survey indicator samples. Details on methods and quality assurance may be found at: https://www.epa.gov/national-aquatic-resource-surveys/nla.

Results and Discussion of Michigan's National Lake Assessment Conditions

Chemical Condition and Trophic State

The 2012 NLA chemical condition assessment is based on information about nutrient concentrations, oxygen content, acidification, and trophic state (i.e., productivity) of lakes. In-lake measurements are compared either to reference conditions developed from a set of reference lakes in each ecoregion or to nationally consistent benchmarks (oxygen, acidification, and trophic state) (USEPA 2016a).

Trophic state is a common approach for classifying the biological productivity in lakes. Lakes with high nutrient levels, high plant production rates, and an abundance of plant life are termed eutrophic, whereas lakes that have low concentrations of nutrients, low rates of productivity, and generally low biological biomass are termed oligotrophic. Lakes that fall in between these two states are called mesotrophic. Lakes naturally exist across all trophic categories; however, hypereutrophic conditions are usually the result of human activity, can be an indicator of stress conditions, and may result in impaired biological communities and recreational use

There is no preferred trophic state for lakes as a whole since lakes naturally fall in all of these categories. Additionally, the determination of "ideal" trophic state depends on how the lake is used or managed. For example, an oligotrophic lake is a better source of drinking water than a eutrophic lake because the water is easier or less expensive to treat. Swimmers and recreational users also prefer oligotrophic lakes because of their clarity and aesthetic quality. Property values on lakes generally increase with water clarity and aesthetic quality (Boyle and Bouchard, 2011; Krysel et al., 2003). Eutrophic lakes can be biologically diverse with abundant fish, plants, and wildlife. Anglers typically prefer more eutrophic lakes since increased concentrations of nutrients, algae, or aquatic plant life generally result in higher fish production. However, eutrophic lakes do not support coldwater fisheries, which require high levels of dissolved oxygen below the lake's thermocline.

Eutrophication of lakes is also a slow, natural part of lake aging known as lake ontogeny. However, human activities such as poorly managed agriculture or suburbanization of watersheds and increases in storm water runoff can result in high levels of nutrients and sediments reaching lakes. This can lead to accelerated eutrophication and related undesirable effects, including nuisance algae, excessive plant growth, murky water, lower levels of dissolved oxygen, odor, and fish kills.

National Trophic State Assessment

Many states classify lakes by trophic state using a variety of thresholds for nutrients (phosphorus or nitrogen), Secchi disk transparency, and/or chlorophyll-*a* (a measure of algal biomass). For the NLA report, the trophic state is characterized using chlorophyll-*a* concentration as measured in a composite water sample from the upper two meters of the lake. For NLA, chlorophyll-*a* is considered to be the most straightforward estimate of trophic state because it is based on direct measurements of live organisms, yet the USEPA acknowledges that other indicators can be used.

Table 2. Trophic State Classification thresholds used in national and ecoregional 2012 NLA analysis (USEPA 2016b). Trophic status based on chlorophyll-*a*, is presented in the national report (USEPA 2016a).

Indicator	Hypereutrophic	Eutrophic	Mesotrophic	Oligotrophic
Chlorophyll-a (µg/L)	>30	>7 and ≤30	>2 and ≤7	≤2
Total Phosphorus (µg/L)	>50	>25 and ≤50	>10 and ≤25	≤10
Total Nitrogen (µg/L)	>1400	>750 and ≤1400	>350 and ≤750	≤350

Using NLA chlorophyll-a data from only lakes greater than or equal to 4 hectares, we calculated that 12% of the nation's lakes were classified as oligotrophic, 38% mesotrophic, 28% eutrophic, 22% hypereutrophic, and <.05% were not assessed. In the Upper Midwest ecoregion, and in Michigan, a larger percentage were mesotrophic (65% and 63% respectively), while hypereutrophic lakes are less common (4% and 1%, respectively; Figure 6).

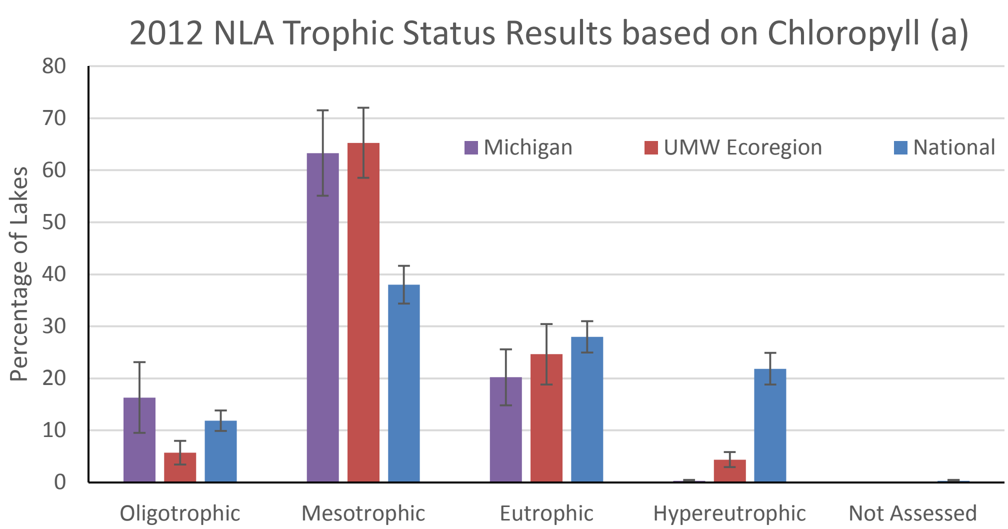

Figure 6. Trophic status comparisons using 2012 NLA data for lakes >4 hectares and USEPA Chlorophyll-*a* thresholds.

Michigan's Trophic State Assessment

Trophic condition thresholds that Michigan uses differ slightly from those used in the NLA studies (Table 3). The Carlson's Trophic State Index (TSI) (Carlson 1977) thresholds are the basis of these numbers, but they have been modified to account for regional characteristics (Michigan Department of Natural Resources [MDNR 1982]). When assessing lakes, Michigan calculates a TSI score for each of three indicators using the equations in Table 4, and then takes an average of these scores and compares them with the modified Carlson TSIs (MDEQ 2016). Figure 7 presents a comparison of statewide trophic condition estimates for Michigan using chlorophyll-*a* and total phosphorus concentrations and secchi depths collected from National Lake Assessment studies in 2007 and 2012 and calculating an average Trophic State Index. Figures 8-10 compare trophic condition estimates for Michigan lakes in 2007 and 2012 using Michigan thresholds for each indicator separately. These scores along with TSI condition estimates for Michigan lakes using the national Chlorophyll-*a* threshold are presented in Table 5 for both the 2007 and 2012 NLA data.

Table 3. Thresholds used to determine trophic state index in Michigan (MDNR 1982).

Indicator	Hypereutrophic	Eutrophic	Mesotrophic	Oligotrophic
Chlorophyll-*a* (µg/L)	>22	6.1-22	2.2-6	<2.2
Total Phosphorus (µg/L)	> 50	21 - 50	10 - 20	<10
Secchi Depth Transparency (m)	0.010-.020	2.2-6	2.3-4.6	>4.6
Carlson's TSI	>61	49-61	38-48	<38

Table 4. Equations used to calculate trophic state index scores in Michigan using three different indicators.

Indicator	Equation
Chlorophyll-*a* (µg/L)	9.81 * ln (chlorophyll-*a*, µg/L) + 30.6
Total Phosphorus (µg/L)	14.42 * ln (total phosphorus, in µg/L) + 4.15
Secchi Depth Transparency (m)	60 - 14.41 * ln (Secchi-disk depth, m)

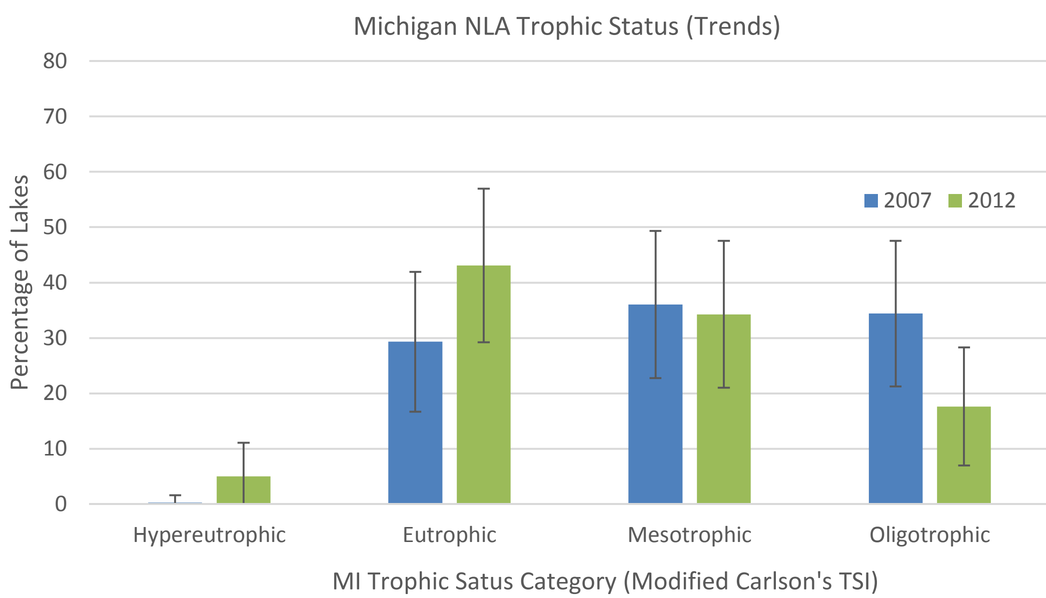

Figure 7. A comparison of statewide trophic condition estimates for Michigan using chlorophyll-*a* and total phosphorus concentrations and secchi depths collected from National Lake Assessment studies in 2007 and 2012 and calculating an average Trophic State Index.

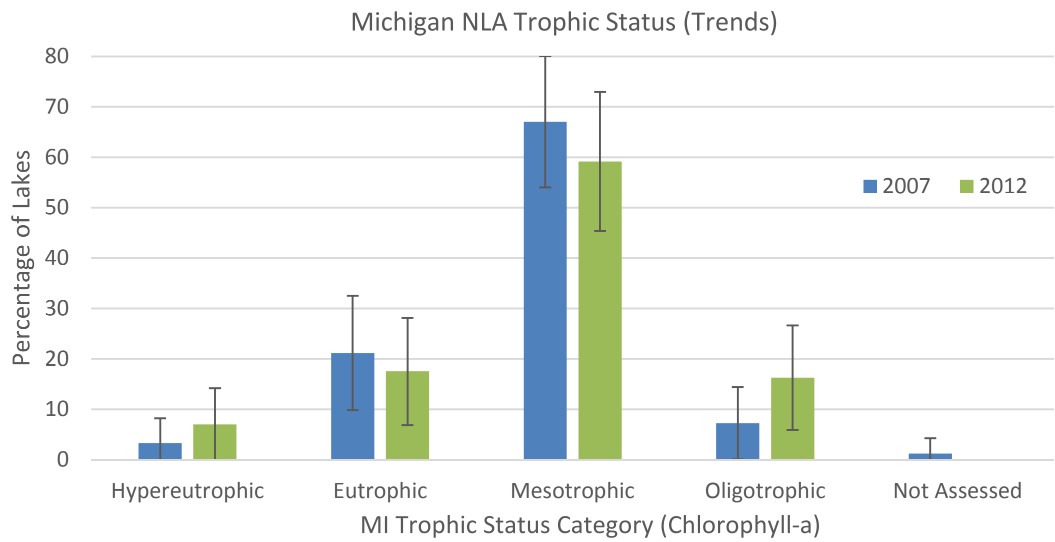

Figure 8. A comparison of statewide trophic condition estimates for Michigan using chlorophyll-*a* concentrations collected from National Lake Assessment studies in 2007 and 2012 and Michigan's trophic state thresholds.

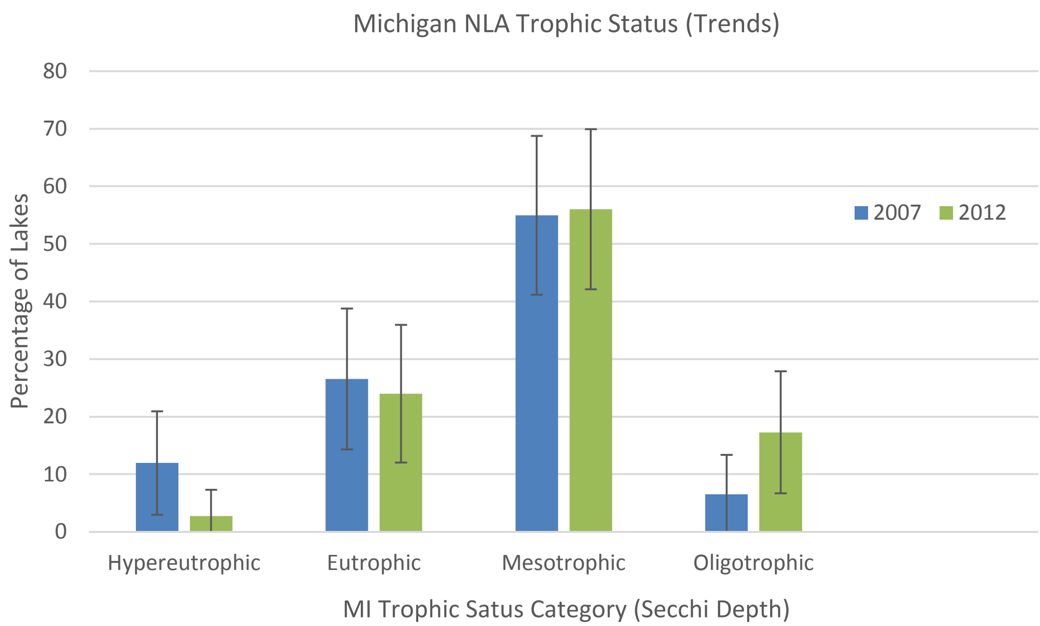

Figure 9. A comparison of statewide trophic condition estimates for Michigan using secchi depths collected from National Lake Assessment studies in 2007 and 2012 and Michigan's trophic state thresholds.

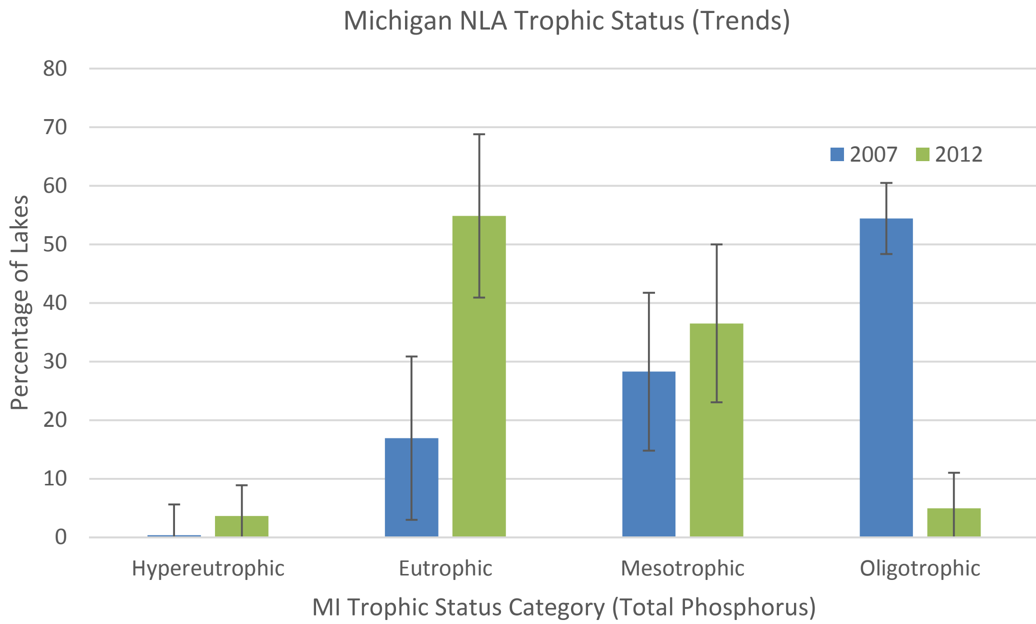

Figure 10. A comparison of statewide trophic condition estimates for Michigan using total phosphorus concentrations collected from National Lake Assessment studies in 2007 and 2012 and Michigan's trophic state thresholds.

Table 5. Summary of trophic state index condition for Michigan inland lakes using 2007 and 2012 NLA data. The 1% of lakes not assessed is not shown in this table for simplicity. Chl-*a* = Chlorophyll-*a*

		Hypereutrophic		Eutrophic		Mesotrophic		Oligotrophic	
		2007	2012	2007	2012	2007	2012	2007	2012
Trophic State Indicator	Chl-*a* (NLA thresholds)	0.1%	0.3%	22%	20%	70%	63%	7%	16%
	Carlson's TSI	0.2%	5%	29%	43%	36%	34%	34%	18%
	Chl-*a* (MI thresholds)	3%	7%	21%	18%	67%	59%	7%	16%
	Secchi	12%	3%	27%	24%	55%	56%	7%	17%
	Total P	0.4%	4%	17%	55%	28%	37%	54%	5%

TSI values vary depending on the metric being used (Table 5), which is one argument for using an average TSI index based on three indicators to determine inland lake trophic status. In 2012, chlorophyll-*a* (NLA) TSI condition estimates of the percent of Michigan lakes classified in each trophic class were similar to trophic status classifications generated by chlorophyll-*a* (Michigan) and secchi disk depth. Using total phosphorus and the average Carlson's TSI values to classify lakes appeared to shift many lakes from the mesotrophic status up to eutrophic status. The average Carlson's TSI values include the total phosphorus data and appeared to place similar percentages of lakes in the mesotrophic to hypereutrophic categories; however, using total phosphorus alone, only classified 5% of Michigan lakes as oligotrophic.

Phosphorus and Nitrogen
Total phosphorus and total nitrogen were evaluated as indicators of the chemical condition of lakes. Both are critical nutrients required for all life. In appropriate quantities, these nutrients power the primary algal production necessary to support lake food webs. Phosphorus and nitrogen are linked indicators that jointly influence both the concentrations of algae in a lake and the clarity of water. The naturally occurring levels of these indicators vary regionally, as does their relationship with turbidity and algal growth. For phosphorus and nitrogen, lakes were assessed relative to regionally specific NLA-derived benchmarks (Figures 11 and 12).

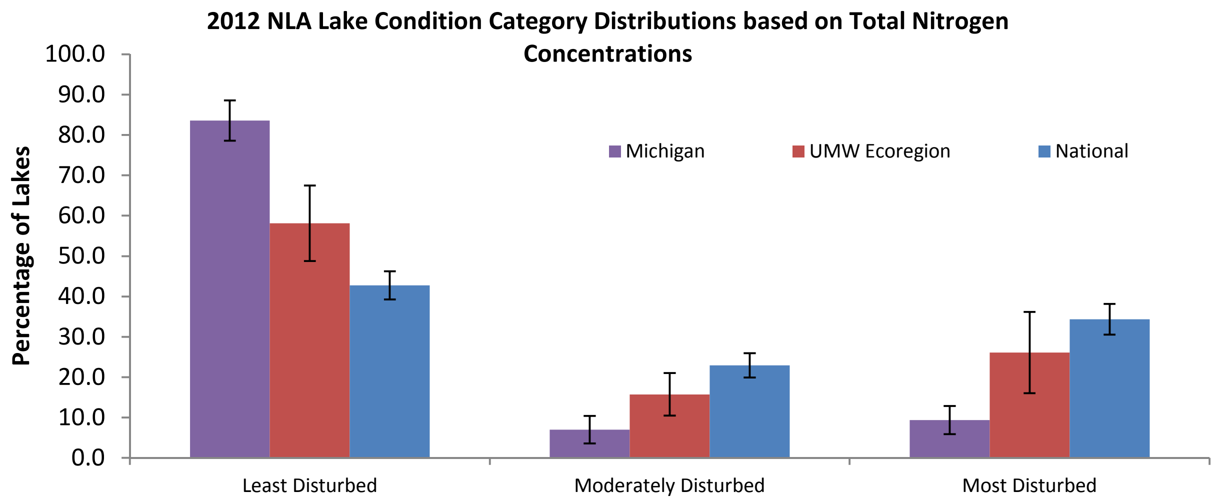

Figure 11. National Lake Assessment condition category results for Michigan Lakes based on total nitrogen concentrations.

For many lakes (including those in Michigan), phosphorus is often considered the limiting nutrient, meaning that the available quantity of this nutrient controls the pace at which algae are produced. This also means that modest increases in available phosphorus can cause very rapid increases in algal growth. National results indicate that approximately 38% of lakes were in the most disturbed condition for phosphorus. In the Upper Midwest, 22% were in the most disturbed condition. In Michigan, only 9% were in the most disturbed condition for phosphorus (Figure 12).

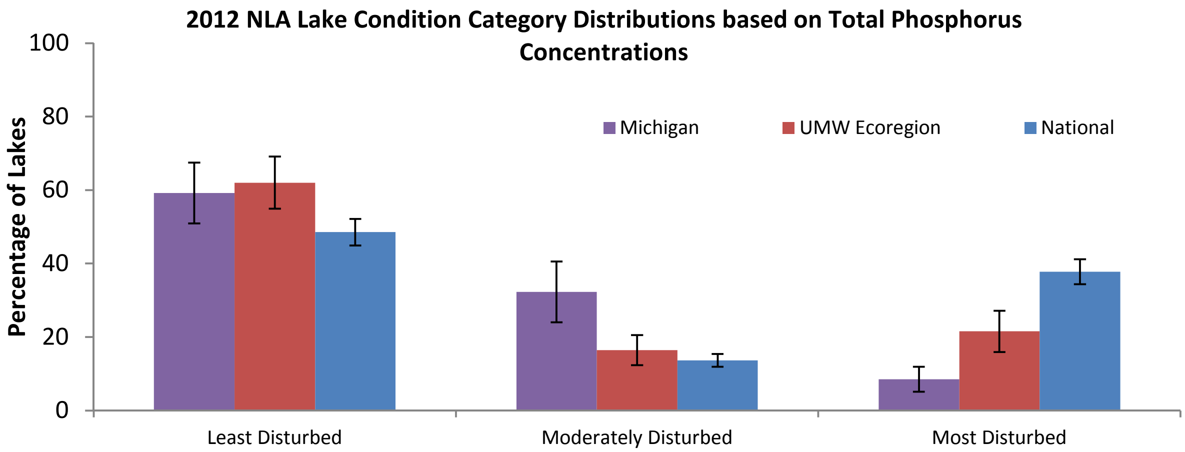

Figure 12. National Lake Assessment condition category results for Michigan Lakes based on total phosphorus concentrations.

When comparing statewide condition of total phosphorus concentration in Michigan lakes between 2007 and 2012, results indicate that there was an increase in the percentage of lakes in the moderately and most disturbed categories and a decrease in the percentage of least disturbed lakes (Figure 13). Using total nitrogen, the percent of lakes in each category was similar in 2007 and 2012 (Figure 14).

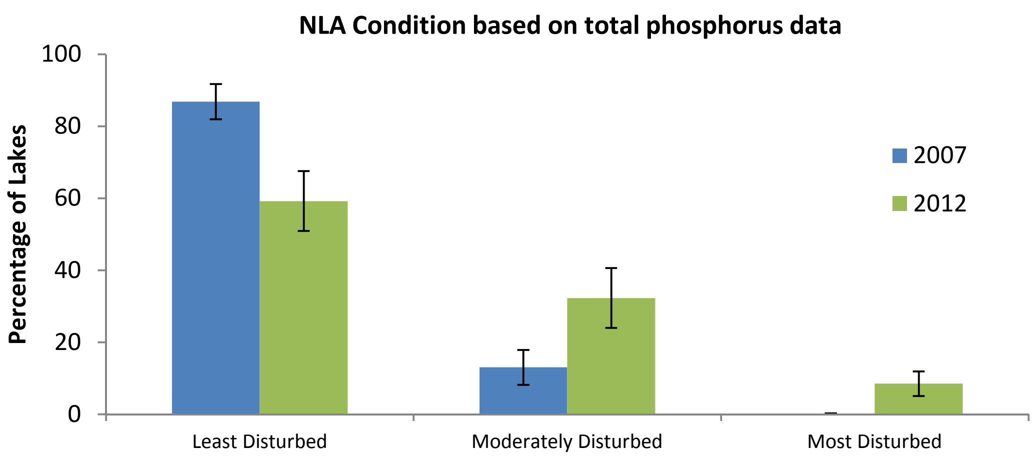

Figure 13. Percentage of Michigan Lakes falling within three National Lakes Assessment condition categories, based on total phosphorus concentrations collected in 2007 and 2012.

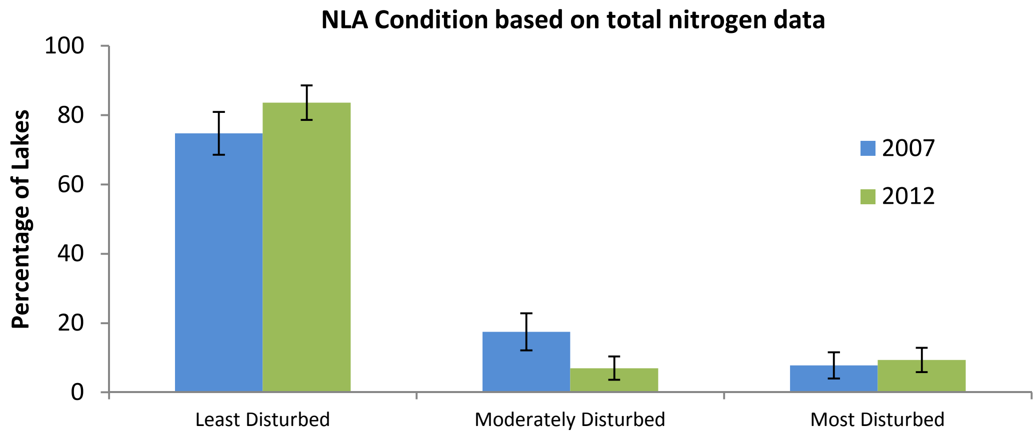

Figure 14. Percentage of Michigan Lakes falling within three National Lakes Assessment condition categories, based on total nitrogen concentrations collected in 2007 and 2012.

Dissolved Oxygen

DO is considered an important measurement of water quality because it is essential for aquatic communities. Without oxygen, a lake would be devoid of fish and macroinvertebrates. Aquatic organisms have differing DO requirements for optimal growth and reproduction. Changes in DO levels can occur for a variety of reasons, including water temperature, wind action, and the amount of algae and aquatic plants in the lake. For all three assessment scales, more than 90% of lakes were in the least disturbed condition category based on DO levels (Figure 15). These results are similar to those found in 2007.

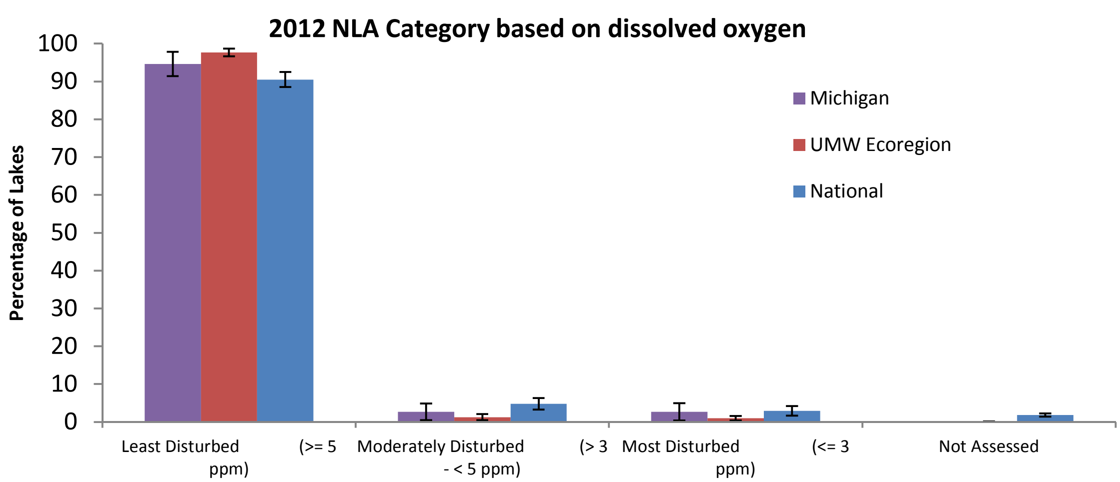

Figure 15. Percentage of Michigan Lakes falling within three 2012 National Lakes Assessment condition categories, based on dissolved oxygen levels.

Atrazine

Atrazine, one of the most widely used agricultural herbicides in the U.S., is applied before and after planting to control broadleaf and grassy weeds. Nationally, atrazine was detected in approximately 30% of lakes greater than 4 hectares. In Michigan, this number was similar with atrazine being detected in

26% of lakes. At the national level concentrations were almost always below 4 micrograms per liter (µg/L), which is the USEPA proposed level of concern for plants in fresh waters (USEPA 2016a) and at the state level the highest level detected was 1.5 µg/L (MDEQ 2015a). This level is well below Michigan water quality standards.

Recreational Condition Indicators

Mercury and Methylmercury in sediment

Mercury is found in many rocks, including coal. When coal is burned, mercury is released into the environment. Some of the mercury in the air eventually settles or is washed into water. Once it is deposited, certain microorganisms can change it into methylmercury, a highly toxic form that builds up in fish, shellfish, and animals (including humans) that eat fish. Mercury exposure at high levels can harm animal behavior, reproduction, growth, and development.

For 2012 total mercury lake sediment data, 25% of the nation's lakes greater than 4 hectares were in the least disturbed condition; 45% indicated moderately disturbed condition; 28% were in the most disturbed condition; and 2% of lakes were not assessed (Figure 16). In the Upper Midwest ecoregion, a majority of the lakes were in the moderately and most disturbed condition category (37% each). In Michigan, there were a larger percentage of lakes in the most disturbed category (42 %). A change analysis was not possible for total mercury because of different sampling protocols between 2007 and 2012.

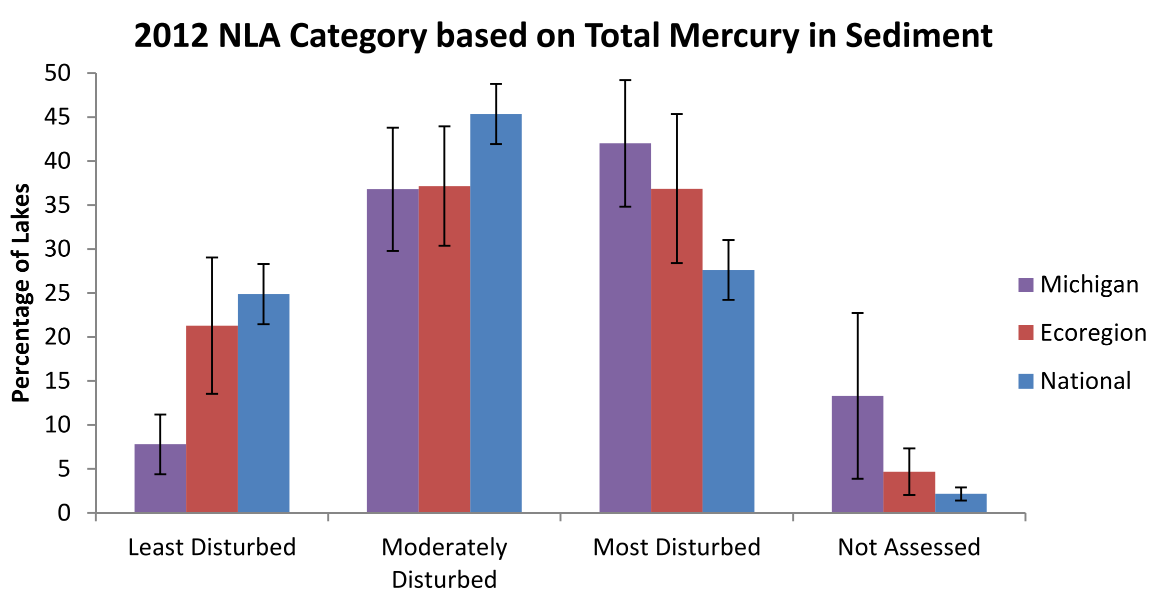

Figure 16. Percentage of Michigan Lakes falling within three 2012 National Lakes Assessment condition categories, based on total mercury levels in bottom sediment.

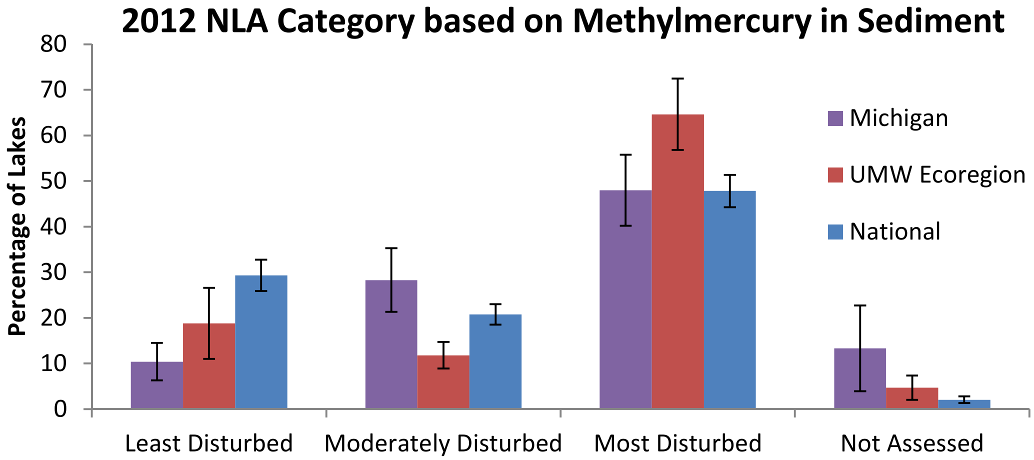

Figure 17. Percentage of Michigan Lakes falling within three 2012 National Lakes Assessment condition categories, based on methylmercury levels in bottom sediment.

For methylmercury in sediment, 29% of national lakes are in the least disturbed condition; 21% are moderately disturbed; 48% are in the most disturbed condition; and 1% of lakes were not assessed (Figure 17). In the Upper Midwest ecoregion, there is a large jump in the percentage of lakes in the most disturbed condition (65%). Reasons for this may include the relatively large number of wetlands in the Upper Midwest ecoregion, including Michigan, that have increased methylmercury levels compared to other aquatic habitats. This is due to biogeochemical conditions that are common within wetlands that facilitate methylation of inorganic matter to the methylmercury. In Michigan, the percent of lakes in the most disturbed category was lower and more similar to the national percentage. A change analysis was not possible for methylmercury because of different sampling protocols between 2007 and 2012.

The high levels of mercury in Michigan water bodies is known to be impacting fish, wildlife, and recreation. Many inland lakes and rivers in Michigan are listed as impaired due to mercury in the water column or mercury in fish tissue. Many water bodies have fish consumption advisories due the elevated mercury levels. Michigan's ambient water quality standard for total mercury is 1.3 nanograms per liter (ng/L) to protect wildlife and 1.8 ng/l to protect human health. A majority of the mercury pollution is a result of mercury depositing into surface waters from the air. A statewide total maximum daily load document for total mercury is being drafted to address mercury impairment in Michigan inland water bodies and will be sent to the USEPA for approval later in 2017.

Algae and Associated Toxins

In addition to mercury, algal toxins can adversely impact human health. Algae and cyanobacteria are a natural part of freshwater ecosystems. Eutrophication in lakes often results in conditions that favor their growth. Many algal blooms are unsightly, but not toxic. However, some blooms of cyanobacteria can be harmful to people and animals. Exposure to cyanobacteria toxins may produce skin rashes, eye irritations, respiratory symptoms, gastroenteritis, and liver and kidney failure. As part of the NLA, three indicators of potential risk to public use and recreation were evaluated including: (1) microcystin, an algal toxin; (2) cyanobacteria, blue green algae that can produce algal toxins; and (3) chlorophyll-*a*, a measure of all algae present.

The World Health Organization established recreational exposure risk guidelines for chlorophyll-*a*, cyanobacterial cell counts, and microcystin (Table 6). These literature benchmarks were used in the NLA to determine risk of exposure to algal toxins. It is important to note that chlorophyll-*a* concentrations and cyanobacteria cell counts serve as proxies for the potential presence of algal toxins. A lake that is in the least disturbed condition exhibits a low risk of exposure; a lake in a most disturbed condition has a high exposure potential to algal toxins.

Table 6. World Health Organization thresholds of risk associated with potential exposure to cyanobacteria toxins.

Indicator (units)	Low Risk of Exposure	Moderate Risk of Exposure	High Risk of Exposure
Chlorophyll-*a* (µg/L)	< 10	10 - < 50	> 50
Cyanobacteria cell counts (#/L)	< 20,000	20,000 – < 100,000	≥ 100,000
Microcystin (µg/L)	< 10	10 - ≤ 20	> 20

Chlorophyll-*a* Recreational Risk Analysis

Using chlorophyll-*a* risk analysis as an indicator of exposure to algal toxins, 51% of the Nation's inland lakes that were greater than 4 hectares were in the least disturbed condition, 29% were moderately disturbed, 14% were in the most disturbed condition, and 1% were not assessed. The percentage of lakes in the least disturbed category was higher at both the ecoregion and state level, at 77% and 82%, respectively (Figure 18). The 2016 NLA reports that there was no statistically significant difference in the percentage of lakes in the most disturbed category based on chlorophyll-*a* risk between 2007 and 2012. The same appeared to be true for Michigan inland lakes.

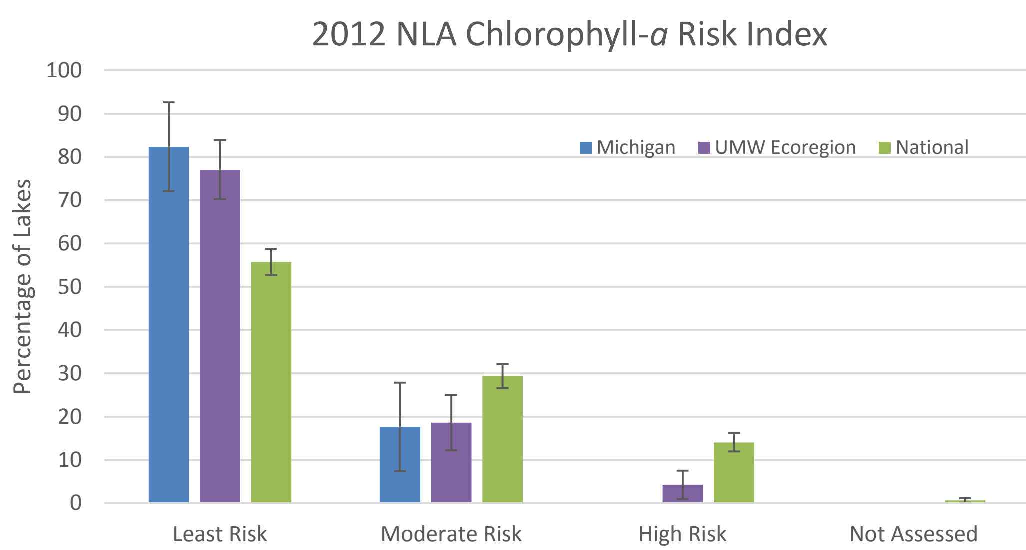

Figure 18. Recreational risk of harm in inland lakes using 2012 NLA Chlorophyll-*a* concentrations as an indicator of blue green algae toxicity.

Cyanobacteria Recreational Risk Analysis

Using cyanobacteria cell counts as an indicator of risk exposure to algal toxins, 63% of the nation's lakes were in the least disturbed condition, 22% indicated moderately disturbed condition; 15% were in the most disturbed condition; and 1% were not assessed. In the Upper Midwest ecoregion and Michigan, the number of lakes in the least disturbed condition increased slightly (Figure 19).

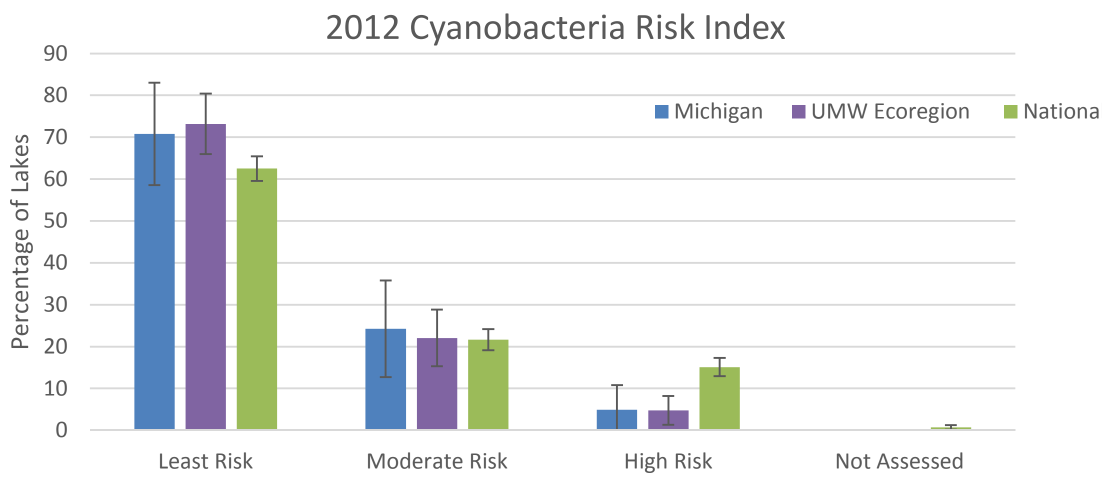

Figure 19. Recreational risk of harm in inland lakes using 2012 NLA Cyanobacteria concentrations as an indicator of blue green algae toxicity.

The 2016 NLA reports that nationally the cyanobacteria cell density showed a statistically significant increase (+8.3%) in the percentage of lakes in the most disturbed (high risk) category between 2007 and 2012. The state-level change results are unclear, since no lakes were found to have a high risk concentration of cyanobacteria in 2007 and only 5% lakes fell into this category in 2012 (Figure 20).

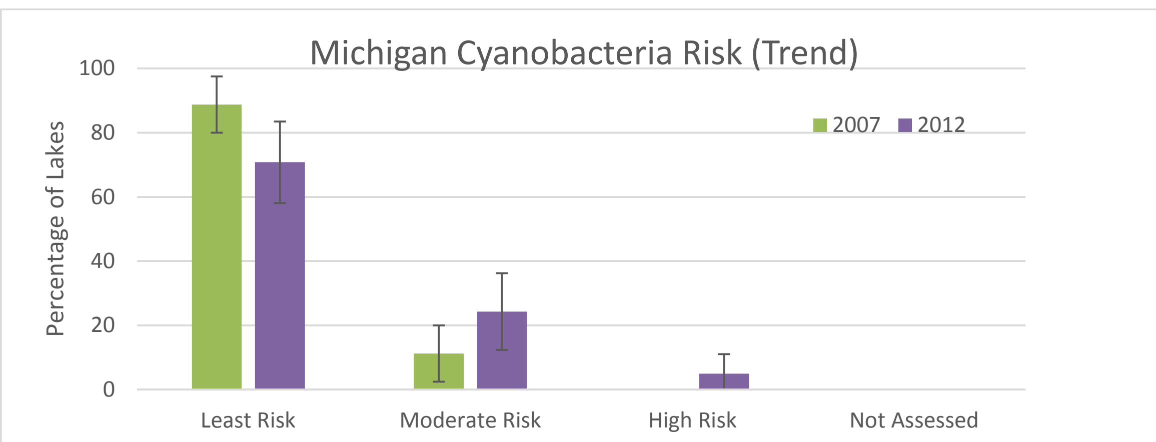

Figure 20. Trends in recreational risk of harm in Michigan inland lakes using Cyanobacteria as an indicator of blue green algae toxicity.

Microcystin Recreational Risk Analysis

Microcystin, an algal toxin, was detected nationally in 39% of lakes. Less than one percent of lakes were in the most and moderately disturbed condition (i.e., have a high or moderate risk of exposure) and 99% were either least disturbed, with a low risk of exposure, or showed no detection of microcystin (Figure 21).

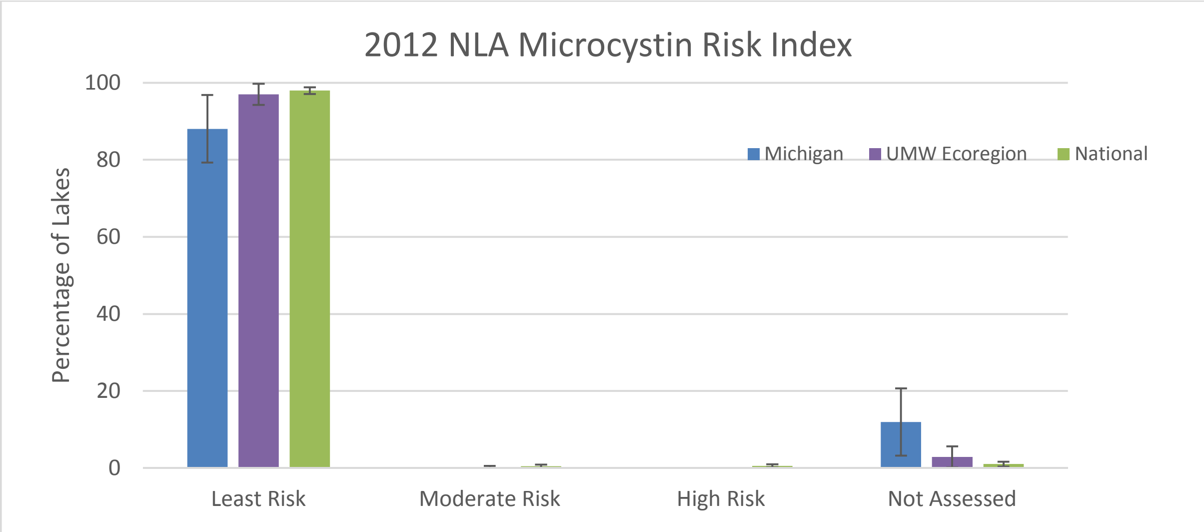

Figure 21. Recreational risk of harm in inland lakes using 2012 NLA microcystin concentrations as an indicator of blue green algae toxicity.

Nationally, there was a significant increase in the detection of microcystin (+9.5%), but the analysis shows no statistically significant difference in the percentage of lakes in the most disturbed category between 2007 and 2012 (USEPA 2016a). In Michigan, microcystin levels were very low and never exceeded the low risk threshold (10 µg/L) in both 2007 and 2010. 2012 NLA data indicate that microcystin was not detected in 49% of Michigan inland lakes (Figure 22).

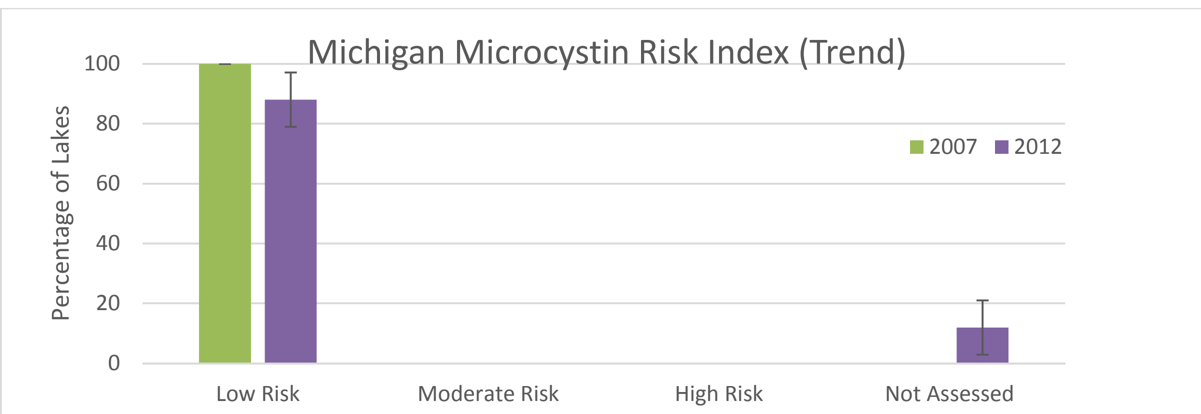

Figure 22. Trends in recreational risk of harm in Michigan inland lakes using Microcystin as an indicator of blue green algae toxicity.

Biological Condition

It is well known that a healthy lake contains a diversity of fish, insects, algae, macrophytes, and other organisms. Aquatic organisms are exposed to water quality over time, and therefore reflect the overall quality of their environment. However, although biological indicators are commonly used in stream and river water quality assessment programs, they are not typically used in lake monitoring programs. The USEPA developed two new biological research indicators for the 2012 NLA, which may be revised and refined in future assessments. The 2012 NLA biological condition assessment indicators are based on information from two communities: benthic macroinvertebrates in the littoral (shallow water) zone, and zooplankton from a pelagic (open water) zone. To assess biological health, NLA analysts combined several measures into indices for each community.

Both approaches use the biological reference conditions developed from constructed sets of reference lakes as described in the NLA Survey report technical appendix (USEPA, 2010). Only a portion of the initial reference lakes selected for the NLA survey were found to be of reference quality. Therefore, the USEPA used the results from these lakes as well as high quality lakes from the random site selection process to establish "least disturbed" condition benchmarks based on statistically derived reference screening criteria. These benchmarks were established for lakes in the aggregate ecoregions as well as the nation's lakes overall.

Benthic Macroinvertebrates

Benthic macroinvertebrates are insects and other small organisms without backbones that live in our surface waters and are excellent indicators of water body health because they often live for a year or more in the water. In addition, some macroinvertebrates are more tolerant to pollution than others; therefore, these organisms may serve as good indicators of the quality of shoreline habitats in lakes.

Six different aspects (i.e., diversity, richness, presence/absence, feeding habits, habitat requirements, and pollution tolerance) of macroinvertebrate communities were used to create the benthic invertebrate indicator. The measures chosen for each of these aspects vary among ecoregions and are described in detail in the 2012 NLA Technical Report (USEPA 2016b). Using the benthic macroinvertebrate indicators, nationally it is estimated that 31% of U.S. lakes greater than 4 hectares are in least disturbed condition; 25% moderately disturbed; 34% are most disturbed; and 10% of lakes were not assessed. In Michigan, a larger proportion of lakes were categorized as most disturbed (Figure 23).

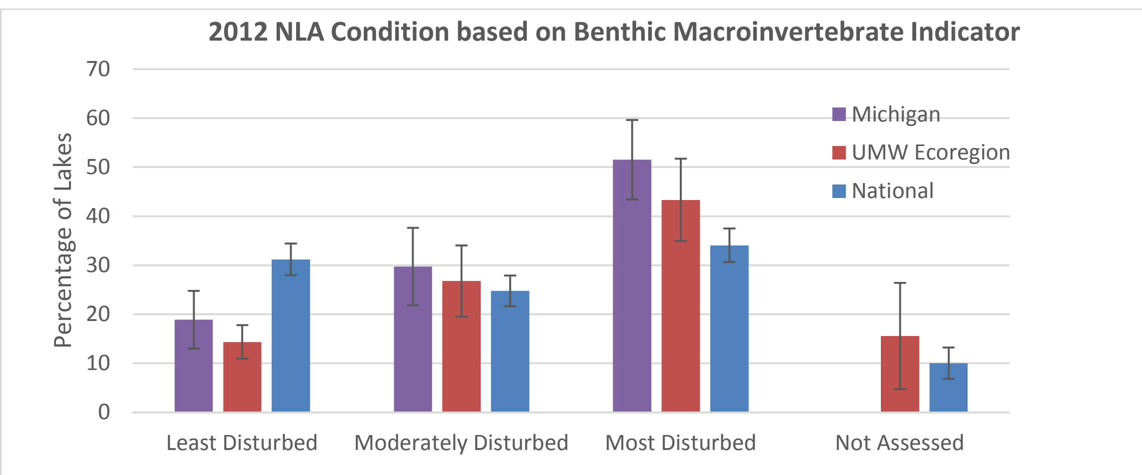

Figure 23. 2012 National Lake Assessment condition category results for Michigan Lakes based on benthic macroinvertebrate composition.

Nationally, an analysis of benthic invertebrates shows no statistically significant difference in the percentage of lakes in the most disturbed category between 2007 and 2012 (USEPA 2016a). In Michigan, there appears to be a significant increase in the number of lakes in the moderately and most disturbed categories (Figure 24). In 2007, the macroinvertebrate community was not assessed for the state scale lakes.

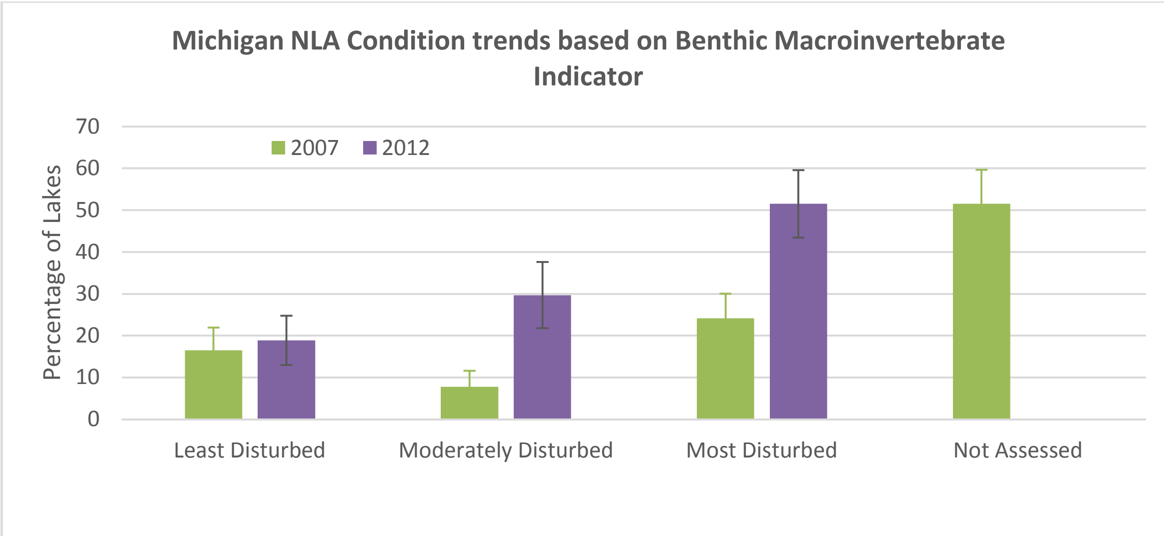

Figure 24. Trends in NLA condition category for Michigan inland lakes based on benthic macroinvertebrate composition.

Zooplankton

Zooplankton are small animals in the water column that are important to the aquatic food web. Zooplankton eat phytoplankton and transfer that energy to macroinvertebrates and fish when they are eaten. Zooplankton are sensitive to changes in the lake ecosystem. Similar to the macroinvertebrate indicator, NLA analysts selected six measures of zooplankton community structure, which is described in more detail in the 2012 technical report (USEPA 2016b).

According to the zooplankton indicator, 51% of lakes greater than 4 hectares in the U.S. were in a least disturbed condition; 30% were moderately disturbed; and 19% were in a most disturbed condition Figure 25). In Michigan, 46% were least disturbed; 27% were moderately disturbed, and 28% were most disturbed. This is opposite of the macroinvertebrate community indicator results where 52% were categorized as being most disturbed (Figure 23). A change analysis was not possible for the zooplankton metric because different sampling protocols were used in 2007 and 2012.

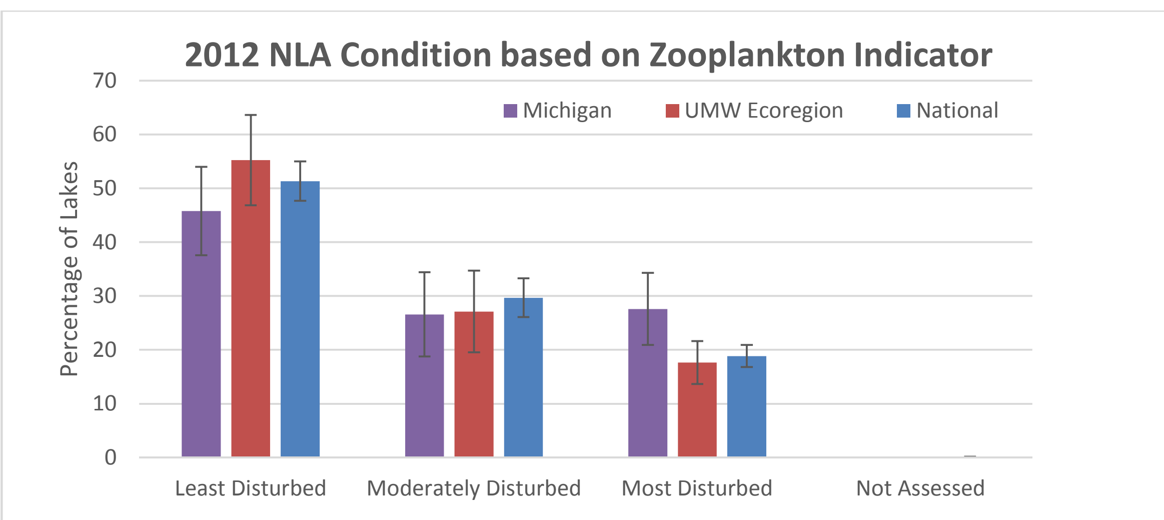

Figure 25. 2012 National Lake Assessment condition category results based on zooplankton community composition.

Physical Habitat Condition Indicators

The condition of lakeshore habitats can have a profound effect on lake biological health. For the 2012 NLA, physical habitat condition was assessed based on observations of five indicators: (1) lakeshore vegetative cover; (2) shallow water habitat; (3) lakeshore habitat disturbance by humans; (4) lakeshore habitat complexity (at the land-water interface); and (5) lake drawdown levels. Habitat indicator condition categories are related to conditions in reference lakes. Therefore, the values are modified regionally to account for differing expectations of natural condition in reference lakes for a particular region (USEPA 2016a).

Riparian Vegetation Cover

The lakeshore (riparian) vegetation cover metric is based on observations of three layers of coverage (understory grasses and forbs, mid-story non-woody and woody shrubs, and over-story trees). Although not all layers occur in all areas of the country, they do occur in Michigan and in general, lakeshores are in better condition when shoreline vegetation cover is lush in all three layers. For other areas of the country, if natural features prevent all three layers, it has been taken into consideration in the benchmark calculations (USEPA 2016b).

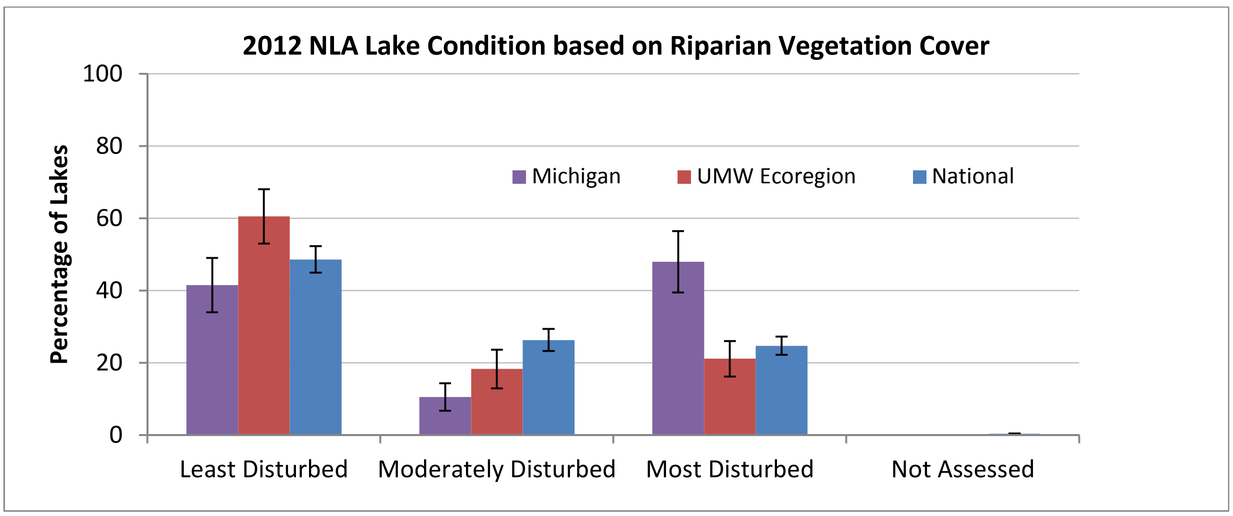

Figure 26. 2012 National Lake Assessment condition category results based on riparian vegetation cover.

Nationally, 49% of lakeshore habitats for lakes greater than 4 hectares were in a least disturbed condition; 26% were moderately disturbed; 25% were most disturbed; and <1% of lakeshores were not assessed. Michigan had higher percentage (48%) of lakes in the most disturbed category (Figure 26). This percentage was also higher than in 2007, when 31% of lakes were in the most disturbed condition based on riparian condition (Figure 27).

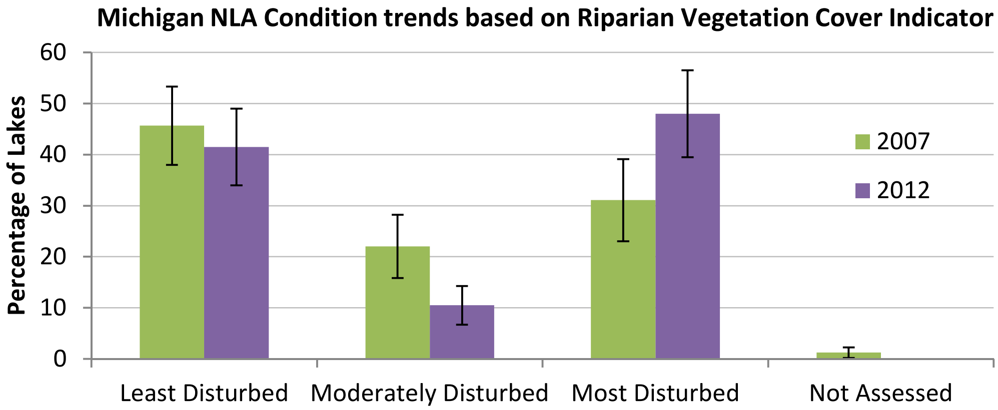

Figure 27. Trends in NLA condition category for Michigan inland lakes based on riparian vegetation cover.

Shallow Water Habitat

The shallow water habitat indicator examines the quality of the shallow edge of the lake (littoral zone) by utilizing data on the presence of living and non-living features such as overhanging vegetation, aquatic plants, large woody snags, brush, boulders, and rock ledges. Lakes with greater and more varied shallow water habitat are typically able to more effectively support aquatic life because they have more complex ecological niches (USEPA 2010). Percentages of NLA lakes in the least disturbed category were similar when comparing national, Upper Midwest ecoregion, and Michigan results (approximately 55%). However, Michigan had a higher percentage of lakes in the most disturbed condition (Figure 28). This percentage was also significantly higher than that estimated in 2007 (Figure 29).

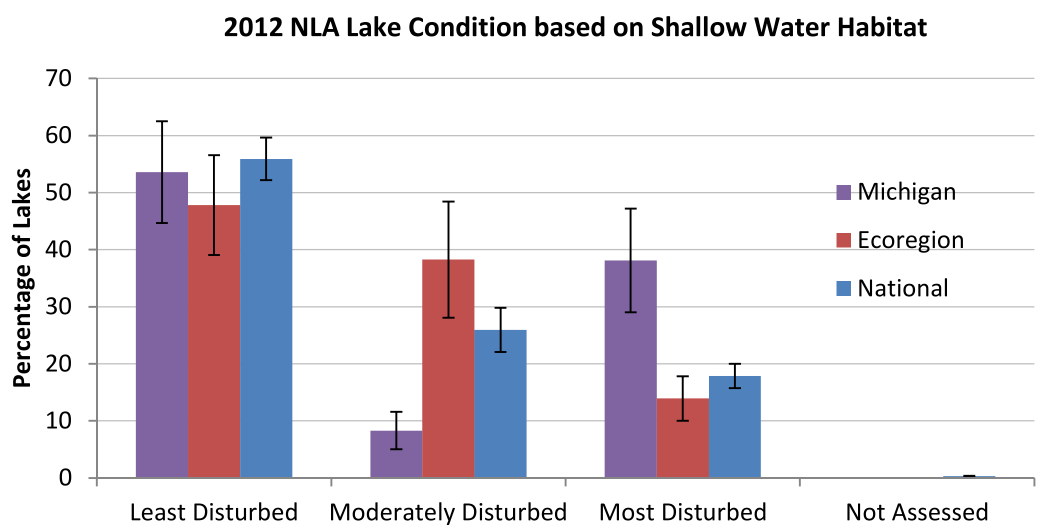

Figure 28. 2012 National Lake Assessment condition category results based on shallow water habitat.

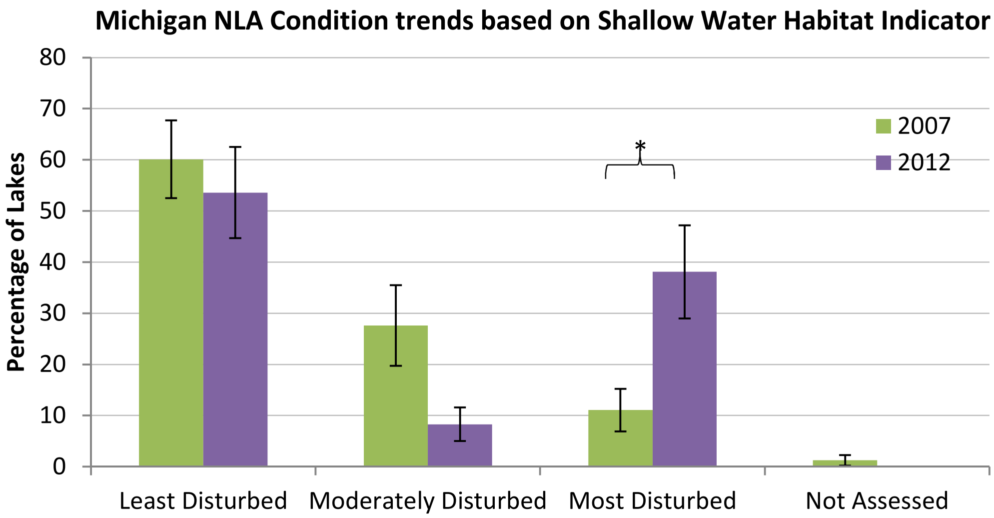

Figure 29. Trends in NLA condition category for Michigan inland lakes based on shallow water habitat.

Lakeshore Disturbance

The lakeshore human disturbance indicator incorporates the extent and intensity of human land use activities that were observed within and adjacent to each physical habitat station. It reflects direct human alteration of the lakeshore ranging from minor changes (such as the removal of trees to develop a picnic area) to major alterations (such as the construction of a large lakeshore residential complex complete with concrete seawalls and artificial beaches) (USEPA 2010). The percentage of NLA lakes in the most disturbed category was estimated to be much higher in Michigan than nationally or in the Upper Midwest ecoregion (Figure 30). This percentage was also higher than that estimated in 2007 (Figure 31).

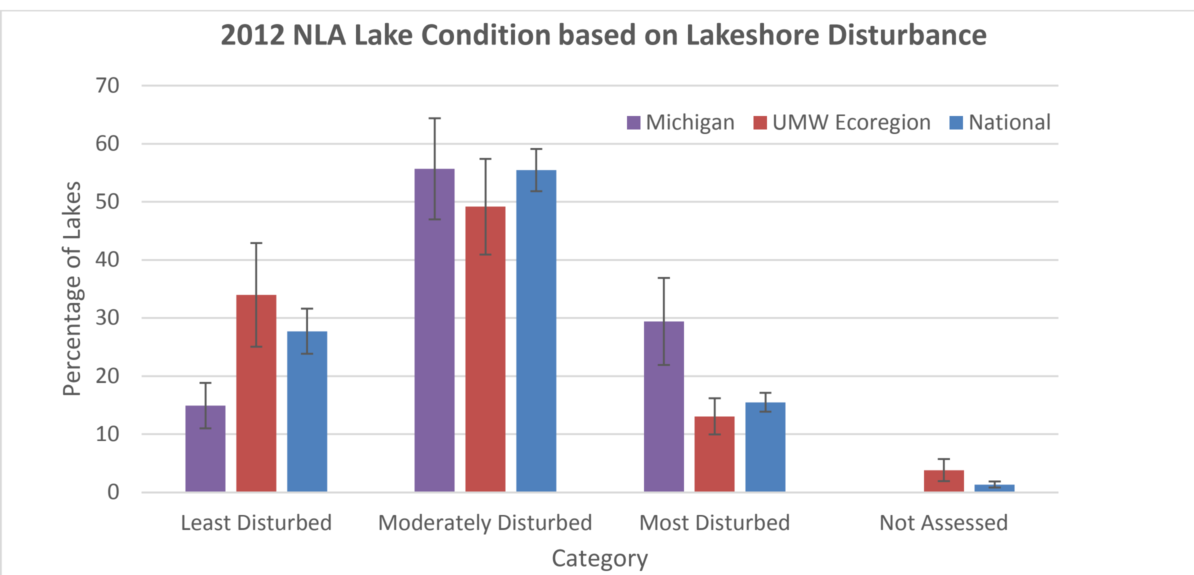

Figure 30. 2012 National Lake Assessment condition category results based on lakeshore disturbance.

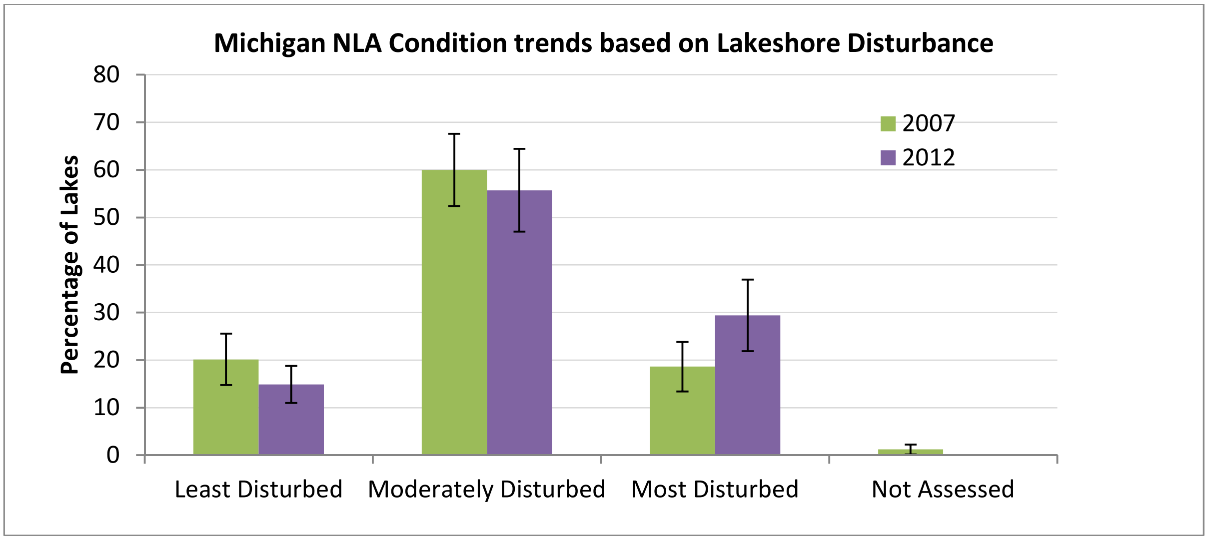

Figure 31. Trends in NLA condition category for Michigan inland lakes based on lakeshore disturbance.

Lake Habitat Complexity

The lake habitat complexity indicator integrates data from the riparian and littoral zones to estimate the amount and variety of all cover types at the water's edge, providing an index of habitat condition at the land-water interface of lakes (USEPA 2010). Once again, the percentage of national and Upper Midwest lakes in the most disturbed condition based on lake habitat complexity is much less than the percentage of Michigan lakes (Figure 32) and trends between 2007 and 2012 are also similar (Figure 33). The NLA habitat results may be reflecting the fact that many Michigan lakes are dominated by lakefront development, including, lawns, man-made beaches, and seawalls.

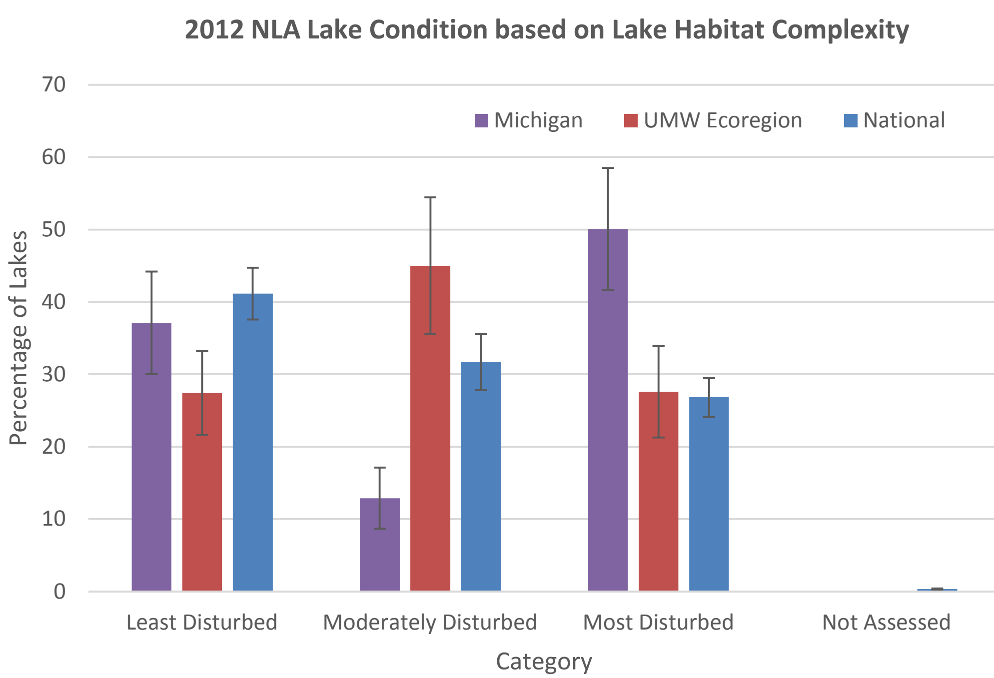

Figure 32. 2012 National Lake Assessment condition category results based on lake habitat complexity.

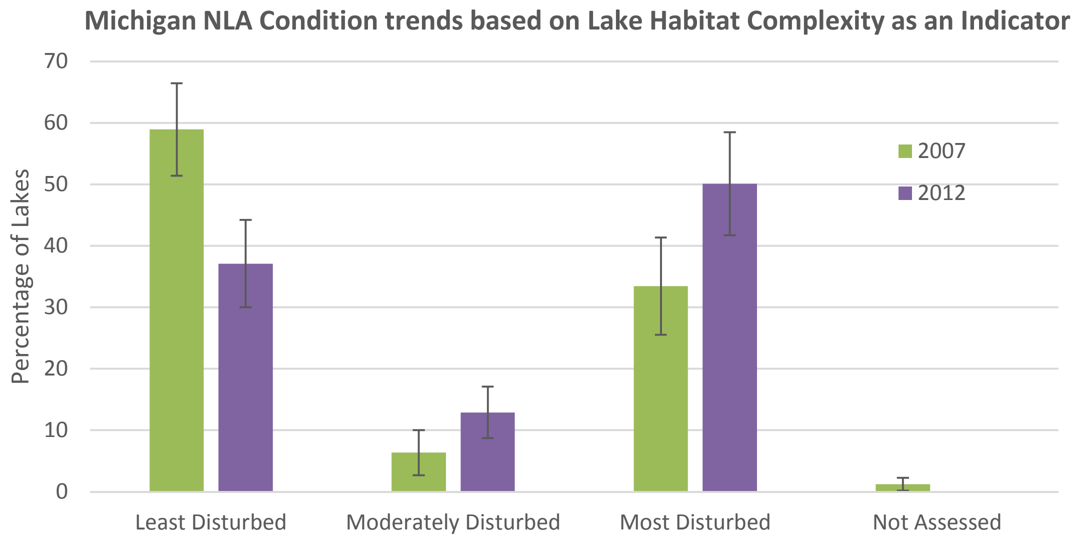

Figure 33. Trends in NLA condition category for Michigan inland lakes based on lake habitat complexity.

Lake Drawdown Exposure

Lake drawdown can occur in both natural lakes and reservoirs. It can be the result of natural processes, such as periodic drought, or the result of direct manipulation of water levels for lake management purposes. Changing or significantly lowered lake water levels can adversely affect physical habitat conditions in and around the lake and therefore can also have an impact on biological communities. The NLA lake drawdown indicator measures whether water levels are lower than their full-lake stage. The majority of lakes at the national, Upper Midwest ecoregion, and state level are in the least disturbed category based on this habitat attribute (Figure 34). This was the case in Michigan in both 2012 and 2007 (Figure 35).

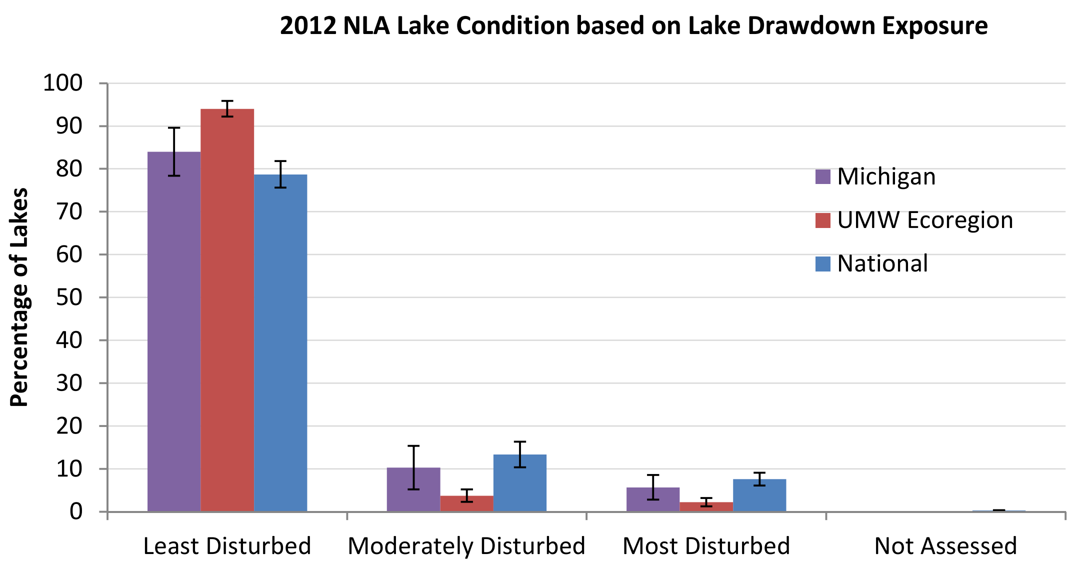

Figure 34. 2012 National Lake Assessment condition category results based on lake drawdown exposure.

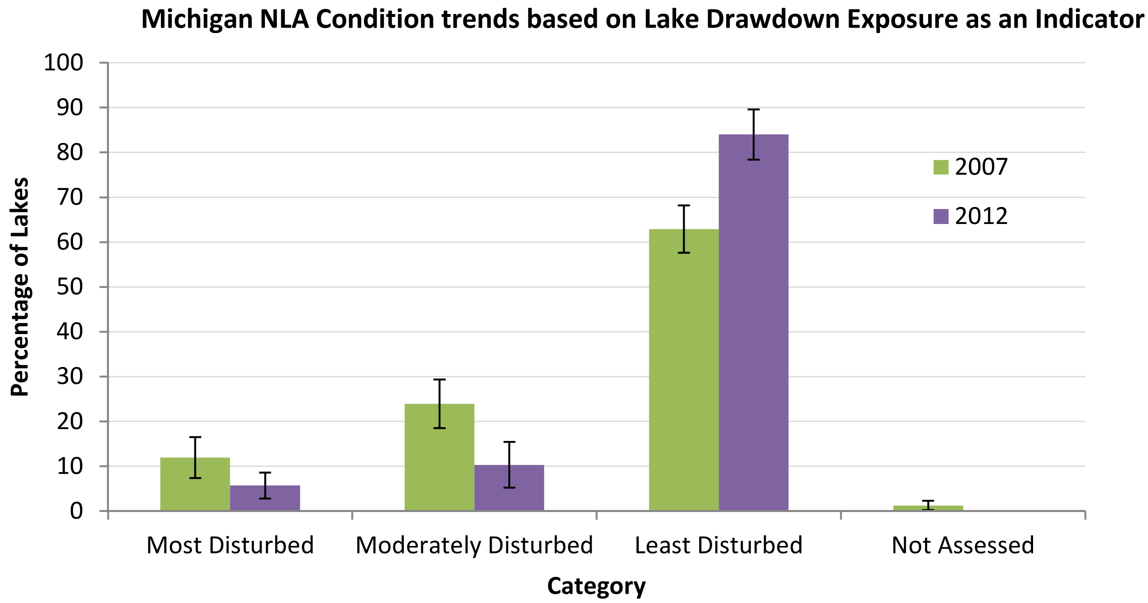

Figure 35. 2012 National Lake Assessment condition category results based on lake drawdown exposure.

<u>Associations between Stressors and Biological Condition</u>

Nationally, the NLA stressors or indicators with the most widespread occurrence in the most disturbed condition category for lakes greater than 4 hectares were methylmercury in sediments, total phosphorus, and total nitrogen (Figure 36). Nationally, nearly 50% of lakes would be categorized as being in the most disturbed condition based on the methylmercury levels in sediment, approximately 20% would be moderately disturbed, and approximately 30% least disturbed.

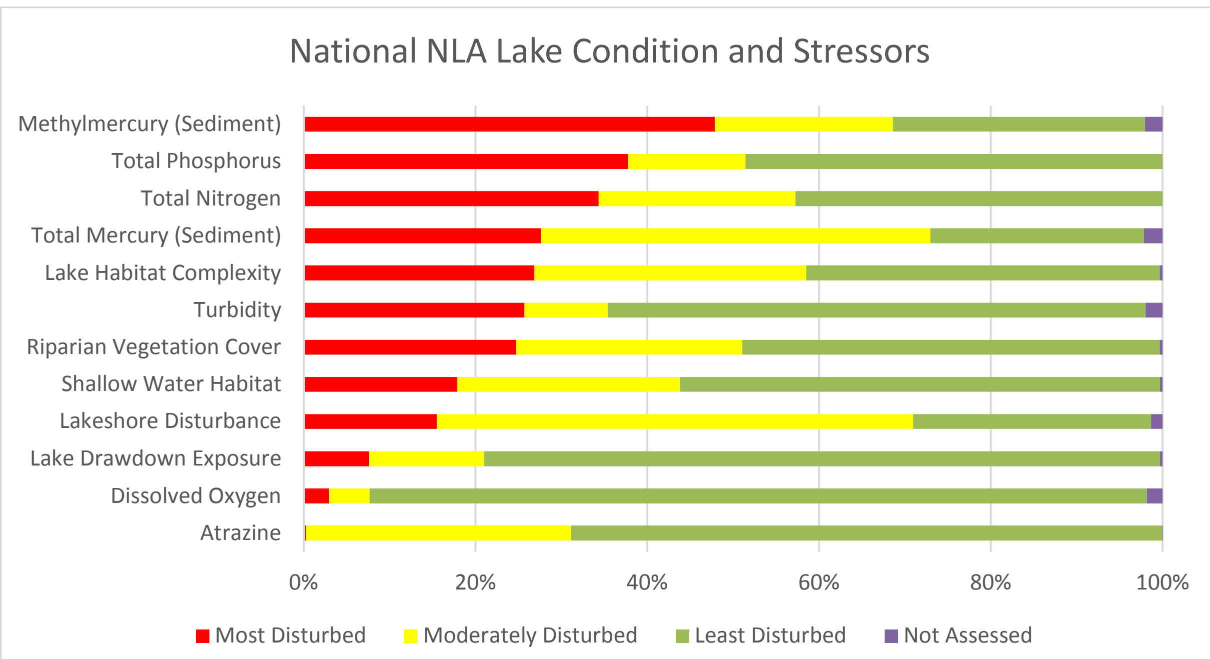

Figure 36. Extent of stressors and their prediction of lake condition, nationally, using 2012 NLA data and condition categories.

In the Upper Midwest ecoregion lakes, total mercury in sediment replaced total phosphorus as the second most frequent stressor, and lake habitat complexity was the third most common stressor, followed by nitrogen and phosphorus (Figure 37).

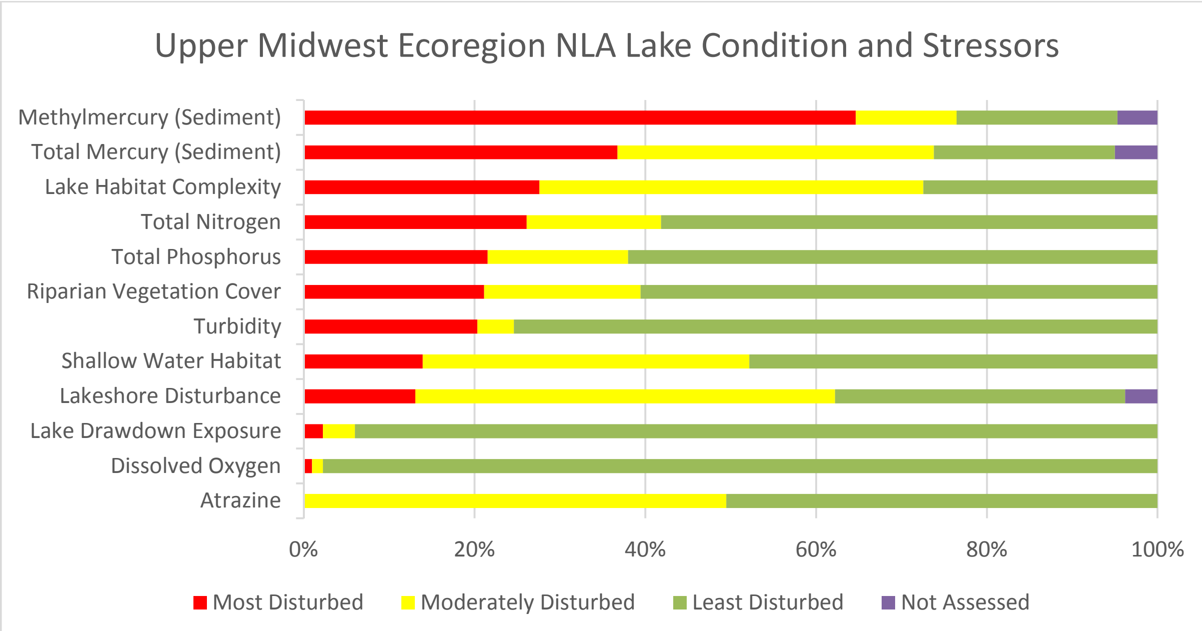

Figure 37. Extent of stressors and their prediction of lake condition, for the Upper Midwest Ecoregion, using 2012 NLA data and condition categories.

In Michigan, lake habitat complexity, methylmercury in sediment and riparian vegetation cover were the most common stressors in lakes categorized as most disturbed (Figure 38). Total mercury in sediment, a lack of shallow water habitat, and lakeshore disturbance followed, and then total nitrogen and total phosphorus. In summary, with the exception of mercury levels in sediment, lakeshore and nearshore habitat quality may be the best indicator of disturbed condition in Michigan lakes. Nearly 50% of Michigan lakes were categorized as being in the most disturbed category when using lake habitat complexity and riparian vegetation cover as the predictor. As noted above, lake habitat complexity indicator integrates data from the riparian and littoral zones to estimate the amount and variety of all cover types at the water's edge. Results from the 2007 NLA were similar with habitat and mercury concentrations being the most common stressors in lakes in the most disturbed category.

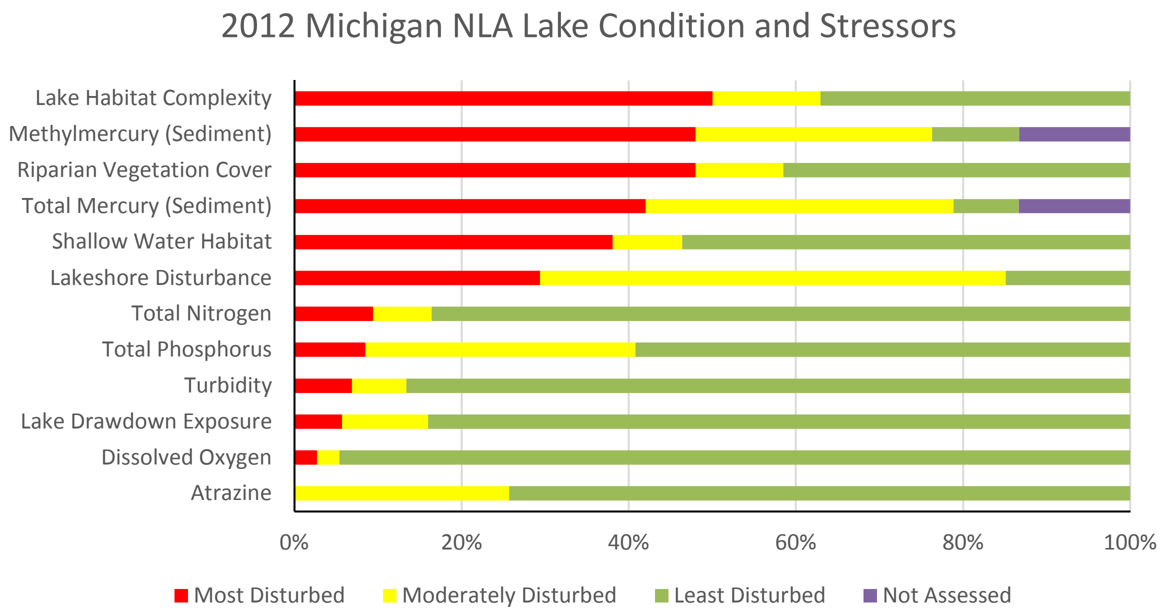

Figure 38. Extent of stressors and their prediction of lake condition, in Michigan, using 2012 NLA data and condition categories.

Conclusions

The 2012 NLA report ((USEPA 2016a) made general conclusions about the conditions of our nation's inland lakes. These conclusions are summarized here and compared with Michigan results:

NLA 2012 – National vs Michigan

1) *The national NLA results indicate that nutrient pollution was common in U.S. lakes and was the most widespread stressor among those measured in the NLA.*

   In Michigan, nutrient pollution was not a widespread stressor. Michigan lakes were only categorized as most disturbed 9% of the time based on total phosphorus or total nitrogen. Lake habitat complexity, which is based on lakeshore and shallow water indicators, and riparian vegetation cover were the most widespread stressors. Fifty percent and 48% of Michigan inland lakes, respectively, are estimated to be in the most disturbed condition for these habitat indicators.

2) *Microcystin was detected nationally in 39% of lakes, but concentrations rarely reach moderate or high levels of concerns established by the World Health Organization (<1% of lakes).*

   In Michigan, microcystin was detected in 29% of lakes in 2012, but levels were always much below the levels of concern established by the World Health Organization.

3) *The herbicide atrazine was detected nationally in 30% of lakes, but concentrations rarely reached the USEPA level of concern for plants in freshwater (<1% of lakes).*

In Michigan atrazine was detected in 13% of lakes, and concentrations never exceeded the USEPA level of concern for plants in freshwater.

4) *Nationally, 31% of lakes had degraded benthic macroinvertebrate communities, while 21% of lakes had degraded zooplankton communities. NLA exploratory analyses indicated an association between nutrients and biological condition. Lakes that had phosphorus pollution were also likely to have a degraded biological condition.*

   In Michigan, 52% of lakes were estimated to be in the most disturbed condition based on macroinvertebrate communities, compared to 17% based on zooplankton communities.

   The NLA report also showed changes between 2007 and 2012. While this report presents both 2007 and 2012 data, overall conclusions regarding trends were not made due to the small sample size of lakes (n =49).

Applicability to Michigan Inland Lake Protection and Monitoring Programs

The NLA randomly-selected lake dataset provides a valuable complement to data collected from the MDEQ targeted lake monitoring programs and the MDNR, Fisheries Division, inland lake Status and Trends Program, which the MDEQ has incorporated in an inland lakes monitoring strategy (MDEQ 2015b). The NLA state-scale assessment allows for extrapolation to the entire state and defined regions. This can provide context for data collected from other monitoring programs (statewide and nationally) and help identify lake management needs, as well as target resources (e.g., additional monitoring or educational efforts) where they may be needed to protect, preserve, and restore water quality.

The NLA results highlight the need for programs that encourage riparian and shoreline protection, improvement, and restoration to improve and maintain inland lake water quality. Michigan currently has several programs focused on shoreline quality. Score the Shore is an assessment option that was recently added to the Michigan Clean Water Corps (MiCorps) volunteer water quality monitoring program. Lake residents fill out assessment forms for each 1,000-foot section of lakeshore. The assessment includes number of houses and docks, riparian and aquatic vegetation condition, and erosion control structures. Residents can identify areas that have the poorest scores and begin educating neighboring residents on ways to improve the score. Results can also be used by lake associations or other entities in writing grant proposals for habitat improvements (MiCorps 2017).

The Michigan Shoreland Stewards Program provides recognition for lakefront property owners who protect inland lakes through best management practices on their property. The intent is to encourage the implementation of lake-friendly landscaping, erosion control methods, and policies to maintain or restore habitat that supports a healthy ecosystem. The program also provides educational resources to help manage lakeshore property (Michigan Shoreland Stewards, 2017).

In 2008, the Michigan Natural Shoreline Partnership (MNSP) was formed with the mission to promote natural shorelines through the use of green landscaping technologies and bioengineered erosion control for the protection of Michigan inland lakes. The partnership conducts research on these technologies and trains contractors and landscape professionals on their use. The MSNP also educates property owners, and encourages local and state policies that promote natural shoreline management (MSNP, 2017).

The 2012 NLA also highlights the need for actions that lead to a reduction of mercury in inland lakes. Many inland water bodies in Michigan are impacted by mercury and do not meet the other indigenous aquatic life and wildlife designated use and/or the fish consumption designated use (MDEQ 2016). A statewide mercury-based fish consumption advisory applies to all of Michigan's inland lakes, reservoirs, and impoundments. More information regarding fish consumption advisories in Michigan can be found at www.michigan.gov/eatsafefish. Atmospheric deposition is considered to be the major source of these persistent bioaccumulative chemicals (MDEQ 2016). Ongoing and future state and federal regulations, cleanup of legacy sources, and regional and national efforts will reduce atmospheric deposition inputs over time. The MDEQ's Water Chemistry Monitoring Program includes annual mercury sampling to monitor trends (MDEQ 2013).

Additional Information and Next Steps

Additional parameters were sampled as part of the 2012 NLA and several are summarized in Appendix B. A report summarizing the unweighted 2012 NLA water chemistry results, including trophic state, for Michigan's lakes is available (MDEQ 2015b). The 2012 results were summarized and compared to results from the 2007 NLA, the MDEQ Lake Water Quality Assessment monitoring project, and Michigan's volunteer lake monitoring network (MiCorps). Fact sheets summarizing water quality parameters for the 2012 lakes are also available and will be published on the MDEQ Web site in the future.

The next NLA Survey is scheduled for summer 2017. The MDEQ will again participate in the survey and sample 50 randomly selected inland lakes in Michigan.

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Appendix A. Michigan Inland Lakes sampled as part of the 2012 National Lake Assessment.

Trophic Status determination based on modified Carlson's Trophic State Index for Michigan (MDNR 1982).

Site Identification Number	Site Type	Lake Name	County	Longitude	Latitude	Trophic Status
NLA12_MI-101	2007 revisit	Pine Lake	KENT	-85.468097	43.218607	Mesotrophic
NLA12_MI-102	2007 revisit	Pere Marquette Lake	Mason	-86.438039	43.930032	Eutrophic
NLA12_MI-103	2007 revisit	Au Sable Lake	OGEMAW	-83.920449	44.430347	Mesotrophic
NLA12_MI-104	2007 revisit	Saddle Lake	VAN BUREN	-86.049285	42.381807	Mesotrophic
NLA12_MI-105	2007 revisit	Muskegon Lake	Muskegon	-86.292145	43.229223	Eutrophic
NLA12_MI-106	2007 revisit	Deer Lake	CHARLEVOIX	-84.978394	45.164457	Mesotrophic
NLA12_MI-107	2007 revisit	Crooked Lake	EMMET	-84.801833	45.414867	Mesotrophic
NLA12_MI-108	2007 revisit	Round Lake	VAN BUREN	-86.210244	42.080861	Mesotrophic
NLA12_MI-109	2007 revisit	Thornapple Lake	BARRY	-85.202682	42.616128	Eutrophic
NLA12_MI-110	2007 revisit	Mill Lake	OAKLAND	-83.310504	42.745060	Oligotrophic
NLA12_MI-111	2007 revisit	Ford Lake	WASHTENAW	-83.584404	42.215874	Eutrophic
NLA12_MI-112	2007 revisit	Palmer Lake	ST JOSEPH	-85.328608	41.937344	Eutrophic
NLA12_MI-113	2007 revisit	Blue Lake	MECOSTA	-85.281984	43.619643	Eutrophic
NLA12_MI-114	2007 revisit	Brighton Lake	LIVINGSTON	-83.796792	42.516530	Eutrophic
NLA12_MI-115	2007 revisit	West Lake	KALAMAZOO	-85.573305	42.186550	Mesotrophic
NLA12_MI-116	2007 revisit	Mud Lake	HOUGHTON	-88.316244	47.129887	Eutrophic
NLA12_MI-117	2007 revisit	Bogie Lake	OAKLAND	-83.505791	42.619108	Mesotrophic
NLA12_MI-118	2007 revisit	Silver Lake	IRON	-88.829600	46.152187	Oligotrophic
NLA12_MI-120	2012 National Site	Garwood Lake	BERRIEN	-86.474245	41.795149	Eutrophic
NLA12_MI-122	2012 National Site	Clear Lake	MONTMORENCY	-84.179898	45.124715	Oligotrophic
NLA12_MI-123	2012 National Site	Fourth Lake	HILLSDALE	-84.595941	41.885951	Mesotrophic
NLA12_MI-124	2012 National Site	Crocker Lake	MUSKEGON	-86.143214	43.373316	Eutrophic
NLA12_MI-125	2012 National Site	Bella Lake	BARAGA	-88.257560	46.791887	Eutrophic

Site Identification Number	Site Type	Lake Name	County	Longitude	Latitude	Trophic Status
NLA12_MI-126	2012 National Site	Seventh Spectacle Lake	OTSEGO	-84.396228	44.885402	Mesotrophic
NLA12_MI-128	2012 National Site	Crooked Lake	KALAMAZOO	-85.702618	42.205359	Mesotrophic
NLA12_MI-129	2012 National Site	Windover Lake	CLARE	-85.001982	43.957925	Mesotrophic
NLA12_MI-130	2012 National Site	Patricia Lake	CHARLEVOIX	-85.107590	45.135206	Mesotrophic
NLA12_MI-132	2012 National Site	Lake Mary	MENOMINEE	-87.757418	45.452106	Mesotrophic
NLA12_MI-133	2012 National Site	Middle Black Lake	KALKASKA	-84.926351	44.729058	Mesotrophic
NLA12_MI-135	2012 National Site	Little Portage Lake	WASHTENAW	-83.931738	42.410239	Mesotrophic
NLA12_MI-136	2012 National Site	Coady Lake	MONTCALM	-85.379790	43.364805	Mesotrophic
NLA12_MI-137	2012 National Site	Unnamed	MARQUETTE	-88.063195	46.276777	Mesotrophic
NLA12_MI-138	2012 National Site	Thompson Lake	MACKINAC	-84.416315	45.745929	Mesotrophic
NLA12_MI-139	2012 State Site	School Lake	CALHOUN	-84.907281	42.387940	Eutrophic
NLA12_MI-141	2012 State Site	Lake Alice	BARAGA	-88.081880	46.697528	Oligotrophic
NLA12_MI-142	2012 National Site	Mud Lake	ISABELLA	-84.768731	43.486468	Eutrophic
NLA12_MI-144	2012 State Site	Unnamed	CASS	-85.862360	41.872305	Mesotrophic
NLA12_MI-145	2012 National Site	Pogy Lake	MECOSTA	-85.309914	43.798774	Eutrophic
NLA12_MI-148	2012 State Site	"South Pond"	DICKINSON	-87.983624	45.949176	Oligotrophic
NLA12_MI-150	2012 Add On	Ionia Lake	ALGER	-86.254904	46.506290	Eutrophic
NLA12_MI-151	2012 Add On	"Hawk Island Park Lake"	INGHAM	-84.532285	42.694383	Mesotrophic
NLA12_MI-152	2012 Add On	Huckleberry Lake	ALLEGAN	-85.638044	42.757373	Eutrophic
NLA12_MI-155	2012 Add On	Jones Lake	INGHAM	-84.167186	42.477859	Eutrophic
NLA12_MI-161	2012 Add On	Lake Mitchell	WEXFORD	-85.485033	44.231653	Eutrophic
NLA12_MI-162	2012 Add On	Bass Lake	LUCE	-85.716662	46.463258	Oligotrophic

Site Identification Number	Site Type	Lake Name	County	Longitude	Latitude	Trophic Status
NLA12_MI-164	2012 Add On	Powell Lake	MARQUETTE	-87.449735	46.399667	Hypereutrophic
NLA12_MI-165	2012 Add On	Clear Lake	MISSAUKEE	-85.307491	44.355451	Eutrophic
NLA12_MI-167	2012 Add On	"Forrest Lake"	SHIAWASSEE	-84.205052	42.915250	Eutrophic
NLA12_MI-168	2012 Add On	Tupper Lake	IONIA	-85.115021	42.784099	Eutrophic
NLA12_MI-169	2012 Add On	Gasley Lake	IRON	-88.751763	46.399898	Eutrophic
NLA12_MI-172	2012 Add On	Stewart Lake	BARRY	-85.451183	42.567764	Mesotrophic
NLA12_MI-177	2012 Add On	Little Glen	LEELANAU	-86.018198	44.867685	Mesotrophic
NLA12_MI-178	2012 Add On	Sucker Lake	SCHOOLCRAFT	-86.105101	46.484487	Eutrophic

Appendix B. Summary of selected parameter results collected from Michigan inland lakes for the 2012 National Lake Assessment.

		Depth (m)	Depth (ft.)	Area (Hectares)	Area (Acres)	Atrazine (ppb)	Littoral Chl. A (µg/L)	Index Chl. A (µg/L)	Average Chl. A (µg/L)	Littoral Microcystin (µg/L)	Index Microcystin (µg/L)	Average Microcystin (µg/L)
Michigan (n=49)	Min	0.90	2.95	1.791	4.43	0.000	1.050	1.045	1.113	0.000	0.00	0.00
	Q1	4.30	14.11	6.583	16.27	0.000	1.840	2.808	2.428	0.051	0.05	0.05
	Median	8.50	27.89	14.485	35.79	0.000	2.910	3.144	3.034	0.111	0.10	0.09
	Q3	13.10	42.98	42.728	105.58	0.050	4.210	5.840	5.228	0.219	0.27	0.24
	Max	26.30	86.29	768.755	1899.63	1.500	35.520	33.440	28.280	4.994	3.54	4.27
	Mean	9.38	30.77	59.731	147.60	0.073	4.222	6.070	5.146	0.247	0.27	0.26
	St Dev.	5.95	19.52	134.400	332.11	0.257	3.892	6.543	4.882	0.602	0.51	0.55
Upper Midwest (n=131)	Min	0.90	2.95	1.635	4.04	0.000	1.050	1.045	1.113	0.000	0.00	0.00
	Q1	3.53	11.56	5.357	13.24	0.000	2.690	3.015	3.034	0.000	0.00	0.00
	Median	6.60	21.65	16.142	39.89	0.000	3.790	4.149	3.970	0.000	0.00	0.06
	Q3	11.60	38.06	41.929	103.61	0.070	5.740	7.536	8.360	0.307	0.12	0.18
	Max	36.00	118.11	768.755	1899.63	1.500	124.800	122.400	123.600	12.620	18.06	15.34
	Mean	8.38	27.51	52.822	130.53	0.053	7.685	9.988	8.837	0.192	0.15	0.17
	St Dev.	6.30	20.66	113.481	280.42	0.135	12.386	15.627	13.507	0.553	0.62	0.57
Nation (n=951)	Min	0.80	2.62	1.627	4.02	0.000	0.000	0.000	0.220	0.000	0.00	0.00
	Q1	2.50	8.20	5.862	14.49	0.000	3.180	3.424	3.677	0.000	0.00	0.04
	Median	7.72	25.31	390.888	965.90	0.000	6.990	6.896	8.330	0.089	0.08	0.09
	Q3	9.10	29.86	56.899	140.60	0.070	20.960	25.760	23.920	0.181	0.14	0.18
	Max	58.50	191.93	67780.700	167489.61	9.700	584.640	764.640	583.000	189.382	66.69	94.93
	Mean	7.72	25.31	390.888	965.90	0.094	24.611	24.164	24.478	0.665	0.54	0.60
	St Dev.	8.46	27.76	3255.056	8043.41	0.378	55.591	44.901	48.209	4.736	3.17	3.67

		1m D.O. (mg/L)	1m TEMP (°C)	1 m PH (S.U.)	1m COND (µS/cm)	SECCHI (m)	Al (mg/L)	Ca (mg/L)	Cl (mg/L)	Color (ALPHA Pt-Co)	DOC (mg/L)	K (mg/L)	Mg (mg/L)
Michigan (n=49)	Min	0.0	0.00	6.68	20.00	0.525	0.00	1.685	0.115	5.0	2.430	0.041	0.557
	Q1	0.0	9.50	8.26	191.30	2.075	0.00	17.530	4.619	12.0	4.180	0.638	6.006
	Median	1.4	17.10	8.47	274.00	3.015	0.00	28.030	9.376	18.0	6.200	0.791	12.910
	Q3	7.9	22.70	8.52	413.00	3.675	0.01	38.640	30.816	24.0	8.680	1.891	18.420
	Max	23.0	29.30	9.28	759.00	8.800	0.09	61.980	137.654	125.0	24.530	7.909	31.520
	Mean	4.3	15.46	8.25	301.73	3.072	0.01	28.526	27.054	25.2	7.364	1.316	12.143
	St Dev.	5.1	9.67	0.59	194.48	1.446	0.02	15.810	36.071	26.4	4.426	1.242	7.366
Upper Midwest (n=131)	Min	0.0	0.00	6.09	12.00	0.150	0.00	1.200	0.071	2.5	2.430	0.000	0.300
	Q1	0.4	0.00	7.35	51.00	1.450	0.00	4.388	0.488	11.0	4.560	0.400	1.698
	Median	8.0	19.40	8.42	240.00	2.500	0.00	23.060	2.427	19.0	8.300	0.938	10.010
	Q3	9.3	22.60	8.56	303.00	4.000	0.02	29.900	9.155	43.0	11.530	1.594	17.640
	Max	23.0	29.30	10.47	970.00	8.800	0.18	70.100	149.797	165.0	24.530	23.800	106.600
	Mean	6.0	14.40	8.08	217.67	2.791	0.02	20.887	11.429	32.0	8.617	1.398	11.565
	St Dev.	4.4	9.85	0.70	164.82	1.677	0.03	14.002	24.883	35.3	4.610	2.044	11.148
Nation (n=951)	Min	0.0	0.00	2.83	2.82	0.020	0.00	0.262	0.053	0.0	0.230	0.000	0.067
	Q1	0.0	0.00	7.35	60.40	0.825	0.00	4.388	1.919	13.0	3.980	0.756	1.377
	Median	6.1	19.93	8.02	211.00	1.550	0.00	19.560	6.777	21.0	6.320	1.775	5.597
	Q3	8.3	25.40	8.57	427.00	3.050	0.01	32.207	21.346	34.0	10.650	4.520	17.640
	Max	23.0	273.00	10.47	64810.00	28.000	2.48	594.900	18012.742	724.0	515.810	3376.000	1023.000
	Mean	5.1	15.48	7.95	1247.42	2.202	0.01	27.557	291.081	26.6	8.531	12.920	33.464
	St Dev.	4.3	11.88	0.85	6957.92	2.112	0.06	45.060	2174.041	23.9	13.522	91.104	128.224

		NH_3 (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)	$NO_3 + NO_2$ (mg/L)	TN (mg/L)	TP (µg/L)	SIO_2 (mg/L)	SO_4 (mg/L)	Na (mg/L)	Turbidity (ntu)
Michigan (n=49)	Min	0.000	0.000	0.000	0.000	0.21	5	0.163	0.858	0.436	0.01
	Q1	0.008	0.000	0.002	0.002	0.40	15	1.820	4.304	2.968	0.75
	Median	0.012	0.000	0.002	0.002	0.55	23	3.673	8.976	5.408	1.26
	Q3	0.025	0.000	0.002	0.002	0.62	31	10.043	17.645	15.270	1.56
	Max	0.049	0.002	3.490	3.493	3.66	75	17.242	51.004	71.660	4.77
	Mean	0.015	0.000	0.054	0.054	0.61	25	5.551	11.717	14.829	1.37
	St Dev.	0.011	0.000	0.402	0.402	0.43	14	4.242	10.167	19.040	1.02
Upper Midwest (n=131)	Min	0.000	0.000	0.000	0.000	0.02	5	0.043	0.031	0.145	0.01
	Q1	0.014	0.000	0.000	0.002	0.51	20	2.943	1.982	1.179	1.26
	Median	0.019	0.000	0.002	0.003	0.66	25	7.027	4.054	2.612	1.42
	Q3	0.040	0.000	0.004	0.017	0.98	39	12.764	9.500	5.196	2.37
	Max	0.242	0.002	3.490	3.493	4.90	524	29.632	226.289	104.500	78.20
	Mean	0.055	0.000	0.018	0.056	0.77	33	8.073	7.601	7.175	2.69
	St Dev.	0.080	0.001	0.208	0.236	0.46	30	6.137	17.720	13.764	4.02
Nation (n=951)	Min	0.000	0.000	0.000	0.000	0.01	4	0.022	0.026	0.000	0.00
	Q1	0.010	0.000	0.000	0.002	0.40	21	2.698	2.351	2.300	1.19
	Median	0.016	0.000	0.002	0.002	0.67	36	6.462	7.028	5.835	1.96
	Q3	0.032	0.000	0.010	0.016	1.06	97	12.100	20.948	21.020	5.16
	Max	3.180	0.419	51.660	52.084	54.00	3636	935.000	47325.202	29890.000	398.43
	Mean	0.040	0.000	0.041	0.051	1.01	90	9.913	122.757	206.106	7.83
	St Dev.	0.094	0.003	0.447	0.455	1.58	191	33.741	842.300	1424.312	20.80