United States
Environmental Protection
Agency

EPA 841-R-16-113 | December 2016

National Lakes Assessment 2012

A Collaborative Survey of Lakes in the United States

Acknowledgements

The U.S. Environmental Protection Agency (EPA) Office of Water (OW) would like to thank the many people who contributed to this project. Without the collaborative efforts and support by state and tribal environmental agencies, federal agencies, and other organizations, this assessment of lakes would not have been possible.

EPA would like to thank the steering committee, state and tribal environmental agencies, field crews, biologists, taxonomists, laboratory staff, data analysts, program administrators, EPA regional coordinators, statisticians, quality control staff, data management staff and many reviewers for their dedication and hard work. Your collective efforts made this report possible. To the many hundreds of participants, EPA expresses its gratitude.

State, Tribal, Territory and Interstate Partners

Alaska Department of Environmental Conservation
Arizona Department of Environmental Quality
Blackfeet Tribe
California Department of Fish and Wildlife
Cheyenne River Sioux Tribe
Colorado Department of Public Health and Environment
Connecticut Department of Energy and Environmental Protection
Crow Nation
Delaware Department of Natural Resources and Environmental Control
Fond du Lac Band of Chippewa Indians
Georgia Department of Natural Resources
Hawaii Department of Health
Hawaii Department of Land and Natural Resources
Idaho Department of Environmental Quality
Illinois Environmental Protection Agency
Indiana Department of Environmental Management
Iowa Department of Natural Resources
Kansas Department of Health and Environment
Lac du Flambeau Band of Chippewa Indians
Leech Lake Band of Ojibwa
Maine Department of Environmental Protection
Maryland Department of Natural Resources
Menominee Indian Tribe of Wisconsin
Michigan Department of Environmental Quality
Minnesota Pollution Control Agency
Missouri Department of Conservation
Montana Department of Environmental Quality
Nevada Division of Environmental Protection
New Hampshire Department of Environmental Services
New Jersey Department of Environmental Protection
North Carolina Department of Environmental Quality
North Dakota Department of Health
Ohio Environmental Protection Agency
Oklahoma Water Resources Board
Oregon Department of Environmental Quality
Pennsylvania Department of Environmental Protection
Rhode Island Department of Environmental Management
Sisseton Wahpeton Oyate Sioux Tribe
South Dakota Department of Environment & Natural Resources
Spirit Lake Nation
Susquehanna River Basin Commission
Texas Commission on Environmental Quality
Turtle Mountain Band of Chippewa Indians
Utah Department of Environmental Quality
Vermont Department of Environmental Conservation
Virginia Department of Environmental Quality
Washington State Department of Ecology
West Virginia Department of Environmental Protection
Wisconsin Department of Natural Resources

Federal Partners

U.S. Department of Agriculture Forest Service
U.S. Department of Interior Geological Survey

Other Partners and Contractors

BSA Environmental Services
Dynamac
EcoAnalysts, Inc.
Great Lakes Environmental Center, Inc.
Indiana University
Kansas Biological Survey
Michigan State University
Midwest Biodiversity Institute
Moss Landing Marine Labs
Oregon State University
SRA International
Tetra Tech, Inc.
University of Missouri
Wisconsin State Lab of Hygiene

The following people played a pivotal role and lent their expertise to data oversight and analysis in this project: Karen Blocksom, Phil Kaufmann, Tom Kincaid, Tony Olsen, Steve Paulsen, Dave Peck, John Stoddard, John Van Sickle, and Marc Weber from EPA Office of Research and Development; Richard Mitchell and Amina Pollard from EPA Office of Water; Alan Herlihy from Oregon State University.

The National Lakes Assessment 2012 was led by Amina Pollard with significant programmatic help from Susan Holdsworth, Marsha Landis, Sarah Lehmann, Richard Mitchell and Mimi Soo-Hoo (ORISE Participant) from EPA Office of Water; Steve Paulsen from EPA Office of Research and Development; and EPA Regional Coordinators.

The NLA 2012 report was written by Amina Pollard with support from Sarah Lehmann. IEc/Crow Insight provided tremendous graphics support for the report and the interactive data dashboards, technical editing, and layout assistance. Comments from three peer reviewers improved this report.

The suggested citation for this document is: USEPA. 2016. National Lakes Assessment 2012: A Collaborative Survey of Lakes in the United States. EPA 841-R-16-113. U.S. Environmental Protection Agency, Washington, DC. https://nationallakesassessment.epa.gov/

Table of Contents

Tables and Figures

1

Executive Summary




Lakes and reservoirs provide many environmental, economic, and public health benefits. We use lakes for drinking water, energy production, food, and recreation, while fish, birds, and other wildlife rely on them for habitat and survival. In the National Lakes Assessment (NLA), the U.S. Environmental Protection Agency (EPA) and its partners surveyed a wide array of lakes representative of those found in the U.S., from small ponds and prairie potholes to large lakes and reservoirs.

The *National Lakes Assessment 2012: A Collaborative Survey of the Lakes in the United States* presents the results of a second evaluation of the biological, chemical, physical, and recreational condition of lakes in the United States, the first having been conducted in 2007. During spring and summer of 2012, 89 field crews sampled 1,038 lakes across the country. Each field crew used consistent procedures to sample benthic macroinvertebrates (e.g., insect larvae, snails, and clams), zooplankton (small animals in the water column), algal toxins, atrazine, and nutrients and to observe near-shore habitat so that results could be compared across the country. These measured values were compared to NLA benchmarks, which are points of reference used to determine the proportion of lakes that are relatively high quality (least disturbed), medium quality (moderately disturbed), and degraded (most disturbed) in condition.

NLA 2012 Condition

- The NLA indicates that nutrient pollution is common in U.S. lakes; 40% of lakes have excessive levels of total phosphorus and 35% have excessive levels of total nitrogen. Nutrient pollution is 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, is detected in 39% of lakes, but concentrations rarely reach moderate or high levels of concerns established by the World Health Organization (<1% of lakes).
- The herbicide atrazine is detected in 30% of lakes, but concentrations rarely reach the EPA level of concern for plants in freshwater (<1% of lakes).
- We find that 31% of lakes have degraded benthic macroinvertebrate communities, while 21% of lakes have degraded zooplankton communities. NLA exploratory analyses indicate an association between nutrients and biological condition, with lakes with phosphorus pollution likely also to have a degraded biological condition.

NLA Change:

- A comparison of the 2007 and 2012 National Lakes Assessments indicates little change between surveys. In most cases, the percentage of lakes in degraded biological, chemical and physical condition did not change at the national scale over this five-year period.

> ***The NLA indicates that nutrient pollution is common in U.S. lakes; 40% of lakes have excessive levels of total phosphorus. Compared to other measures, nutrient pollution is the most widespread stressor measured in the NLA and can contribute to algae blooms and affect recreational opportunities in lakes.***

- One notable exception to this pattern was observed with algal toxin measures. An analysis of cyanobacteria cell density, a measure of the density of cells that could produce cyanotoxins, shows a statistically significant increase (+8.3%) in the percentage of lakes in the most disturbed category between 2007 and 2012. The NLA identified a significant increase in the detection of microcystin among lakes in 2012 (+9.5%). However, concentrations of this algal toxin remained low and rarely exceeded WHO recreational levels of concern (<1% of the population) in both assessments.
- Another difference emerged through additional in-depth analyses of nutrient data. While we did not observe changes in the condition categories, analysts found a dramatic 18.2% decline in the percentage of oligotrophic lakes (<10 µg/L of total phosphorus) and an overall increase in the median concentration of phosphorus across all lakes.

The NLA offers a unique opportunity to frame discussions and plan strategies for the protection and restoration of lakes across the United States. Results of the NLA provide a broad range of information that can help us better understand the condition of lakes in the United States, some of the stressors affecting them, and how stressors relate to local conditions. While we explore associations between these indicators, the NLA analysis presented in this report does not seek to explain or identify the causes of degraded conditions or sources of stressors.

Additional information from the NLA, including assessment of conditions at regional scales, differences between natural lakes and reservoirs, and an opportunity to explore population-level results in an interactive dashboard, is available online: https://www.epa.gov/national-aquatic-resource-surveys/nla.

2

Introduction





Healthy lakes enhance our quality of life. They support complex and important food web interactions and provide habitat for many types of fish and wildlife. Lakes contribute to a healthy economy: they are an important draw for tourism and provide recreational opportunities for millions of Americans.

The National Lakes Assessment (NLA) is one of four statistical surveys that make up the National Aquatic Resource Surveys (NARS). The NARS are implemented by the U.S. Environmental Protection Agency (EPA), states, and tribes to provide nationally consistent assessments of surface waters in the U.S. For more information on NARS, visit https://www.epa.gov/national-aquatic-resource-surveys.

The NLA is designed to answer the following questions about lakes across the United States.

1. What is the current biological, chemical, physical, and recreational condition of lakes?
    a. What is the extent of degradation among lakes?
    b. Is degradation widespread (e.g., national) or localized (e.g., regional)?
2. Is the proportion of lakes in the most disturbed condition getting better, worse, or staying the same over time?
3. Which environmental stressors are most strongly associated with degraded biological condition in lakes?

This brief report presents information from the second National Lakes Assessment (NLA 2012). It provides national-scale assessments and also compares the condition of lakes to those from the earlier NLA 2007 conducted by EPA and its partners. You can find results for regional scales and comparisons between natural lakes and reservoirs using our interactive dashboard at https://nationallakesassessment.epa.gov/.

3

Design of the Lakes Survey

Lakes in the U.S. are as varied and unique as the landscapes surrounding them. The NLA includes examples of all lake types, including lakes, ponds, and reservoirs on private, state, tribal, and federal lands across the conterminous U.S.

3.1 CHOOSING INDICATORS

Lakes vary greatly and indicators selected to characterize them should represent their varied aspects. For the NLA 2012, several indicators were chosen to assess the chemical, physical, recreational, and biological condition of lakes. Although there are many more factors that affect lakes or could be used to describe their condition, we believe these indicators to be the most representative at a national scale (USEPA 2009).

The chemical characteristics of lake condition, such as nutrient levels and dissolved oxygen, create environments essential for aquatic organisms to survive and grow. Chemical conditions in lakes affect the health of primary producers (algae), zooplankton, macroinvertebrates, and fish. Chlorophyll-*a* was used as an indicator of trophic state (productivity).

To address recreational and human health-related considerations, the NLA examined concentrations of the algal toxin microcystin, along with cyanobacteria cell counts and chlorophyll-*a* concentrations as indicators of the potential for the presence of algal toxins. Mercury in sediment was assessed because it bioaccumulates in the food chain. This survey also measured atrazine in water samples. Atrazine is one of the most commonly used herbicides in the United States.

Physical indicators of lake condition evaluated for the NLA 2012 include conditions on the water's edge (lakeshore) and in shallow water, measures of human disturbance, and drawdown (the natural or intentional lowering of lake water levels). Healthy physical habitat affects biological communities in many ways, such as providing food and shelter for aquatic wildlife and moderating the magnitude, timing, and pathways of water, sediment, and nutrient inputs into lakes.

To evaluate the biological condition of lakes for the 2012 assessment, NLA analysts developed two new research indicators, one based on benthic macroinvertebrate communities (bottom-dwelling animals without backbones) and one using zooplankton (microsopic animals in the water column).

3.2 SELECTING LAKES

EPA used a statistical sampling approach incorporating survey design techniques to select lakes for this assessment. This approach has been used in social science and health fields to determine the status of populations using a representative sample of relatively few individuals.

The 1,038 lakes sampled were identified using a stratified random sampling technique called probability-based sample design. In such a design, every lake in the target population has a known probability of being selected for sampling. Site selection was controlled for lake size and spatial distribution to make sure that sample sites were representative of lakes in the U.S., reflecting the full range in character and variation among lakes across the U.S.

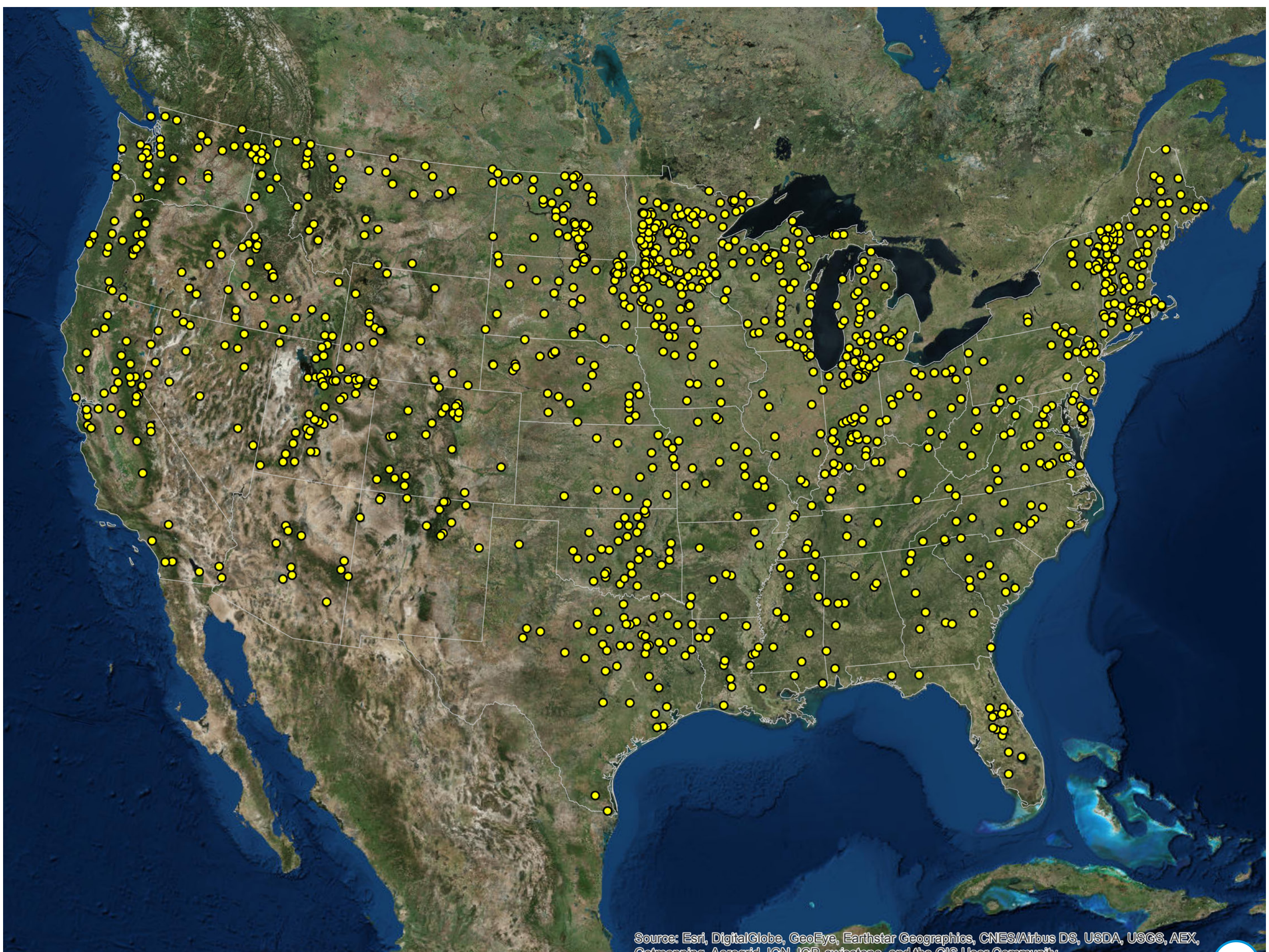
The USGS/EPA National Hydrography Dataset plus (NHDPlus), version 2 (http://www.horizon-systems.com/nhdplus/NHDplusV2_home.php) was used to compute the number of lakes throughout the U.S. The NHDPlus is a multi-layered series of digital maps that show topography, area, flow, location, and other attributes of U.S. surface waters. The NHDPlus V2 has 389,005 features listed that could potentially be lakes in the conterminous U.S.

To be included in the survey, a water body had to be either a natural or man-made freshwater lake, pond, or reservoir greater than 2.47 acres (1 hectare), at least 3.3 feet (1 meter) deep, with a minimum quarter acre (0.1 hectare) of open water. In addition, lakes were required to have a lakewater minimum residence time of one week (these latter three criteria could only be determined at the site). The Great Lakes and the Great Salt Lake were not included in the survey, nor were commercial treatment and/or disposal ponds, brackish lakes, or ephemeral lakes. After applying these criteria, analysts estimate that 159,652 water bodies are considered lakes by the NLA 2012 definition and thus comprise the target population.

Another determinant of lake inclusion was accessibility. In some cases, crews were either denied permission by the landowner or unable to reach the lake because of safety concerns, such as sharp cliffs or unstable ridges. Using both data from the crews' experience and pre-sampling reconnaissance, an estimated 30% or 47,833 lakes were found to be inaccessible. This leaves 111,818 lakes that the NLA 2012 was able to assess and is also known as the larger inference population.

The NLA 2012 collected data from 1,038 lakes selected from a stratified random sample based on ecoregion, state, and surface area in the larger inference population (Figure 3.1). Consequently, throughout this report, percentages reported for a given indicator are relative to the 111,818 lakes in the inference population. For example, if the

Figure 3.1: NLA 2012 Sampled Sites



condition is described as most disturbed for 10% of lakes nationally, this means that the number of lakes estimated to be degraded for that indicator is 11,181 lakes. Findings from the 2007 and 2012 assessments indicate that the lakes distributed across the conterminous U.S. are roughly equally split between man-made and natural in origin.

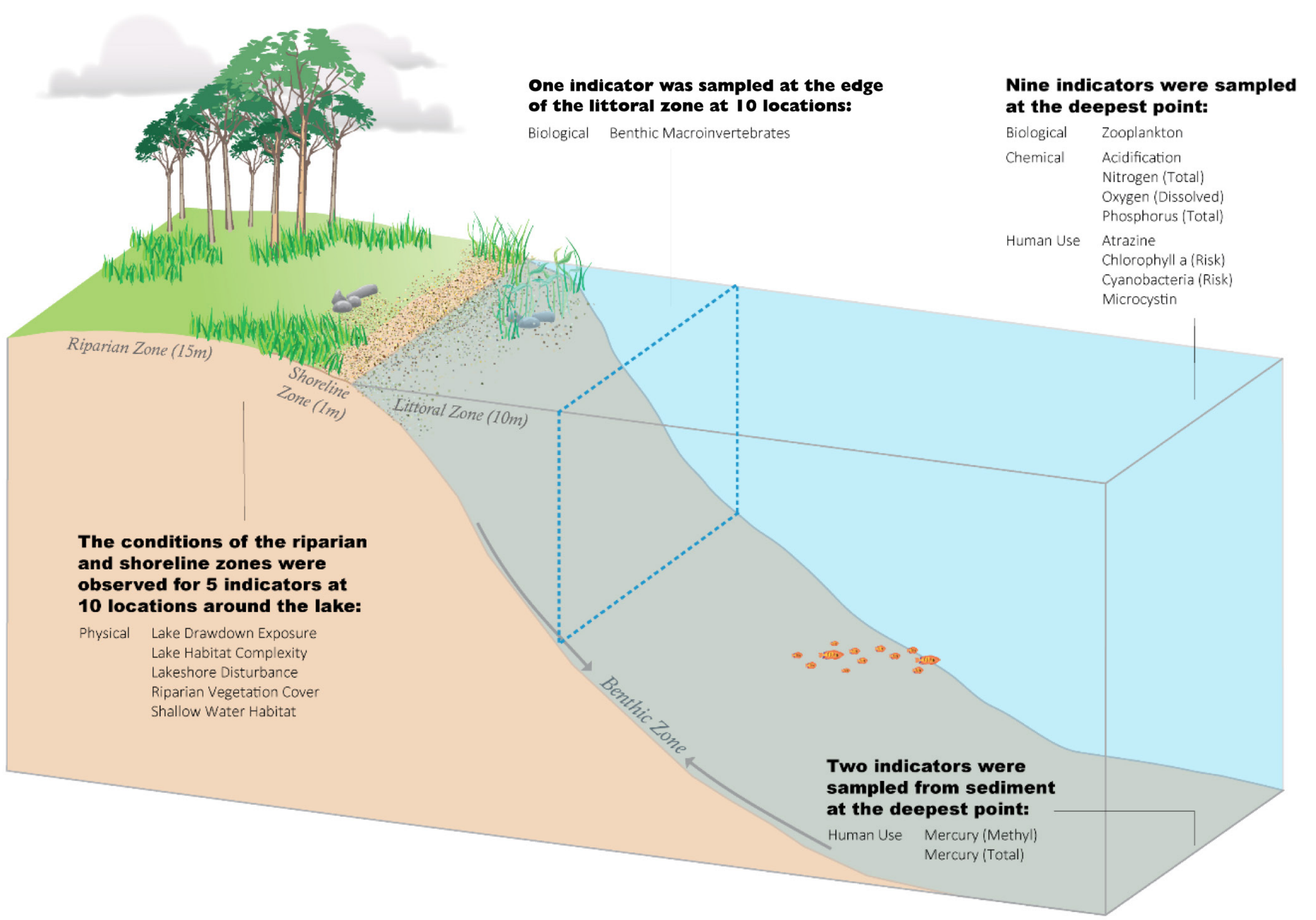
NLA site selection ensures that EPA can make unbiased estimates concerning the health of lakes and that it can quantify the uncertainty of its estimates. The greater the number of sites sampled, the more confidence in the results. The NLA population results are determined by first calculating the number of lakes in each condition class for each indicator. Then the site weights from the probability design, which reflect the number of lakes each site represents across the total population of NLA lakes, are summarized within condition classes to estimate the lakes in least, moderate, and most disturbed condition. The number of sites included in the NLA 2012 allows EPA to determine the percentage of lakes in the conterminous U.S. that exceed a benchmark of concern with 95% confidence.

3.3 FIELD SAMPLING

Throughout the summer of 2012, 89 field crews sampled lakes across the U.S. Sampling each lake took a full day. To ensure consistency in collection procedures and to 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 2012).

At each lake site, crews collected samples at a standard single station located at the deepest point in the lake (or at 50m in deep lakes) and recorded shoreland and shoreline observations at ten stations evenly distributed around the lake perimeter (Figure 3.2). At the mid-lake station (the deepest point of 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

Figure 3.2: NLA Field Crew Indicator Sampling Locations



from the euphotic zone to measure nutrients, chlorophyll-*a*, and the algal toxin microcystin. Field crews used a fine mesh (50µm) and coarse mesh (150µm) plankton net to collect a vertically integrated zooplankton sample, and took a sediment core to provide data on concentrations of mercury in sediments.

At the ten lake perimeter stations, crews collected data and information on the physical characteristics that could affect habitat quality. Crews also collected benthic macroinvertebrates from this area using a 500µm D-frame net. Filtering and other sample preparations took place on shore.

3.4 ASSESSING 2012 LAKE CONDITIONS

Many of the measures included in NLA are natural components of lakes. For example, some level of a nutrient like phosphorus is necessary to support lake communities, while algal toxins like microcystin occur naturally in lakes. The NLA explores whether these measures are out of balance compared to expectations or benchmarks.

Many of the measures included in NLA are natural components of lakes. For example, some level of a nutrient like phosphorus is necessary to support lake communities, while algal toxins like microcystin occur naturally in lakes. The NLA explores whether these measures are out of balance compared to expectations or benchmarks.

NLA analysts reviewed the data for each indicator independently and split the population into three 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). These condition category terms were selected for internal consistency and to more closely align with the relative nature of most of the measures. More specifically, the observed value for an indicator at each sampled lake was assessed against benchmark levels to determine its condition.

The NLA 2012 uses two types of assessment benchmarks. The first type is the 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 (Figure 3.3). Appendix A provides general information about each NLA 2012 indicator and the NLA 2012 Technical Report provides specific details about benchmarks (USEPA 2016).

3.4.1 Developing NLA-Derived Benchmarks

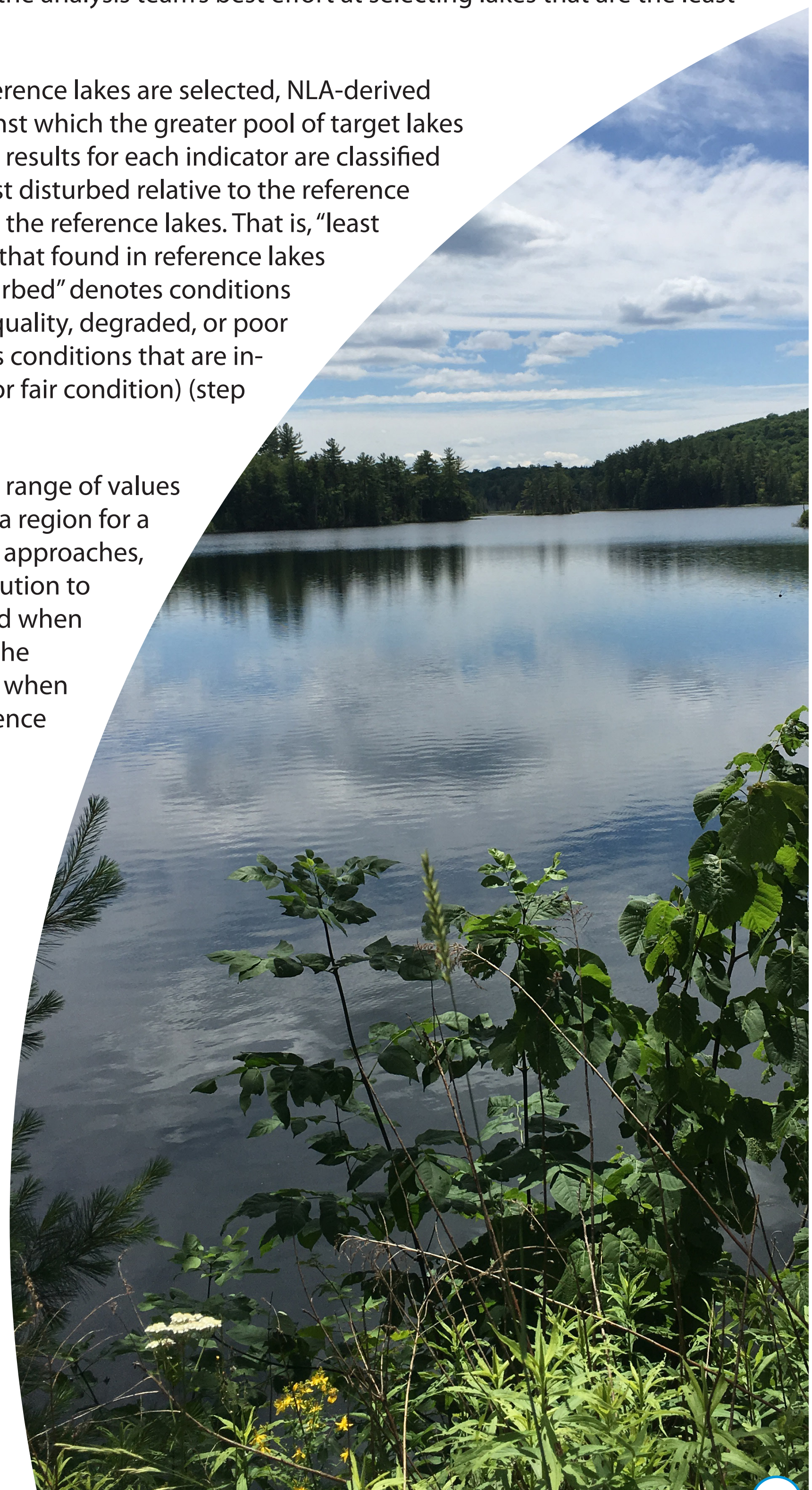
Selecting Reference Lakes. In order to assess the condition of the country's lakes, some measures are compared to benchmarks developed from the range of values observed in a set of reference lakes. A reference lake in the NLA is a lake, either natural or man-made, with attributes (such as water quality) that come as close as practical to those expected in a natural state, i.e., a least disturbed lake.

Data from all sampled lakes are evaluated against reference screening criteria to determine the final set of lakes used to characterize the reference condition (steps 1 and 2 in Figure 3.3). Four groups of reference lakes are selected, one for each biological condition (benthic macroinvertebrates and zooplankton), one for nutrient condition, and one for physical habitat condition. Our expectations for lake characteristics differ between temperate forests and xeric areas, so screening criteria reflect the least disturbed conditions found in the different ecoregions. Detailed information about reference selection, including ecoregions and screening criteria, is in the NLA 2012 Technical Report (USEPA 2016). In refining benchmarks for the NLA 2012, some 2007 benchmark values were revised;

therefore, direct comparisons should not be made between 2012 results and those reported in 2007. For purposes of identifying change in this report, 2007 results were recalculated based on new 2012 benchmarks.

When considering reference condition, it is important to remember that many areas in the U.S. have been altered, with natural landscapes transformed by urban and suburban development, agricultural activities, and resource extraction. To reflect the variability across the American landscape, least disturbed lakes diverge from the natural state by varying degrees. For example, remote lakes like those in the upper elevation wilderness areas of Montana may be virtually pristine, while the highest quality least disturbed lakes in other parts of the country, especially in urban or agricultural areas, may exhibit various levels of human disturbance. For this reason, reference conditions might differ among regions. The resulting reference lakes represent the analysis team's best effort at selecting lakes that are the least disturbed in specific regions across the country.

Benchmarks. After lakes are screened and reference lakes are selected, NLA-derived benchmarks are set for each of the regions against which the greater pool of target lakes are compared (step 3 in Figure 3.3). For NLA, the results for each indicator are classified as least disturbed, moderately disturbed, or most disturbed relative to the reference conditions established for each ecoregion using the reference lakes. That is, "least disturbed" denotes an indicator value similar to that found in reference lakes (i.e., high quality or good condition); "most disturbed" denotes conditions worse than most reference conditions (i.e., low quality, degraded, or poor condition); and "moderately disturbed" indicates conditions that are in-between these two states (i.e., medium quality or fair condition) (step 4 in Figure 3.3).



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 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.

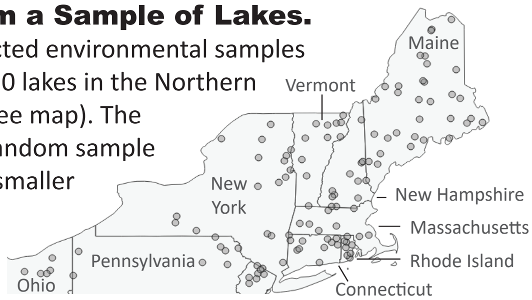
3.5 ESTIMATING THE 2012 CONDITION OF THE POPULATION OF LAKES

After indicators were characterized as least disturbed, moderately disturbed, and most disturbed, we used the sampled lake information to develop inferences for the population of lakes. During this step, the site weights from the probability design, which

Figure 3.3: Using Reference Lakes to Estimate Conditions

EPA designed its sample to be representative of the unique characteristics of lakes within nine different ecoregions. For many of the biological, chemical, and physical NLA indicators, this representativeness is essential for an accurate understanding of our lakes. The steps below describe EPA's process for determining the relative condition of lakes, which takes into account the differing landscapes within each ecoregion. For simplicity, this infographic identifies the steps involved in estimating phosphorus conditions for lakes in the Northern Appalachian ecoregion. The steps for other ecoregions and indicators are similar.

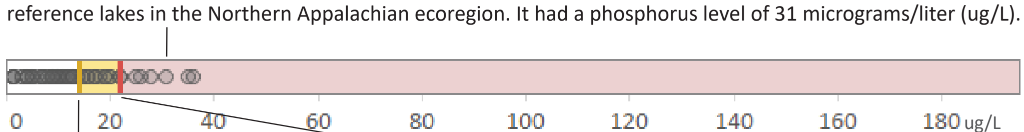
1. Collect Data from a Sample of Lakes. In 2012, NLA teams collected environmental samples and observations from 120 lakes in the Northern Appalachian ecoregion (see map). The lakes comprised a large random sample (99), supplemented by a smaller set of hand-picked lakes believed by EPA to be least disturbed (21).



2. Analyze Data to Identify Reference Lakes. For each of the 120 lakes, EPA scientists compared selected data against reference screening criteria. This process yielded 45 lakes considered relatively undisturbed. EPA screened and added to the list 26 additional lakes from the 2007 NLA, for a total of 71 reference lakes in the Northern Appalachian ecoregion.

3. Calculate Condition Benchmarks. EPA then analyzed the distribution of phosphorus values among reference lakes, to set the benchmarks for the condition categories.

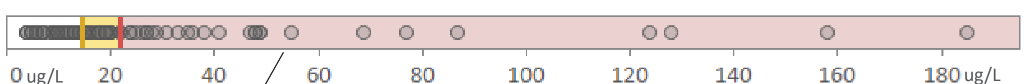
Each dot below indicates the observed phosphorus level at a reference lake. Many of the dots overlap because they have a similar value. The Vermont lake indicated below by a short vertical black line was one of 71 reference lakes in the Northern Appalachian ecoregion. It had a phosphorus level of 31 micrograms/liter (ug/L).



75% of reference lakes have phosphorus levels below 14.5 ug/L in the Northern Appalachian ecoregion and are considered to be in least disturbed condition.

5% of reference lakes have phosphorus levels above 22 ug/L and are considered to be in the most disturbed category. Those in between 14.5 ug/L and 22 ug/L (highlighted in yellow) are considered moderately disturbed.

4. Assign Condition Categories. Using a regional benchmark, EPA then determined the phosphorus condition of each randomly sampled lake.



For instance, this New York lake was assigned to the "most disturbed" category because its phosphorus level of 55 ug/L was above the benchmark in that region. Of the 99 randomly sampled Northern Appalachian lakes, 27 met the criteria for the most disturbed condition for phosphorus. EPA also categorized 25 lakes as moderately disturbed and 47 lakes as least disturbed for the same indicator.

5. Estimate the Condition of Lakes in the Ecoregion. Based on a weighted analysis of randomly sampled lakes, EPA estimated the proportion of all Northern Appalachian lakes in each condition category. For instance, **EPA found that 31% of all Northern Appalachian lakes are designated as most disturbed for phosphorus. The confidence interval for this estimate is ±20% (11% to 51%).** EPA used similar procedures to assess the phosphorus conditions in other ecoregions. Based on this analysis, EPA found that 40% of all lakes nationally are designated as most disturbed for phosphorus. The confidence interval for this estimate is ±6% (34% to 47%). EPA is more certain about the national estimate because it is based on information from a much larger number of lakes. *Find all the national condition estimates in Chapter 4.*

reflect the number of lakes each site represents, are applied to estimate the percentage of lakes in each condition category. This analysis provides a point estimate of condition and the 95th percentile confidence intervals around that estimate. In the graphs throughout this report, the margin of error is depicted as narrow darkened lines on either side of the bars and represents the confidence interval for the estimate. For national estimates, the margin of error around the NLA findings is approximately ±5% (Brown et al. 2001). For more information on the probability design and how sites are weighted, please see the NLA 2012 Technical Report (USEPA 2016).

3.6 DIFFERENCES BETWEEN THE 2012 AND 2007 ASSESSMENTS

We included several improvements to the National Lakes Assessment between 2007 and 2012. The design was expanded to be more representative of lakes in the U.S. by including smaller lakes between 1 and 4 hectares of surface area. This change in design increased the number of lakes assessed from approximately 50,000 in 2007 to 111,818 in 2012. We added atrazine as an indicator in NLA 2012. Additional modifications included using different zooplankton sampling nets to improve our sampling method and collecting more sediment for mercury analyses.

3.7 ASSESSING CHANGES IN CONDITION BETWEEN 2007 AND 2012

Whenever possible, this report discusses changes in condition between 2007 and 2012. The smallest lakes in the 2012 assessment (1-4 hectares) were not sampled in 2007. We adjusted for this by excluding the smaller size class from the change analysis, so that the inference populations were equivalent between assessments (Figure 3.4). The 2007 and the 2012 data were assessed against the 2012 benchmarks so that the assessment endpoints were comparable. Following these adjustments, NLA analysts compared the proportion of the inference population in each of the disturbance categories to determine whether there was a change between the 2007 and the 2012 assessments.

Figure 3.4: Distribution of Lakes Among Size Classes in NLA

	1-4 Hectares	4-10 Hectares	10-20 Hectares	20-50 Hectares	>50 Hectares
NLA 2007	0	73	162	211	684
NLA 2012	87	142	173	225	411

Lakes included in the analysis of 2012 condition

Lakes included in the change analysis

4

The Condition of Lakes in the United States

In this chapter, we describe the condition of lakes based on chemical, physical, human use, and two new research biological indicators. Additionally, we compare results to NLA 2007 to indicate whether lake conditions changed (questions 1a and 2).

Results for lake condition estimate the proportion of lakes in three condition classes (least disturbed, moderately disturbed, and most disturbed) relative to either literature benchmarks or NLA-derived benchmarks.

Chapter 3 of this report and the NLA 2012 Technical Report (USEPA 2016) explain the assumptions underlying the analysis and give details on how these estimates were prepared. The estimated number of lake results are referred to as population estimates and each estimate is accompanied by a confidence interval that conveys the level of certainty in the estimate. Figure 4.1 describes how to interpret the lake condition graphics.

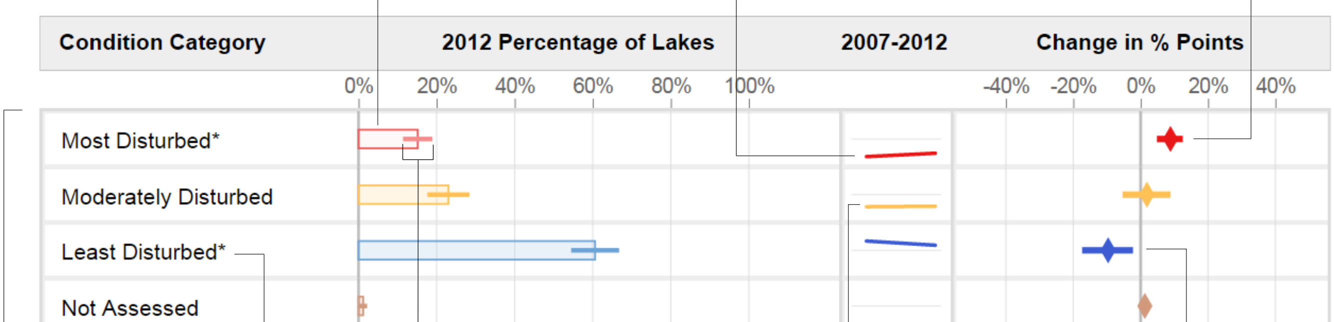
Figure 4.1: Interpreting Lake Condition Graphics

This figure describes how to interpret the graphics depicting the biological, chemical, physical, and recreational condition in lakes as well as change since NLA 2007. The change analysis only applies to lakes 4 hectares and larger because smaller lakes were not sampled in 2007.

Current Condition
The bars represent EPA's 2012 estimate for the proportion of lakes in each condition category – here, 15%.

Direction of Change
The slope graphs show the change from 2007 to 2012. Here, the gentle slope indicates a change of 8 percentage points. The sloped line will be used to display trends in future assessments.

Magnitude of Change
The diamond shows the change estimate and the line conveys the range of uncertainty. Here, the percentage of lakes in the most disturbed category increased by 8 percentage points with a confidence interval of 4 to 13.



Statistical Significance
Statistically significant change within a condition category is indicated by an asterisk (*). Here, EPA is 95% confident that the proportion of lakes in the least disturbed condition decreased from 2007 to 2012.

Confidence Intervals
The darker line represents the confidence intervals reflecting the margin of error around the point estimate. In this case, EPA is 95% certain that, in 2012, between 11% and 19% of all lakes in the target population are in the most disturbed category.

Good or Bad?
Falling to the left or right of the zero line means something different for each condition category. Here, the decrease in percentage points for lakes designated as least disturbed is undesirable, as is the increase in lakes designated as most disturbed.

Slope Graphs
Many lines will appear nearly flat signaling that there is little change. The light gray line shows the position of 50%.

4.1 CHEMICAL CONDITION INDICATORS

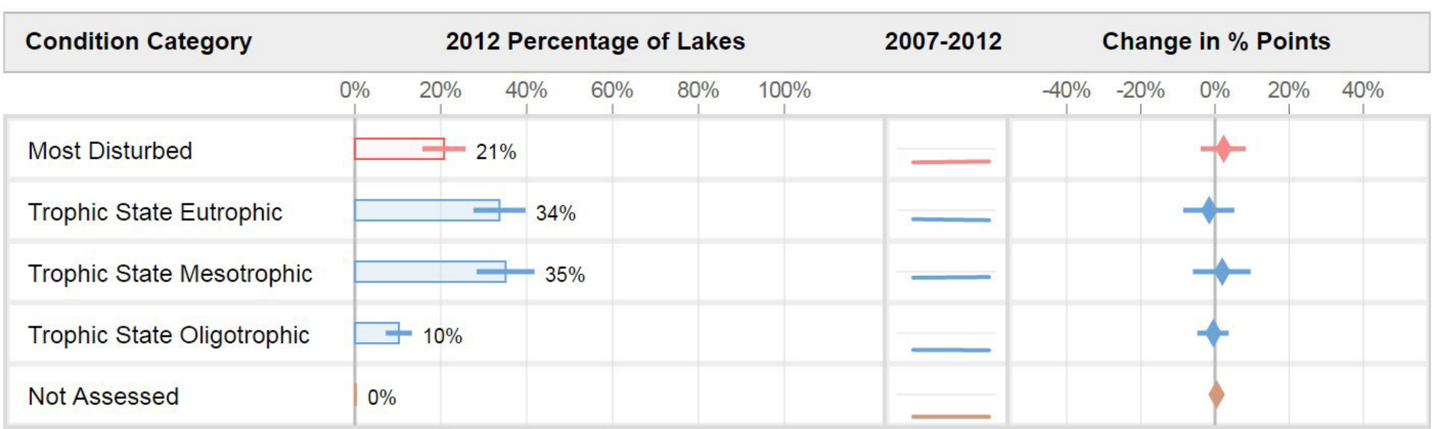
The NLA 2012 chemical condition assessment is based on information about nutrient concentrations, oxygen content, acidification, and trophic state (i.e., productivity) of lakes. In-lake measurements are compared either to reference conditions developed from a set of reference lakes in each ecoregion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

Trophic State. 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 and can be an indicator of stress conditions.

Eutrophication is a slow, natural part of lake aging, but today human influences can increase the amount of nutrients entering lakes. Human activities such as poorly managed agriculture or suburbanization of watersheds can result in high levels of nutrients 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 (DO), odor, and fish kills.

We use chlorophyll-*a* concentration as a surrogate for measuring algal biomass and thus to estimate the trophic status of lakes. Based on published chlorophyll-*a* benchmarks, 10% of U.S. lakes are classified as oligotrophic, 35% are mesotrophic, 34% are eutrophic, and 21% are hypereutrophic (i.e., most disturbed, Figure 4.2). An analysis of trophic state shows no statistically significant difference in the percentage of lakes in the most disturbed (i.e., hypereutrophic) category between 2007 and 2012.

Figure 4.2: Trophic State | National Condition Estimates



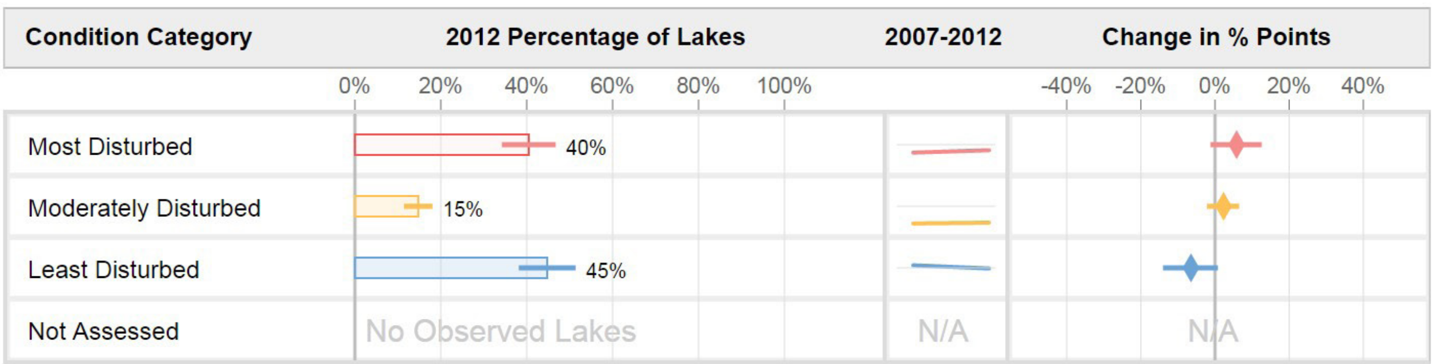
Phosphorus and Nitrogen. For this assessment, nutrients in the form of total phosphorus and total nitrogen were evaluated as indicators of the chemical condition of lakes. Phosphorus and nitrogen are critical nutrients required for all life. In appropriate quantities, these nutrients power the primary 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.

In many lakes, phosphorus is 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. Results indicate that 45% of lakes are in least disturbed condition, 15% are in a moderately disturbed condition, and 40% are in the most disturbed condition for phosphorus (Figure 4.3).

An analysis of total phosphorus shows no statistically significant difference in the percentage of lakes in the most disturbed category between 2007 and 2012.

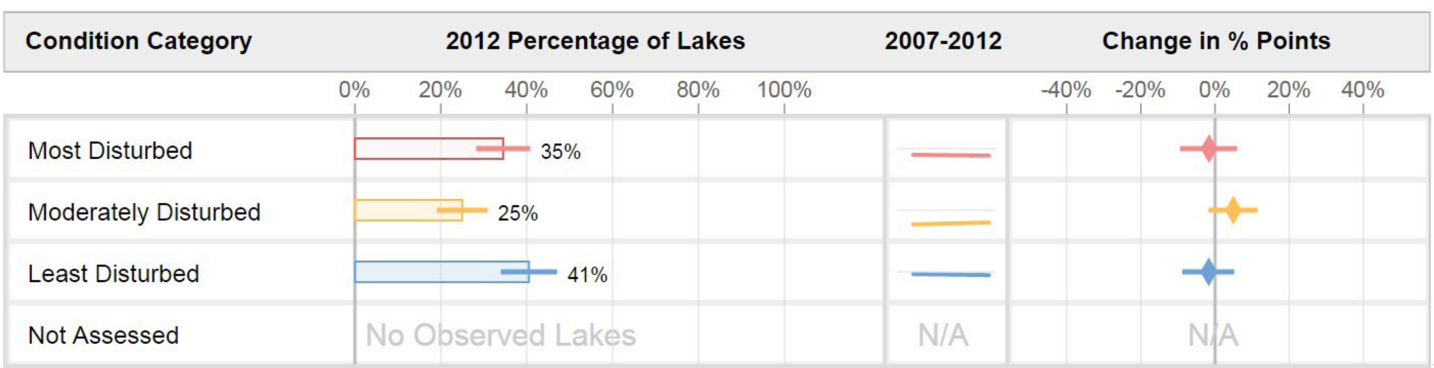
While there has been no detectable change in the proportion of lakes in each condition category, additional in-depth analyses of the NLA data indicate striking differences in the distribution of phosphorus concentrations, particularly at the low end of the phosphorus gradient (Stoddard et al. 2016). Increases in phosphorus in previously low phosphorus lakes raised the median concentration across all lakes from 20 µg/L in 2007 to 37 µg/L in 2012. Equally striking is the dramatic decline in the percentage of naturally oligotrophic lakes (<10 µg/L of TP L-1), where the proportion changed from 24.9% to 6.7% of the population. Please see Stoddard et al. (2016) for details of the analysis and discussion of potential causes for these differences between assessments.

Figure 4.3: Phosphorus (Total) | National Condition Estimates



Other lakes are limited by nitrogen. In these lakes, modest increases in available nitrogen might yield the same effects that increases in phosphorus do elsewhere. NLA 2012 indicates that 41% of lakes exhibit a least disturbed condition, 25% are in a moderately disturbed condition, and 35% are in the most disturbed condition for nitrogen (Figure 4.4). An analysis of total nitrogen shows no statistically significant difference in the percentage of lakes in the most disturbed category between 2007 and 2012.

Figure 4.4: Nitrogen (Total) | National Condition Estimates

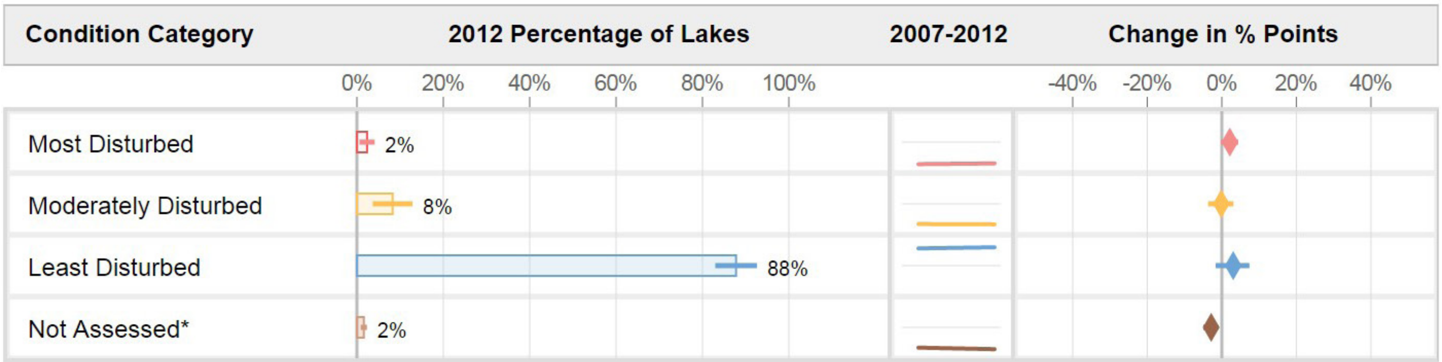


Dissolved Oxygen. Dissolved oxygen, or DO, is considered an important measurement of water quality because it is essential for aquatic communities. Without oxygen, a lake would be devoid of fish and macroinvertebrates. Aquatic organisms have differing DO requirements for optimal growth and reproduction. 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.

Eighty-eight percent of lakes have high levels of dissolved oxygen (DO), which is essential for healthy aquatic communities.

Eighty-eight percent of lakes have high levels of surface (epilimnetic) DO (are in the least disturbed condition); 8% are moderately disturbed; 2% are in the most disturbed condition; and 2% of lakes were not assessed (Figure 4.5). An analysis of DO shows no statistically significant difference in the percentage of lakes in the most disturbed category between 2007 and 2012.

Figure 4.5: Oxygen (Dissolved) | National Condition Estimates

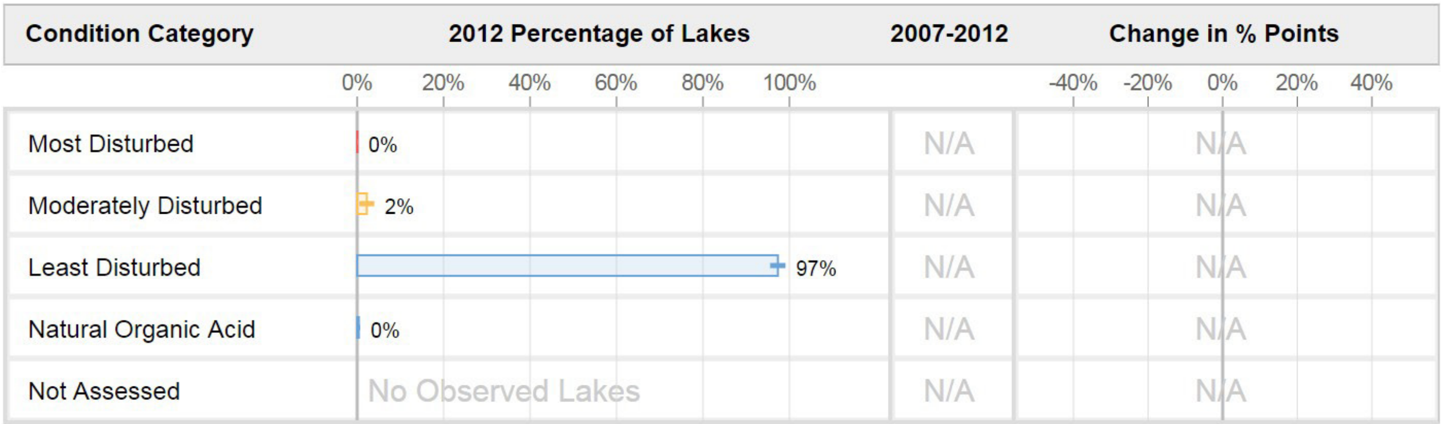


** Reflects a statistically significant change between 2007 and 2012 (95% confidence).*

Acidification. Lake acidification can be an important indicator of lake condition. Acid rain and acid mine drainage are major sources of acidifying compounds that can change the pH of lake water, impacting fish and other aquatic life. Acid-neutralizing capacity (ANC) serves as an indicator of sensitivity to changes in pH. The ANC of a lake is determined by the soil and underlying geology of the surrounding watershed. Lakes with high levels of dissolved bicarbonate ions (e.g., limestone watersheds) are able to neutralize acid depositions and buffer the effects of acid rain. Conversely, watersheds that are rich in granites and sandstones contain fewer acid-neutralizing ions and have low ANC; these systems have a predisposition to acidification. Maintaining stable and sufficient ANC is important for fish and aquatic life because ANC protects or buffers against pH changes in the water body. Most aquatic organisms function at the optimal pH range of 6.5 to 8.5. Sufficient ANC in surface waters will buffer acid rain and prevent pH levels from straying outside this range. In naturally acidic lakes, the ANC may be quite low, but the presence of natural organic compounds in the form of dissolved organic carbon, or DOC, can mitigate the effects of pH fluctuations.

Results indicate that almost all of the nation's lakes – 97% – can be classified in the least disturbed condition for acidification (Figure 4.6). A 2012 vs. 2007 change analysis was not conducted for acidification.

Figure 4.6: Acidification | National Condition Estimates



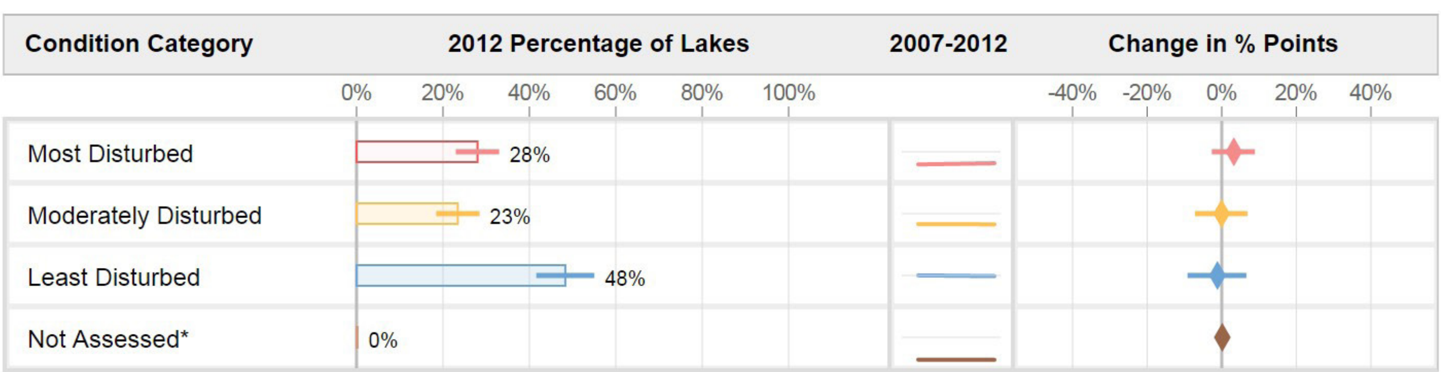
4.2 PHYSICAL HABITAT CONDITION INDICATORS

The condition of lakeshore habitats provides important information relevant to lake biological health. For the NLA 2012, physical habitat condition was assessed based on observations of five indicators: riparian (lakeshore) vegetation cover, littoral (shallow water) habitat, lake drawdown (lowering of lake levels), habitat disturbance (extent and intensity of human activity), and habitat complexity (a combined index of condition at the land-water interface). Although lake drawdown is a new indicator for 2012, data are available from 2007 that allowed analysts to develop results from both periods.

Riparian Vegetation Cover. Evaluation of riparian or lakeshore vegetation cover is based on observations of three layers of vegetation – understory grasses and forbs, mid-story non-woody and woody shrubs, and over-story trees. Although generally shorelines are in better condition when vegetation cover is high in all layers, not all three layers occur in all areas of the country. For example, in the Northern Plains there is typically no natural over-story tree cover; in the West, steep rocky shores are the norm for high-mountain or canyon lakes. These natural features have been factored into the calculation of the riparian vegetation cover indicator.

Nationally, 48% of lakeshore habitats are in a least disturbed condition; 23% are in a moderately disturbed condition; 28% are in most disturbed condition; and <1% of lakeshores were not assessed (Figure 4.7). An analysis of riparian vegetation cover indicates no significant difference in the percentage of lakes in the most disturbed category between 2007 and 2012[1].

Figure 4.7: Riparian Vegetation Cover | National Condition Estimates



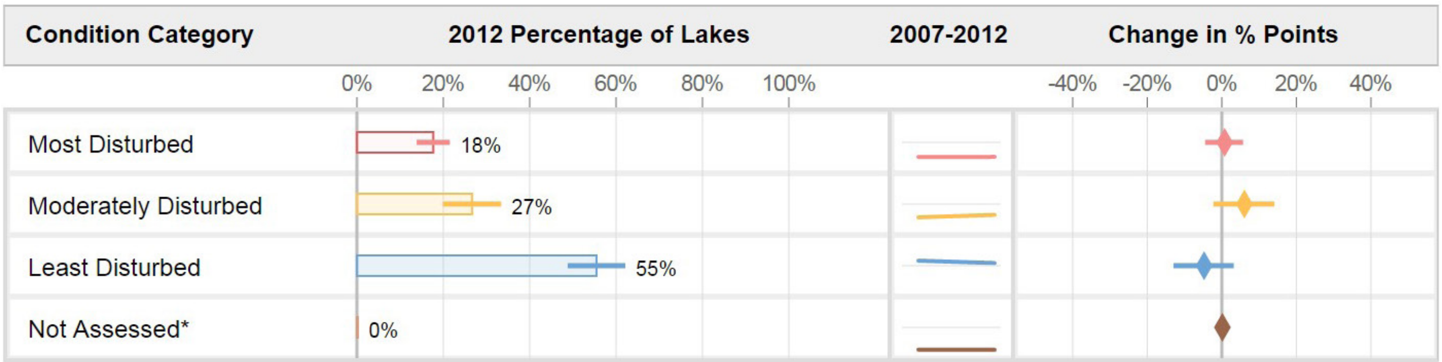
** Reflects a statistically significant change between 2007 and 2012 (95% confidence).*

[1] NLA 2007 did not require physical habitat observations on lakes >5,000 ha. NLA 2012 increased this limit to >10,000 ha. This slight methodological change is associated with a small, significant increase in the proportion of lakes assessed for habitat measures.

Shallow Water Habitat. The shallow water habitat indicator examines the quality of the shallow edge of the lake by using 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 many complex ecological niches. Like the riparian or lakeshore habitat indicator, the shallow water indicator is related to conditions in reference lakes and is modified regionally to account for differing expectations of natural condition.

The NLA 2012 finds that shallow water habitats are in a least disturbed condition in 55% of U.S. lakes; are moderately disturbed in 27% of lakes; and are most disturbed in 18% of lakes (Figure 4.8). An analysis of shallow water habitat shows no statistically significant difference in the percentage of lakes in the most disturbed category between 2007 and 2012.

Figure 4.8: Shallow Water Habitat | National Condition Estimates

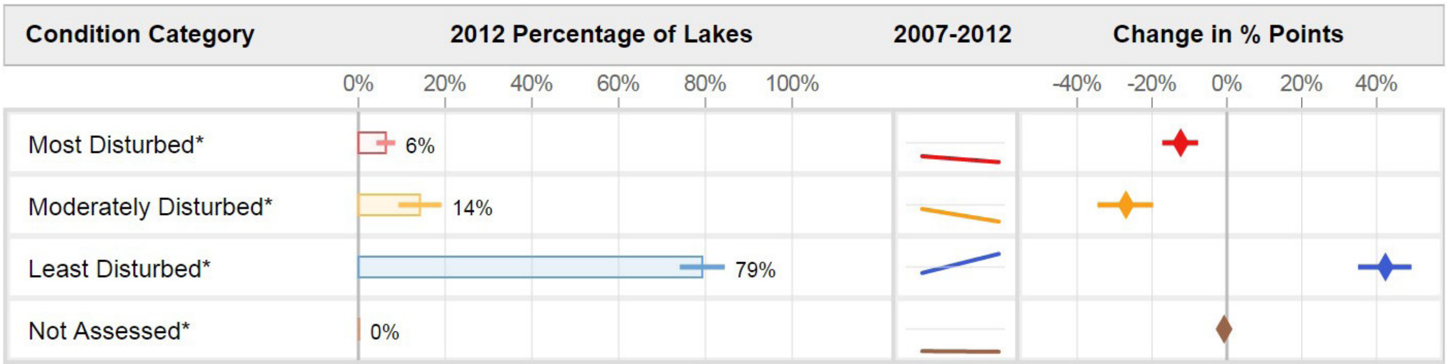


** Reflects a statistically significant change between 2007 and 2012 (95% confidence).*

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.

Most U.S. lakes (79%) showed least disturbed levels of lake drawdown in 2012; 14% showed moderately disturbed levels; and 6% showed most disturbed levels of lake drawdown (Figure 4.9). An analysis of lake drawdown exposure shows a statistically significant lower (-12.9%) percentage of lakes in the most disturbed category between 2007 and 2012.

Figure 4.9: Lake Drawdown Exposure | National Condition Estimates

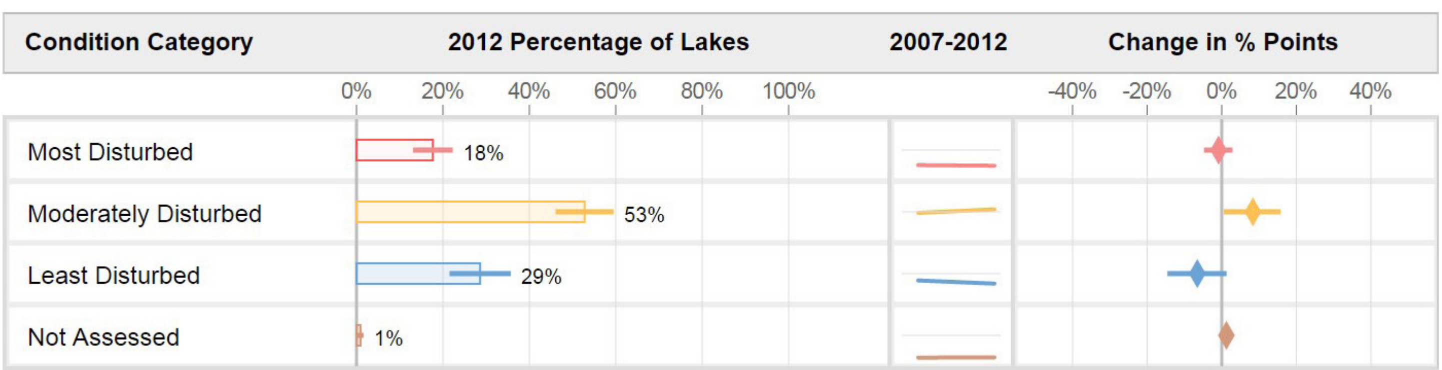


** Reflects a statistically significant change between 2007 and 2012 (95% confidence).*

Lakeshore Disturbance. The lakeshore disturbance indicator reflects direct human alteration of the lakeshore itself. These disturbances can range from minor changes, such as the removal of a few trees to develop a picnic area, to major alterations, such as the construction of a large lakeshore residential complex. The effects of lakeshore development on the quality of lakes include excess sedimentation, loss of native plants, alteration of native plant communities, loss of vegetation structure and complexity, and modifications to substrate types. These impacts, in turn, can negatively affect fish, wildlife, and other aquatic communities.

Across the lower 48 states, 29% of lakeshores are in the least disturbed condition; 53% show moderately disturbed levels; 18% are most disturbed; and 1% of lakeshores were not assessed (Figure 4.10). An analysis of lakeshore disturbance shows no statistical difference in the percentage of lakes in the most disturbed category between 2007 and 2012.

Figure 4.10: Lakeshore Disturbance | National Condition Estimates



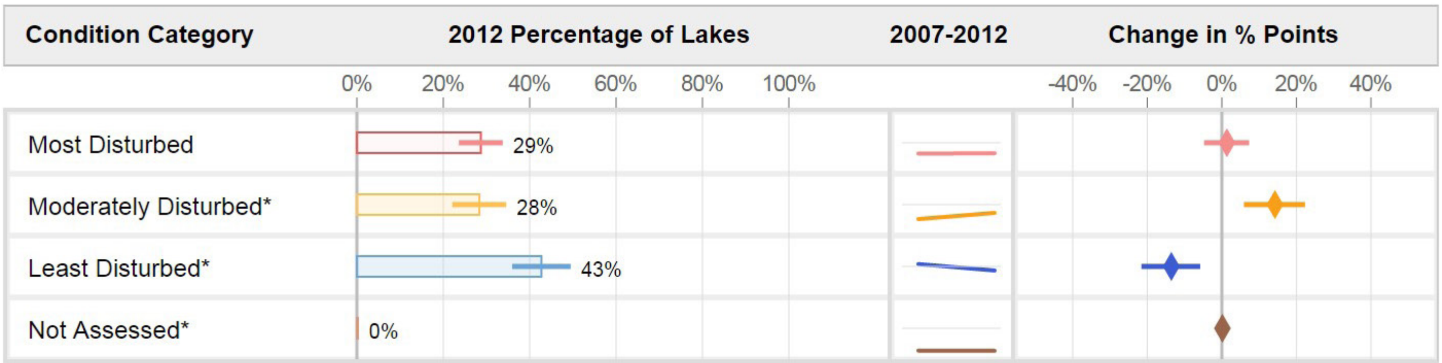




Lake Habitat Complexity. The habitat complexity indicator combines lakeshore and shallow water indictors described above to estimate the amount and variety of all cover types at the water's edge (on land and in water). This indicator is compared to NLA-derived regional benchmarks.

For lake habitat complexity at the land-water interface, 43% of lakes are in a least disturbed condition; 28% are in moderately disturbed condition; and 29% are in a most disturbed condition (Figure 4.11). An analysis of lake habitat complexity shows no statistically significant difference in the percentage of lakes in the most disturbed category between 2007 and 2012. There were fewer lakes in the least disturbed category and more lakes in the moderately disturbed category.

Figure 4.11: Lake Habitat Complexity | National Condition Estimates



** Reflects a statistically significant change between 2007 and 2012 (95% confidence).*

4.3 RECREATIONAL CONDITION INDICATORS

Lakes are used for a wide variety of recreational purposes, including swimming, waterskiing, windsurfing, fishing, and boating. Contaminants in lakes can pose a potential threat to humans, pets, and wildlife. The NLA 2012 assessed algal toxins, mercury in sediment, and atrazine as indicators of human use or recreational condition in U.S. lakes.

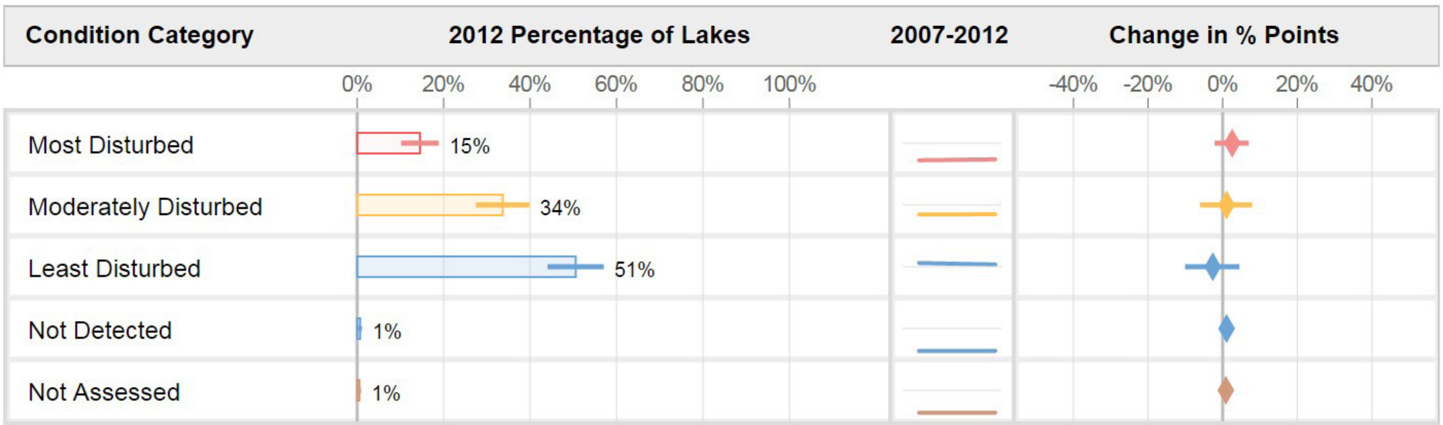
Algal Toxins. Algae and cyanobacteria are a natural part of freshwater ecosystems. Eutrophication in lakes often results in conditions that favor their growth. Many algal blooms are unsightly, but not toxic. However, some blooms of cyanobacteria can be harmful to people and animals. Exposure to cyanobacteria toxins may produce skin rashes, eye irritations, respiratory symptoms, gastroenteritis, and liver and kidney failure.

The World Health Organization (WHO) established recreational exposure risk guidelines for chlorophyll-*a*, cyanobacterial cell counts, and microcystin. 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 least disturbed condition exhibits a low risk of exposure; a lake in a most disturbed condition has a high exposure potential.

The algal toxin microcystin was detected in 39% of lakes, but very rarely at levels that represent moderate or high levels of exposure risk to the recreating public.

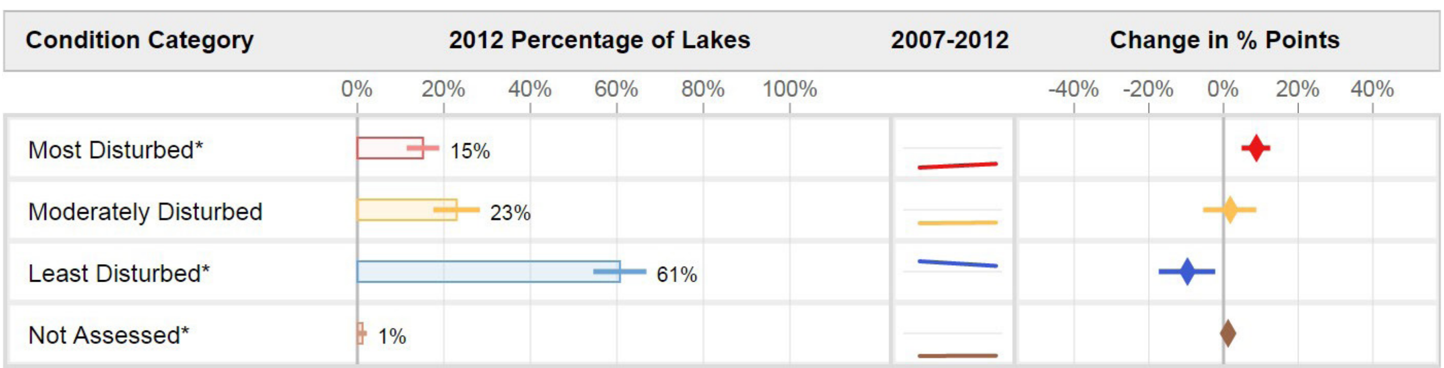
Using the WHO literature benchmarks, the level of risk associated with exposure to algal toxins varies by indicator. For chlorophyll-*a*, 15% of lakes are in the most disturbed condition (i.e., pose a high risk of exposure according to the WHO literature benchmarks), 34% pose a moderate risk, and 51% are in the least disturbed condition (Figure 4.12). An analysis of chlorophyll-*a* shows no statistical difference in the percentage of lakes in the most disturbed category between 2007 and 2012.

Figure 4.12: Chlorophyll-*a* (Risk) | National Condition Estimates



Using cyanobacteria cell counts as an indicator of risk for exposure to algal toxins, 15% of lakes are in the most disturbed condition (i.e., pose a high risk of exposure to the public); 23% indicate moderately disturbed condition; 61% are in the least disturbed condition; and 1% were not assessed (Figure 4.13). An analysis of cyanobacteria cell density shows a statistically significant increase (+8.3%) in the percentage of lakes in the most disturbed category between 2007 and 2012.

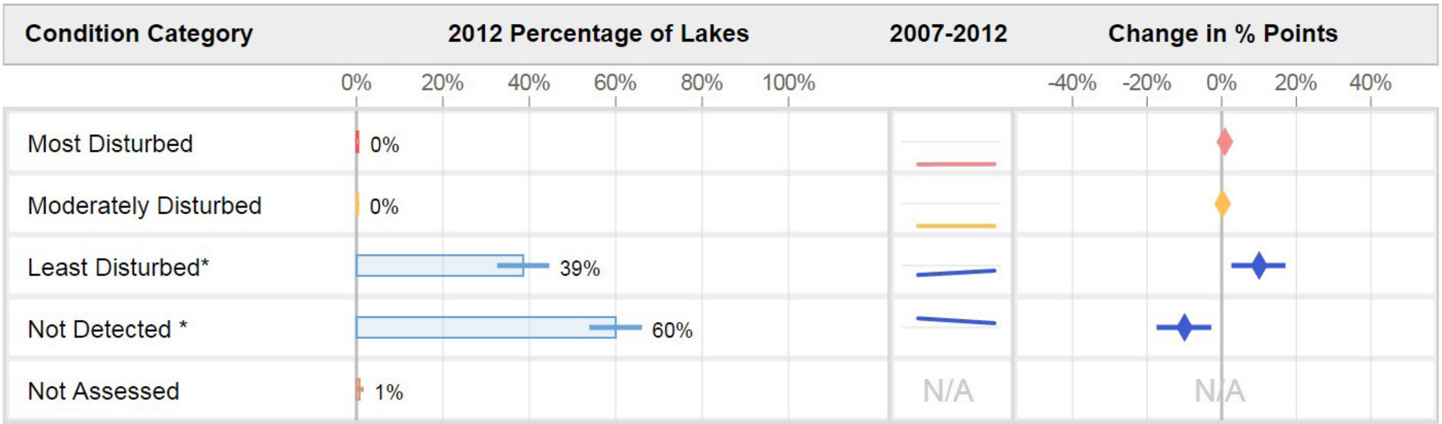
Figure 4.13: Cyanobacteria (Risk) | National Condition Estimates



** Reflects a statistically significant change between 2007 and 2012 (95% confidence).*

Microcystin, a direct measure of an algal toxin, was detected in 39% of lakes. Less than one percent of lakes are in the most and moderately disturbed condition (i.e., have a high or moderate risk of exposure) and 99% are either least disturbed, with a low risk of exposure, or show no detection of microcystin (Figure 4.14). Although there was a significant increase in the detection of microcystin (+9.5%), the analysis of microcystin shows no statistically significant difference in the percentage of lakes in the most disturbed category between 2007 and 2012.

Figure 4.14: Microcystin (Risk) | National Condition Estimates

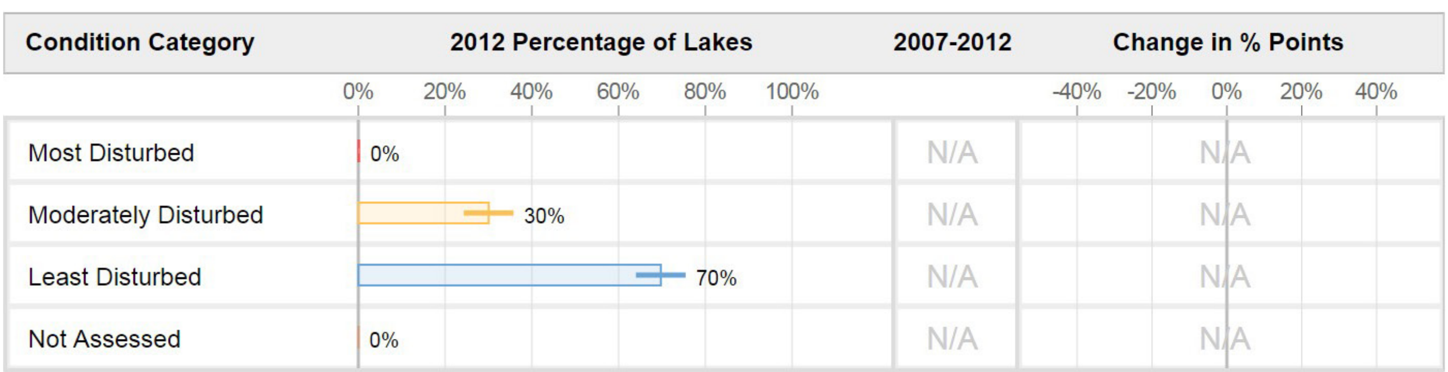


** Reflects a statistically significant change between 2007 and 2012 (95% confidence).*

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. According to studies by the U.S. Geological Survey, atrazine is the most frequently detected pesticide in streams and shallow groundwater (Gilliom et al. 2006). Atrazine can also end up in lakes. We added atrazine to the NLA 2012 to examine the frequency of detection of atrazine in lakes across the U.S. during the summer index period.

Atrazine was detected in 30% of lakes and not detected in 70% of lakes (least disturbed). Less than one percent of lakes are in the most disturbed condition (where atrazine has a high risk of affecting plant communities) according to the EPA-proposed level of concern for plants in freshwaters (4 ppb) (Figure 4.15). Because atrazine is a new indicator in the NLA 2012, a comparison with 2007 is not possible for atrazine measures.

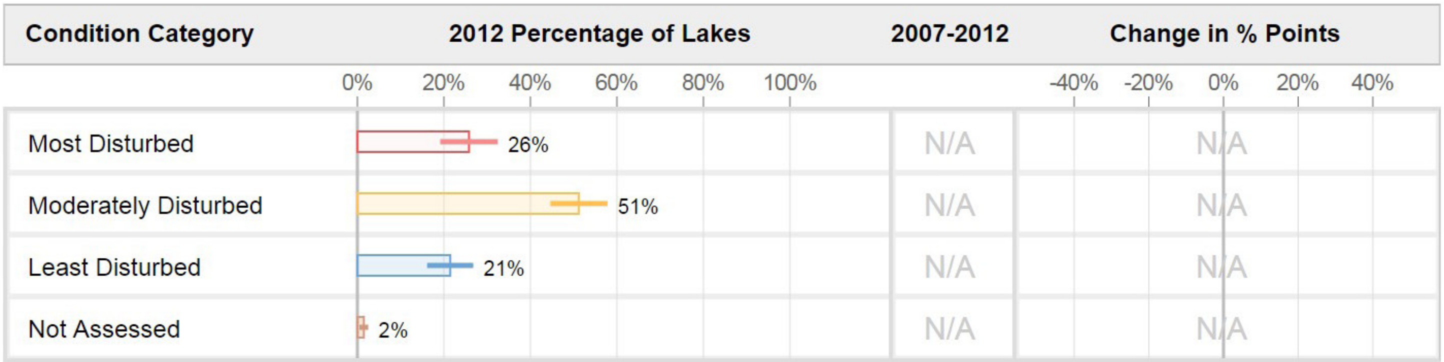
Figure 4.15: Atrazine (Exceed 4 ppb) | National Condition Estimates



Mercury 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 into water or is washed into water. Once mercury 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.

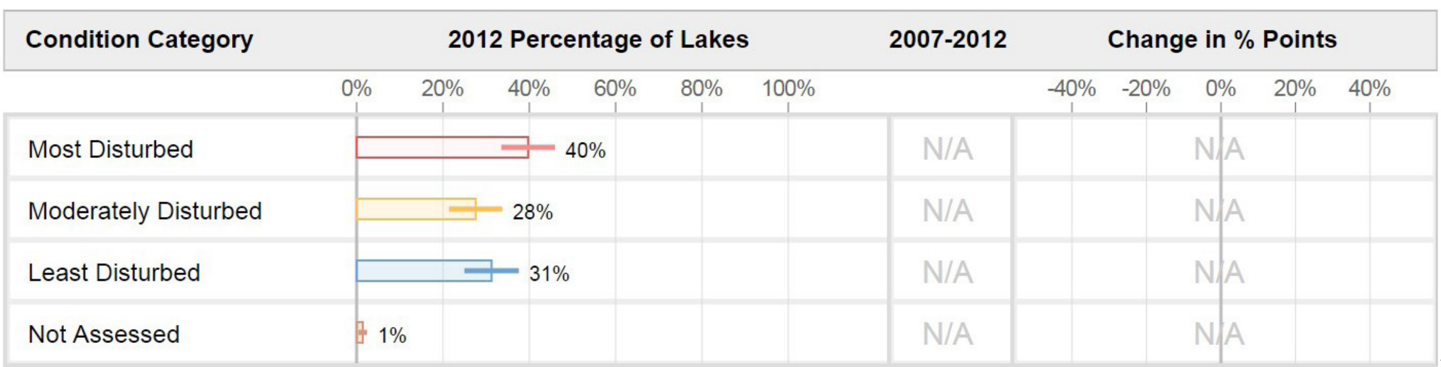
For total mercury in sediment, 21% of lakes are in the least disturbed condition; 51% indicate moderately disturbed condition; 26% are in the most disturbed condition; and 2% of lakes were not assessed (Figure 4.16). A change analysis was not possible for total mercury because of different sampling protocols between 2007 and 2012.

Figure 4.16: Mercury (Total) | National Condition Estimates



For methylmercury in sediment, 31% of lakes are in the least disturbed condition; 28% are moderately disturbed; 40% are in the most disturbed condition; and 1% of lakes were not assessed (Figure 4.17). A change analysis was not possible for methylmercury because of different sampling protocols between 2007 and 2012. Additional research is needed to evaluate the relationships between mercury in sediments and other lake conditions.

Figure 4.17: Mercury (Methyl) | National Condition Estimates



4.4 BIOLOGICAL CONDITION RESEARCH INDICATORS

Biological indicators are commonly used in stream and river water quality assessment programs, but they are not typically used in lake monitoring programs. Aquatic organisms integrate multiple water quality factors over time, such that communities reflect their environment. Because of this assessment benefit, we developed two new biological research indicators for NLA 2012. The sensitivity of these new indicators to environmental factors (e.g., the effect of soft sediment versus cobble substrate) and biological variables (e.g., the effect of fish predation) is an area of active research. For this reason, we present them as research indicators in this report. In future assessments, we may revise and refine these biological indicators to reflect new understanding.

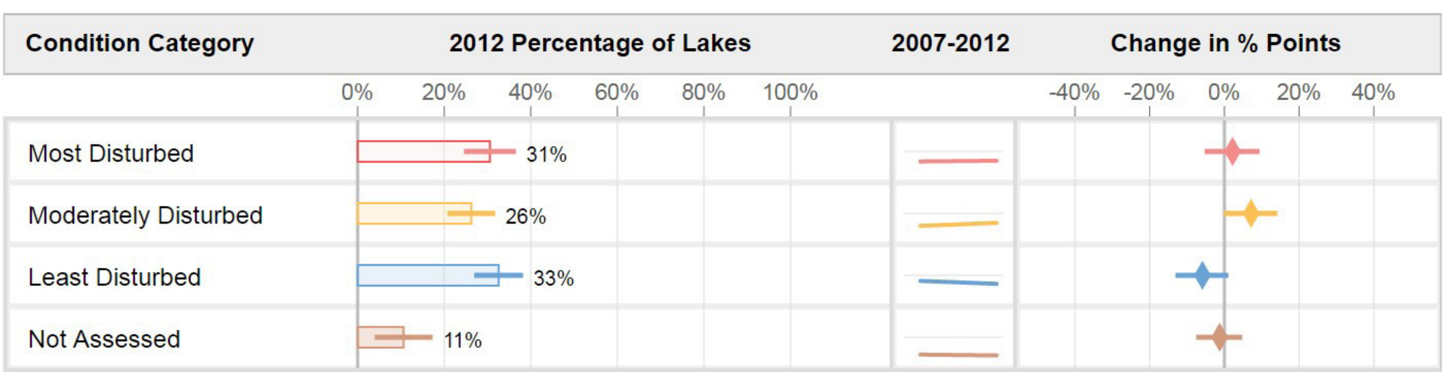
The biology of a lake can be characterized by the presence, number, and diversity of macroinvertebrates, algae, vascular plants, and other organisms that together provide information about the health and productivity of the lake ecosystem. The new NLA 2012 biological condition assessment indicators are based on information from two biological communities: benthic macroinvertebrates in the littoral (shallow water) zone, and zooplankton from a pelagic (open water) zone. In order to assess biological health, NLA analysts combined several measures into indices.

Benthic Macroinvertebrates. Benthic macroinvertebrates include aquatic insects in their larval stage, small aquatic mollusks (snails and clams), crustaceans (e.g., crayfish), aquatic worms, and leeches. They live on and under the rocks, sediments, and vegetation at the bottom of lakes. These organisms were selected as indicators of biological condition because they spend most of their lives in water and are thought to respond to human disturbance. Given their broad geographic distribution, abundance, ease of collection, and connection to fish and other aquatic organisms (e.g., as a source of food), these organisms may serve as good indicators of the biological quality of shoreline habitats in lakes.

To create the benthic invertebrate indicator, NLA analysts selected measures of six different aspects of macroinvertebrate community structure: taxonomic composition; taxonomic diversity; feeding groups; habits/habitats; taxonomic richness; and pollution tolerance. The measures chosen for each of these aspects vary among ecoregions and are described in detail in the NLA 2012 Technical Report (USEPA 2016).

According to the benthic macroinvertebrate indicator, we estimate that 33% of U.S. lakes are in least disturbed condition; 26% are in moderately disturbed condition; 31% are in a most disturbed condition; with 11% of lakes not assessed (Figure 4.18). An analysis of benthic invertebrates shows no statistically significant difference in the percentage of lakes in the most disturbed category between 2007 and 2012.

Figure 4.18: Benthic Macroinvertebrates | National Condition Estimates



Zooplankton. Zooplankton are small animals in the water column that constitute an important element of the aquatic food web. These organisms serve as an intermediary species, transferring energy from algae (primary producers) to larger invertebrate predators and fish. Zooplankton are sensitive to changes in the lake ecosystem. Given their broad geographic distribution, abundance, ease of collection, and connection to fish and other aquatic organisms, these organisms may serve as good indicators of the biological quality of open water in lakes. To determine the zooplankton indicator, NLA analysts selected six measures of community structure: abundance, taxonomic richness, trophic guild, and three taxonomic measures (cladoceran, copepod, and rotifer). The specific metrics chosen for each of these characteristics varied among the ecoregions and are described in detail in the NLA 2012 Technical Report.

According to the zooplankton indicator, 53% of lakes in the U.S. are in a least disturbed condition; 27% are in a moderately disturbed condition; and 21% are in a most disturbed condition (Figure 4.19). A change analysis was not possible for the zooplankton metric because different sampling protocols were used in 2007 and 2012.

Figure 4.19: Zooplankton | National Condition Estimates

Condition Category	2012 Percentage of Lakes	2007-2012	Change in % Points
Most Disturbed	21%	N/A	N/A
Moderately Disturbed	27%	N/A	N/A
Least Disturbed	53%	N/A	N/A
Not Assessed	0%	N/A	N/A

5

Comparing Conditions Across Ecoregions

The design of the NLA allows us to explore indicators regionally as well as nationally (Question 1b). In this chapter, we provide a simple example of how new NLA graphics can be used to consider questions about lakes at the scale of ecological regions.

Results for all of the NLA 2012 indicators for each ecoregion are presented in a size plot (Figure 5.1). Similar to heat maps that use color to represent data values, a size plot provides an immediate visual summary of complex data sets. In this case, the size of each box represents the proportion of lakes in most disturbed condition for the related indicator – the larger the box, the more lakes NLA found to be in most disturbed condition. This graphic allows us to look at patterns in data across ecoregions and indicators at a glance.

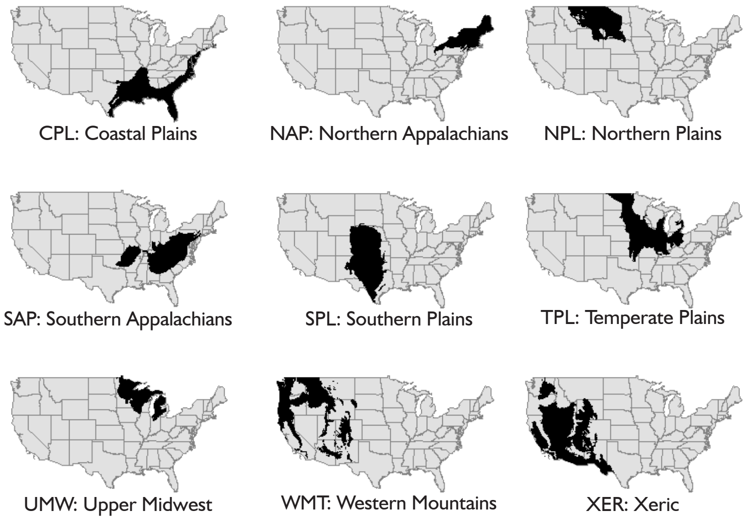
Figure 5.1: Ecoregion Conditions at a Glance

Comparing NLA results across ecoregions and indicators can illuminate patterns that might otherwise remain hidden. Below, read more about the value of ecoregion analysis and a graphical tool for high-level comparisons.

What Are Ecoregions?

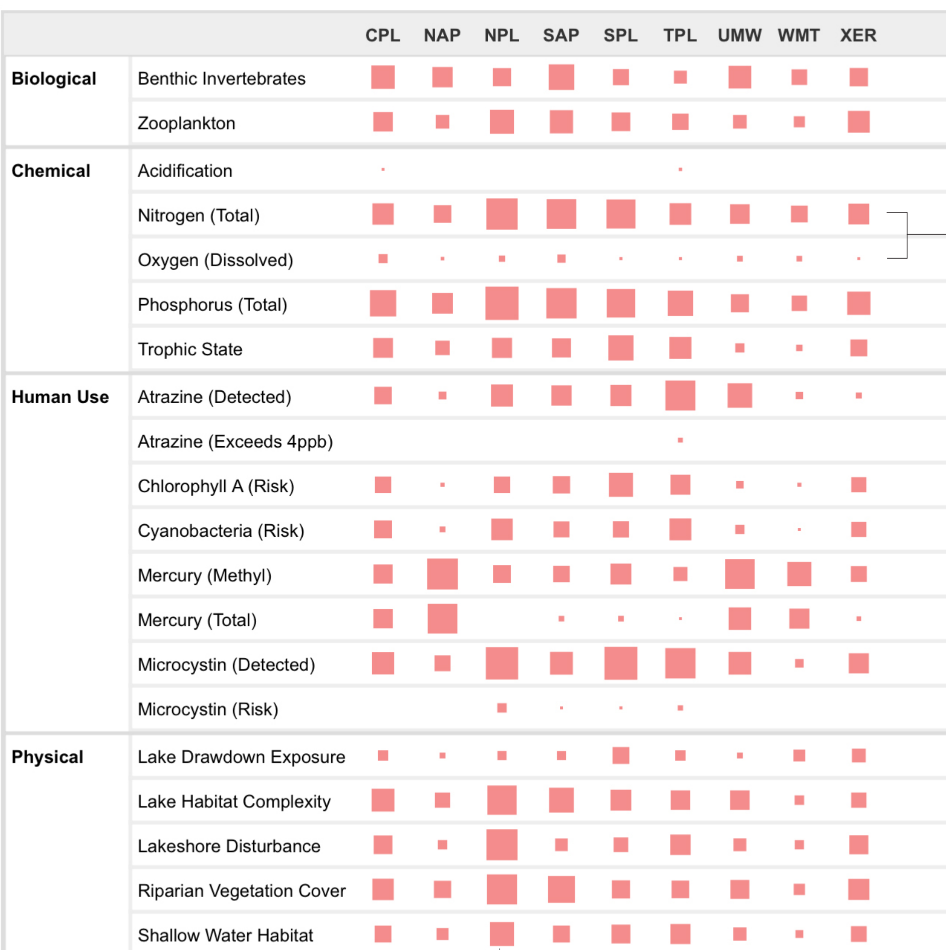
Ecoregions are areas that contain similar environmental characteristics and are defined by common natural characteristics such as climate, vegetation, soil type, and geology. Because of the diversity of landscapes, it is important to assess waterbodies in their own geographical setting. The NLA was designed to report findings on an ecoregional scale.

By looking at lake conditions in ecoregions, decision-makers can begin to understand patterns based on landform and geography, and whether key lake condition challenges are isolated or widespread. The maps shown to the right represent the regions displayed in the size plot below.

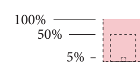


High-Level View of Conditions Across Ecoregions and Indicators

This graphic summarizes the percentage of lakes in most disturbed condition for each indicator and ecoregion. Use it to spot high-level differences, similarities and outliers. Then dig deeper with the interactive graphics at the NLA website: https://www.epa.gov/national-aquatic-resource-surveys/nla.



The area of the squares is proportionate to the point estimate for lakes in the most disturbed condition.

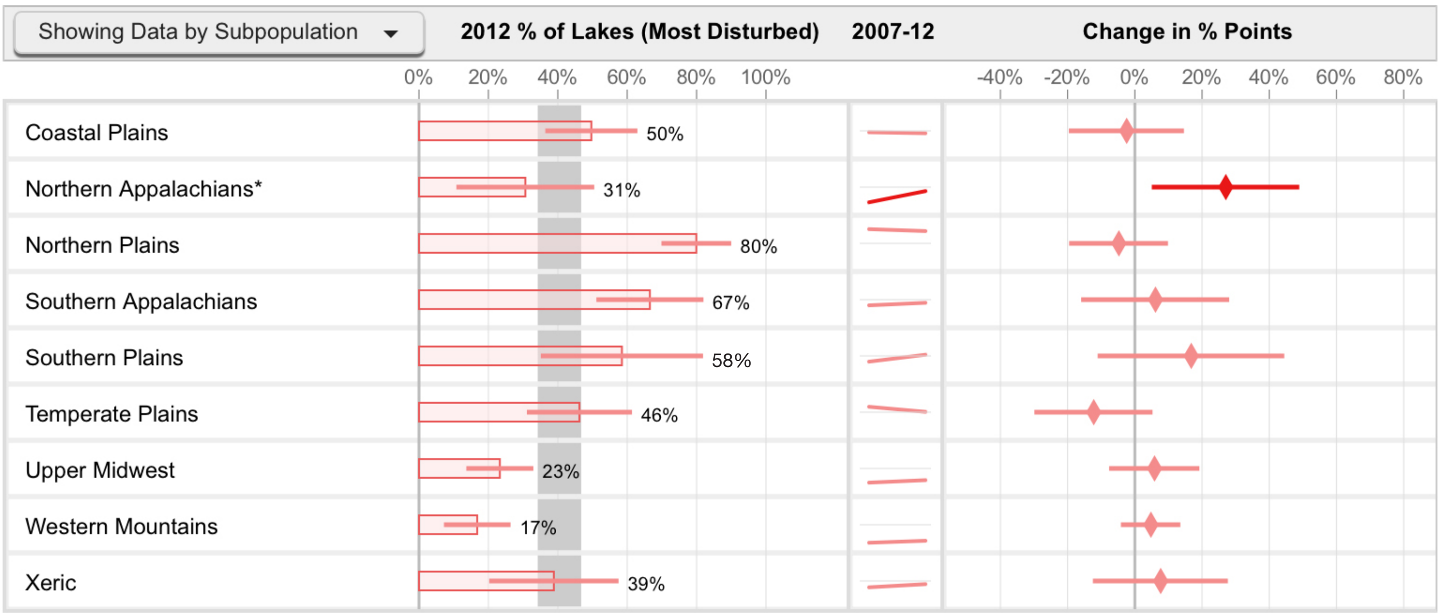


Large proportions of lakes in each ecoregion are in the most disturbed condition for Nitrogen (Total), in contrast with consistently low proportions for Oxygen (Dissolved). We see a similar pattern when comparing the two microcystin indicators.

The column for Northern Plains (NPL) shows a high proportion of lakes in the most disturbed condition for many physical indicators, a pattern that stands out from other ecoregions. What patterns do you see?

Next, we can explore regional differences in more detail. Nutrient pollution is common across the United States, but levels vary widely among ecoregions. For total phosphorus (Figure 5.2), NLA results indicate that the Northern Plains has the highest proportion of lakes in the most disturbed condition (80%). The Northern Plains and the Southern Appalachians have statistically significant higher proportions of lakes in a most disturbed condition for phosphorus than is observed across the national data set (the national confidence interval, surrounding the national point estimate of 40%, is noted by the solid gray band that falls between 34% and 47% in Figure 5.2). The Upper Midwest and the Western Mountains have statistically significant lower proportions of lakes in the most disturbed category for phosphorus than observed nationally. A statistically significant increase (+27%) in the proportion of lakes in the most disturbed condition is observed in the Northern Appalachians.

Figure 5.2: Phosphorus (Total) | Ecoregion Condition Estimates

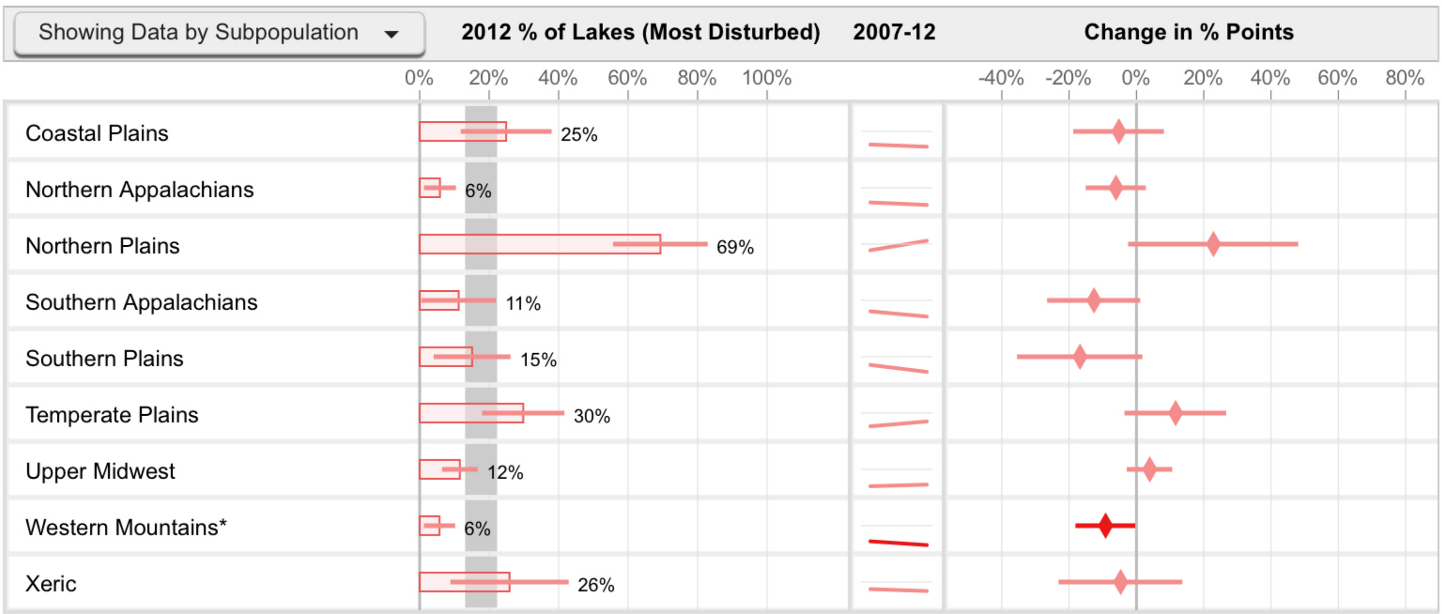


** Reflects a statistically significant change between 2007 and 2012 (95% confidence).*

Some NLA results show big differences among regions in the U.S. For example, the proportion of lakes in the most disturbed condition for total phosphorous ranges from 80% in the Northern Plains to 17% in the Western Mountains.

Levels of lakeshore disturbance also vary among ecoregions (Figure 5.3). The Northern Plains has the highest proportion of lakeshores in the most disturbed condition (69%), and this is a statistically significant difference from national levels (the national confidence interval, which surrounds the national point estimate of 18%, is noted by the solid gray band that falls between 13% and 22% in Figure 5.3). The Northern Appalachians (6%) and the Western Mountains (6%) had statistically significant lower proportions of lakeshores in the most disturbed condition category compared to national levels. A significant decrease (-9%) in the proportion of lakeshores in the most disturbed condition is observed in the Western Mountains.

Figure 5.3: Lakeshore Disturbance | Ecoregion Condition Estimates



** Reflects a statistically significant change between 2007 and 2012 (95% confidence).*

6

Assessment Results and Future Data Uses




The NLA offers a unique opportunity to frame discussions and planning strategies across jurisdictional lines. It is an evaluation of the collective successes of management efforts to protect, preserve, or restore water quality. The NLA condition results provide information to understand the condition of lakes in the U.S.

6.1 CURRENT CONDITION AND CHANGE

While many lakes are in good condition, the NLA indicates that a substantial portion of lakes in the U.S. are in a most disturbed condition for nutrients; 40% of lakes contain excessive total phosphorus concentrations and 35% of lakes have excessive nitrogen concentrations. NLA indicates that 21% of the population of lakes are hypereutrophic. For research biological measures, we find that 31% and 21% of lakes are in the most disturbed condition based on benthic macroinvertebrate and zooplankton, respectively.

An analysis of change between 2007 and 2012 assessments indicates that the proportion of lakes in the most disturbed condition did not change significantly for most indicators on a national scale. The lack of change might be because lakes are slow to change. There were three exceptions to this pattern. First, there was a significant 8.3% increase in the percentage of lakes in the most disturbed condition based on cyanobacteria cell density, an indicator of risk to exposure to algal toxins. There was also a significant 9.5% increase in the detection of an algal toxin, microcystin, among lakes in 2012; however, concentrations of this algal toxin remained low and exceeded WHO recreational levels of concern in both assessments in less than 1% of lakes. The third exception was a significant 12.9% decrease in the percentage of lakes in the most disturbed category for lake drawdown exposure. We encourage additional investigation into the causes and consequences of these noted changes.

6.2 ASSOCIATIONS BETWEEN STRESSORS AND BIOLOGICAL CONDITION

In this section, we evaluate which most disturbed environmental conditions, or stressors evaluated in NLA, are associated with degraded biological condition in lakes (Question 3). This simple analysis relies on the new research indicators for biological condition and could be updated as we refine our understanding of the biological measures. We rank these stressors in terms of the benefits expected to be derived from reducing or eliminating them.

For the NLA, analysts applied three approaches to rank stressors. The first looks at the extent of lakes in the most disturbed condition for chemical, physical, and human use measures, e.g., what proportion of lakes have excess phosphorus concentrations. The second examines the severity of the impact from an individual stressor when it is present, e.g., how severe is the biological impact when excess phosphorus levels occur. Ranking ultimately requires taking both of these perspectives into consideration. The third approach involves attributable risk, which is a value derived by combining the first two risk values into a single number for ranking across lakes.

Throughout this section, relative and attributable risks of chemical and physical stressors to the benthic macroinvertebrate indicator are assessed and reported as if the stressors were entirely independent. Consequently, the attributable risk percentages do not sum to 100%. In reality, lakes typically experience multiple stresses simultaneously, resulting in cumulative effects that cannot easily be attributed to a single stressor. Similar results for zooplankton are available online.






6.2.1 Relative Extent of Most Disturbed Condition

Relative extent depicts the percentage of lakes in the most disturbed condition and is a way of evaluating how pervasive a particular condition is. An indicator with a high relative extent is widespread nationally. Conversely, indicators that occur either in a small area or infrequently across a wide area will have lower relative extent estimates.

The NLA indicators with the most widespread occurrence are phosphorus, methylmercury in sediments, and nitrogen, which are in the most disturbed condition in 40%, 40%, and 35% of lakes, respectively (Figure 6.1).

6.2.2 Relative Risk

The evaluation of simplified relative risk ratios is a way to estimate the severity of effects. Relative risk conveys the likelihood of having poor biological condition when a particular stressor is high. For example, one can examine the likelihood of having poor biological conditions when phosphorus concentrations are high compared with the likelihood of poor biological conditions when phosphorus concentrations are low or moderate. When these two likelihoods are quantified, their ratio is called the relative risk. A relative risk value less than 1 indicates no evidence for an effect of a stressor on condition. Relative risk values greater than 1 indicate that the stressor likely has an impact on biological condition.

Results of the relative risk analyses for benthic macroinvertebrates are presented in the middle panel of Figure 6.1. For benthic macroinvertebrates, total phosphorus has the highest relative risk estimate nationally (2.2). This means that lakes with high levels of phosphorus are about 2.2 times more likely to also have most disturbed macroinvertebrate condition. Next, lakeshore disturbance and total nitrogen show risk values similar to one another; lakes in the most disturbed condition for these indicators are about 1.6 times more likely to also have most disturbed macroinvertebrate condition.

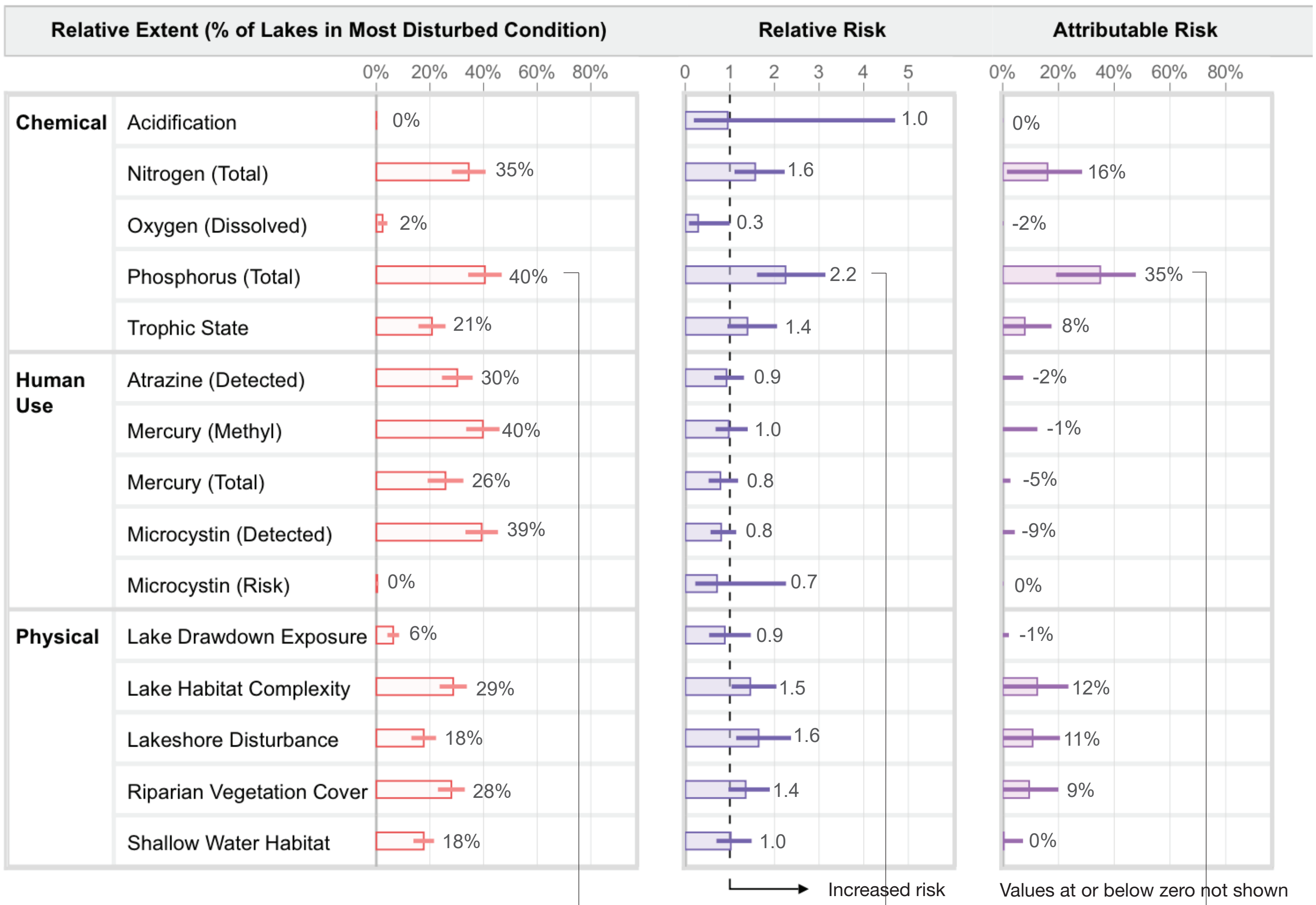
6.2.3 Attributable Risk

Attributable risk represents the estimated effect of potential stressors; it allows us to rank stressors based on the magnitude of the improvement to biological condition that would result from reducing those stressors. It is derived by combining relative extent and relative risk into a single number (see third panel of Figure 6.1). This risk number is presented in terms of the percentage of lakes that could be improved – that is, moved into either the least- or moderately disturbed condition from most disturbed – if high levels of the stressor were reduced to low or moderate.

Attributable risk involves assumptions, including: 1) that a causal relationship exists, where the stressor causes a lake to have an increased probability of being in a most disturbed biological condition; 2) that effects would be reversed if the stressor were removed from a lake in most disturbed condition; and 3) that the stressor's impact on a lake's biological condition is independent of other stressors. These assumptions are difficult to meet with survey data like those collected in the NLA. Despite this limitation, attributable risk can provide a hypothesis of which stressors might be higher priorities at the national level. Considering attributable risk rankings can serve as a tool for policymakers and managers when making decisions related to restoration and protection. Estimates for attributable risk for the benthic macroinvertebrate biological condition are presented in the right panel of Figure 6.1.

Figure 6.1: Estimated Risk to Biota Caused by Stressors

In relation to: Benthic Invertebrates | National



Relative Extent

Relative extent depicts the percentage of lakes in the most disturbed condition. In 2012, EPA found that 40% (45,262) of all national lakes are designated as most disturbed for phosphorus (total). The confidence interval for this estimate is 34% to 47% (36,637 to 53,886 lakes).

Relative Risk

Relative risk conveys the likelihood of having poor biological condition when a particular stressor is high. In 2012, EPA found that when phosphorus (total) is present at most disturbed levels, benthic invertebrates are 2.2 times more likely to be in a most disturbed condition. The confidence interval for this estimate is 1.6 to 3.1.

Attributable Risk

Attributable risk is presented in terms of the percentage of lakes in the most disturbed condition for biological condition that could be improved if high levels of a particular stressor were reduced to low or moderate levels. In 2012, EPA found that the number of lakes in the most disturbed condition for benthic macroinvertebrates could be reduced by approximately 35% if lakes with phosphorus (total) levels were improved to moderate or least disturbed conditions. The confidence interval associated with this estimate is 19% to 48%.

The attributable risk results suggest a need to focus on reducing nutrients in our lakes.

Two NLA indicators have statistically significant attributable risk levels. Based on the NLA 2012 assessment, total phosphorus has the highest attributable risk at 35% (Figure 6.1). Phosphorus is followed by total nitrogen, which has an attributable risk estimate of 16%.

As an example of interpreting attributable risk, phosphorus occurs at high levels in 40% of lakes. Lakes are more than twice as likely to have poor conditions for benthic macroinvertebrates when phosphorus is high (relative risk of 2.2). Relative extent and relative risk, combined, result in an attributable risk level of about 35%. That is, if phosphorus levels were reduced such that lakes were moved out of the most disturbed category, one might expect to see 35% of lakes move from most disturbed to least disturbed or moderate conditions for benthic macroinvertebrates.

6.3 IMPLICATIONS FOR LAKE MANAGERS

The NLA provides a number of findings that lake managers can use to protect and restore lakes. It is important to keep in mind, however, that while survey results fill information gaps in national monitoring by generating estimates of the condition of water resources, evaluating the prevalence of key stressors, and documenting changes in the population of waters over time, they do not address all information needs at all scales. For example, the lakes survey does not address causal factors or sources of stress. In-depth monitoring and analysis of individual lakes, whether already being carried out or needed in the future, are required to establish causality and to better inform restoration.

Nutrients have been longstanding stressors of water bodies in this country. Nationally, over 40% of lakes exhibit most disturbed conditions for phosphorus, while 35% are in the most disturbed condition for nitrogen. Other widespread stressors include methylmercury, where 40% of lakes are in the most disturbed condition, and two physical habitat measures, lake habitat complexity and riparian vegetation cover (29% and 28% are in the most disturbed condition, respectively).

Lake managers could also consider the national 2007-2012 comparison information in evaluating site-specific information in a broader context. Conducted on a five-year basis, future lake surveys will help water resource managers assess broad-scale temporal differences in the data and perform trend analyses.

States, tribes, and others may consider using NLA regional data and methods to meet their lake assessment needs and to inform resource management priorities and actions.

6.4 NEXT STEPS FOR THE NATIONAL SURVEYS

EPA, in partnership with states and tribes, produces national water quality assessments on a regular cycle under the NARS program. With the release of the National Wetland Condition Assessment in 2016, all waterbody types – rivers and streams, lakes, coastal and Great Lakes waters, and wetlands – have been assessed at least once.

EPA is committed to continually enhancing and refining these surveys. As technologies and analytical methods advance, future surveys may also include new indicators and new ways of presenting findings. In the case of the NLA, EPA and its partners have considered the results of this second survey and discussed whether changes are needed to the design, assessment indicators, field methods, laboratory methods, and/or analysis procedures. Sampling for the third NLA will take place in the summer of 2017. EPA encourages researchers to further explore the findings of this and other surveys in the series.

The NLA 2012 would not have been possible without the involvement of scientists and resource managers working for state and tribal agencies across the United States. EPA will continue to help state and tribal partners translate the expertise gained through these national surveys in carrying out studies of their own waters. Finally, we will work to encourage wide use of the NLA data to evaluate the success of efforts to protect and restore the quality of U.S. waters. We hope that NLA 2012 data are used in subsequent analyses to improve assessment results and to enhance general ecological understanding.

7

Sources and References




Brown, L.D., Cai, T.T. and DasGupta, A., 2001. Interval estimation for a binomial proportion. Statistical science, pp. 101-117.

Gilliom and others, 2006. The Quality of Our Nation's Waters—Pesticides in the Nation's Streams and Ground Water, 1992–2001: U.S. Geological Survey Circular 1291,172 p.

Stoddard, J.L., J. Van Sickle, A.T. Herlihy, J. Brahney, S. Paulsen, D.V. Peck, R. Mitchell, and A.I. Pollard, 2016. Continental-scale increase in lake and stream phosphorus: are oligotrophic systems disappearing in the United States? Environmental Science and Technology, 50(7):3409-3415. doi:10.1021/acs.est.5b05950.

U.S. Environmental Protection Agency (USEPA), 2009. *National Lakes Assessment: A Collaborative Survey of the Nation's Lakes*. EPA 841-R-09-001. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, D.C.

USEPA, 2011. 2012 National Lakes Assessment. Field Operations Manual. EPA 841-B-11-003. U.S. Environmental Protection Agency, Washington, DC.

U.S. Environmental Protection Agency (USEPA), 2016. National Lakes Assessment: Technical Report. EPA 841-R-16-114. U.S. EPA, Washington, DC.

Appendix A

The following lookup table provides summary information for each of the NLA 2012 indicators.

Category	Indicator	Benchmark approach	Was change assessed?	General assessment notes
Biological	Benthic macroinvertebrates	NLA-derived, regionally specific benchmarks	Yes	Collected from the lake bottom at 10 shoreline locations and composited for each lake. Organisms were usually identified to genus and an index was developed based on life history characteristics and tolerance to environmental conditions.
	Zooplankton	NLA-derived, regionally specific benchmarks	No	Collected from the water column at the open-water site. Organisms were usually identified to genus and an index was developed based on life history characteristics and tolerance to environmental conditions.
Chemical	Acidification	Nationally consistent, literature-benchmark	No	ANC (corrected for DOC) measured from a vertically integrated water column at the open-water site. Measured concentrations were compared to benchmarks.
	Oxygen (Dissolved)	Nationally consistent, literature- benchmark	Yes	Measures were collected from the in-situ oxygen measure from the top 2m of the profile at the index site. Measured concentrations were compared to benchmarks.
	Nitrogen (Total)	NLA-derived, regionally specific benchmarks	Yes	Collected from a vertically integrated water column at the open-water site. Measured concentrations were compared to benchmarks.
	Phosphorus (Total)	NLA-derived, regionally specific benchmarks	Yes	Collected from a vertically integrated water column at the open-water site. Measured concentrations were compared to benchmarks.
	Trophic State	Nationally consistent, literature-benchmark	Yes	A trophic state index was calculated based on measured chlorophyll-*a* concentration.

Category	Indicator	Benchmark approach	Was change assessed?	General assessment notes
Human Use	Atrazine	Nationally consistent, literature-benchmark	No	Collected from a vertically integrated water column at the open-water site. We report on detection; measured concentrations were compared to an EPA plant-effects benchmark.
	Chlorophyll-*a* (Risk)	Nationally consistent, literature-benchmark	Yes	Collected from a vertically integrated water column at the open-water site. Concentrations were compared to WHO algal toxin benchmark for recreation.
	Cyanobacteria (Risk)	Nationally consistent, literature-benchmark	Yes	Collected from a vertically integrated water column at the open-water site. Concentrations were compared to WHO algal toxin benchmark for recreation.
	Mercury (Methyl)	Nationally consistent, literature-benchmark	Yes	Collected from the top 2cm of sediment from a core taken from the bottom of the lake. Concentrations were compared to a benchmark.
	Microcystin (Risk)	Nationally consistent, literature-benchmark	Yes	Collected from a vertically integrated water column at the open-water site. We report on detection; measured concentrations were compared to WHO algal toxin benchmark for recreation.
	Mercury (Total)	Nationally consistent, literature-benchmark	Yes	Collected from the top 2cm of sediment from a core taken from the bottom of the lake. Concentrations were compared to a benchmark.
Physical	Lake drawdown exposure	NLA-derived, regionally specific benchmarks	Yes	Observations were recorded from 10 shoreline locations around each lake. Information was compared to regionally specific benchmarks.
	Lake habitat complexity	NLA-derived, regionally specific benchmarks	Yes	Observations were recorded from 10 shoreline locations around each lake. Information was compared to regionally specific benchmarks.
	Lakeshore disturbance	Nationally consistent, literature-benchmark	Yes	Observations were recorded from 10 shoreline locations around each lake. Information was compared to regionally specific benchmarks.
	Riparian vegetation cover	NLA-derived, regionally specific benchmarks	Yes	Observations were recorded from 10 shoreline locations around each lake. Information was compared to regionally specific benchmarks.
	Shallow water habitat	NLA-derived, regionally specific benchmarks	Yes	Observations were recorded from 10 shoreline locations around each lake. Information was compared to regionally specific benchmarks.

NLA 2012 Report Photographs

Report page number	Photograph location	Photograph courtesy of
Cover and section header (left 3 and right)		Eric Vance, EPA
Cover (2nd to right) and section header	Lake Wood, Maine	Hilary Snook, EPA Region 1
1		Katie DeGoosh, Rhode Island Department of Environmental Management
2		Eric Vance, EPA
Section 2 header (left)	Kansas	Debbie Baker, Kansas Biological Survey
3	Long Pond, Massachusetts	Susan Holdsworth, EPA
7		Eric Vance, EPA
8	Lake Pleasant, New York	Susan Holdsworth, EPA
13		Eric Vance, EPA
14	Sacheen Lake, Washington	Jenny Hall, Washington Department of Ecology
16		Anne Rogers, Texas Parks and Wildlife Department
17 (left)	Virginia	EPA
17 (2nd from left)	Saguaro Lake, Arizona	EPA
17 (mid)	Pyramid Lake, Nevada	Marianne Denton, Nevada Division of Environmental Protection
17 (2nd from right)	Elaine Lake, Tennessee	Tetra Tech
17 (right)	Swofford Pond, Washington	Jenny Hall, Washington Department of Ecology
18	Wilmington, North Carolina	Compiled by National Environmental Education Foundation for USEPA
19	Kansas	Debbie Baker, Kansas Biological Survey
21	Peace Dale Reservoir, Rhode Island	Katie DeGoosh, Rhode Island Department of Environmental Management
21	Slatersville Reservoir, Rhode Island	Katie DeGoosh, Rhode Island Department of Environmental Management
23	Belleville Pond, Rhode Island	Katie DeGoosh, Rhode Island Department of Environmental Management
24	Belleville Pond, Rhode Island	Katie DeGoosh, Rhode Island Department of Environmental Management
26	Missouri	Tony Thorpe, University of Missouri
27	Wisconsin	https://pixabay.com/en/wisconsin-lake-water-sailboat-140392/
29 (top)		Eric Vance, EPA
29 (2nd down)	Belleville Pond, Rhode Island	Katie DeGoosh, Rhode Island Department of Environmental Management
29 (3rd down)	Oklahoma	Jessie Stine, Oklahoma Water Resources Board
29 (4th down)	Baker Lake, Washington	Jenny Hall, Washington Department of Ecology
29 (5th down)		https://pixabay.com/en/duck-drake-mallard-plumage-711443/
29 (bottom)	Long Pond, Massachusetts	Susan Holdsworth, EPA
31		Eric Vance, EPA
34 (left)	Spring Lake, Vermont	Hilary Snook, EPA Region 1
34 (2nd from left)	Swiggetts Pond, Delaware	Ellen Dickey, Delaware Division of Water Resources
34 (3rd from left)	Kansas	Debbie Baker, Kansas Biological Survey