National Lakes Assessment

A Collaborative Survey of the Nation's Lakes

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The following people played a pivotal role and lent their expertise to the data analysis of this project. These individuals painstakingly reviewed the dataset to ensure quality and consistency. These NLA analysts included Neil Kamman (lead, on detail from VT Department of Environmental Conservation), Richard Mitchell, and Ellen Tarquinio from EPA Office of Water; Phil Kaufmann, Tony Olsen, Dave Peck, Spence Peterson, Steve Paulsen, Amina Pollard, John Stoddard, John Van Sickle and Henry Walker from EPA Office of Research and Development; Donald Charles and Mihaele Enache from the Academy of Natural Sciences, Philadelphia PA; Charles Hawkins from Utah State University; Alan Herlihy from Oregon State University; Paul Garrison from WI Department of Natural Resources; Jennifer Graham and Keith Loftin from U.S. Geological Survey, Lawrence, KS; Jan Stevenson from Michigan State University, and Julie Wolin from Cleveland State University, OH.

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Additional Reports and Information

To augment the findings of this report, EPA is providing several additional reports. The first is the *National Lakes Assessment: Technical Appendix.* This appendix describes in detail the data analyses and scientific underpinnings of the results. It is intended to aid States and other institutions who would like a more in-depth explanation of the data analysis phase with the possible intention of replicating the survey at a smaller scale. Additional results are also forthcoming. Due to a number of reasons, EPA is not able to report at this time the results from several indicators (*e.g.*, sediment mercury, *enterococci*, and benthic macroinvertebrates). Work is on-going for each of these indicators and results will be published when complete. The Technical Appendix, Field Methods and Laboratory Protocols are currently available on EPA's web site at http://www.epa.gov/lakessurvey/.

For those wishing to access data from the survey to perform their own analyses, EPA has made flat files of the data available via the internet at http://www.epa.gov/owow/lakes/lakessurvey/web_data.html. Additionally, raw data and information on the sampled lakes will be uploaded to EPA's STOrage and RETrieval (STORET) warehouse at http://www.epa.gov/STORET.

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Photo courtesy of Frank Borsuk

Executive Summary

"A lake is the landscape's most beautiful and expressive feature. It is earth's eye; looking into which the beholder measures the depth of his own nature."

These words by the American poet Henry David Thoreau underscore America's love of lakes. Lakes are places of reflection, relaxation, and repose, but like all our waters, they are being increasingly stressed. Growing anthropogenic pressures have prompted many governments, associations, and individuals to invest time in preserving or restoring the water quality of their lakes. To protect our nation's lakes, Americans must strive to understand how their actions as individuals and as a society are affecting them.

Under the Clean Water Act (CWA), the U.S. Environmental Protection Agency (EPA) must report periodically on the condition of the nation's water resources by summarizing water quality information provided by the states. However, approaches to collecting and evaluating data vary from state to state, making it difficult to compare the information across states, on a nationwide basis, or over time. EPA and the states are continually working on ways to address this problem to improve water quality reporting.

Congress, environmental groups, and concerned citizens routinely ask EPA questions about the quality of the nation's waters such as: What are the key problems in our waters? How widespread are the problems? Are there hotspots? Are we investing in water resource restoration and protection wisely? Are our waters getting cleaner? To better answer questions about the condition of waters across the country, EPA along with its state and tribal partners have embarked on a series of surveys to be conducted under the National Aquatic Resource Surveys (NARS) program. This relatively new program provides statistically valid data and information vital to describing water resource quality conditions across the country, how these conditions vary with geographic setting, and the extent of human and natural influences.

The National Lakes Assessment (NLA) is one in a series of annual NARS surveys. The NLA is the first statistical survey of the condition of our nation's lakes, ponds, and reservoirs.[1] Based on the sampling of over 1,000 lakes across the country, the survey results represent the state of nearly 50,000 natural and man-made lakes that are greater than 10 acres in area and over one meter deep. In the summer of 2007, lakes were sampled for their water quality, biological condition, habitat conditions, and recreational suitability. Field crews used the same methods at all lakes to ensure that results were nationally comparable. For many of the indicators, scientists analyzed the results against a reference condition. Reference conditions were derived from a set of lakes that were determined to be the least disturbed lakes for a region.

Key Findings

Biological Quality - 56% of the nation's lakes are in good biological condition. Natural lakes had a higher percentage of lakes in good condition than man-made lakes (Figure ES-1).

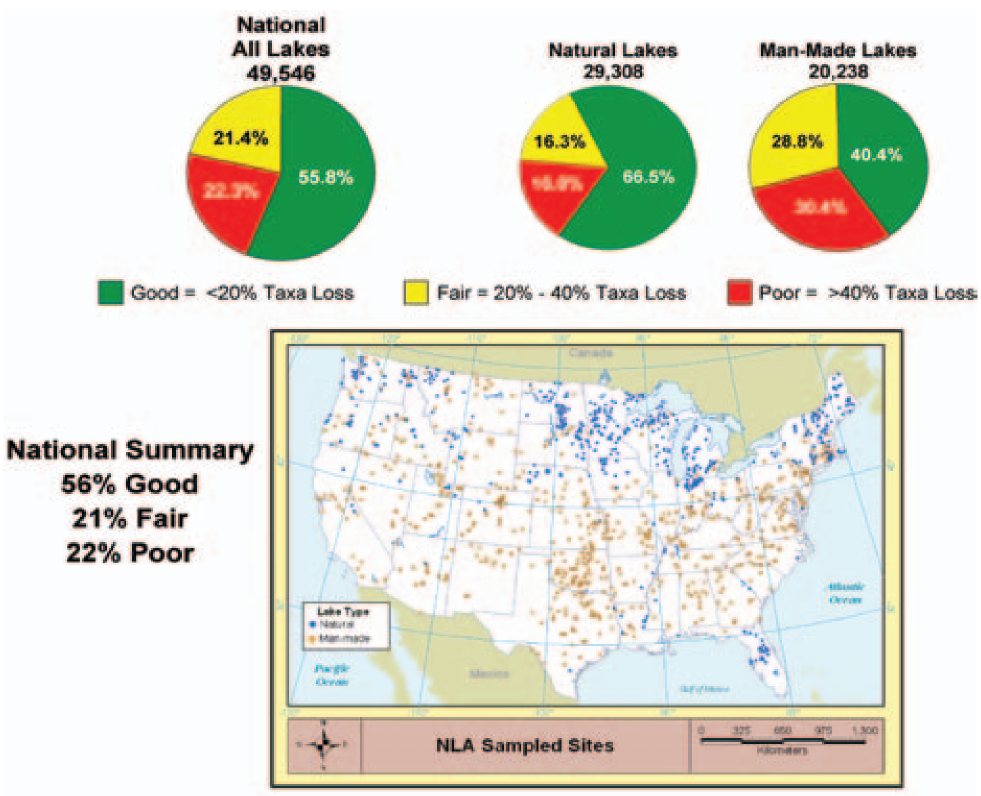


Figure ES-1. Biological condition of lakes nationally and based on lake origin.

[1]The full report including technical supporting documents is available on-line at http://www.epa.gov/lakessurvey/

Lake Physical Habitat - Of the stressors included in the NLA, poor lakeshore habitat is the biggest problem in the nation's lakes; over one-third exhibit poor shoreline habitat condition. Poor biological health is three times more likely in lakes with poor lakeshore habitat (Figure ES-2).

Nutrients - About 20% of lakes in the U.S. have high levels of phosphorus or nitrogen. High nutrient levels are the second biggest problem in lakes. Lakes with excess nutrients are two-and-a half-times more likely to have poor biological health (Figure ES-2).

Algal Toxins - The NLA conducted the first-ever national study of algal toxins in lakes. Microcystin – a toxin that can harm humans, pets, and wildlife – was found to be present in about one-third of lakes and at levels of concern in 1% of lakes.

Fish Tissue Contaminants - A parallel study of toxins in lake fish tissue shows that mercury concentrations in game fish exceed health based limits in about half of lakes (49%); polychlorinated biphenyls (PCBs) at potential levels of concern are found in 17% of the lakes.

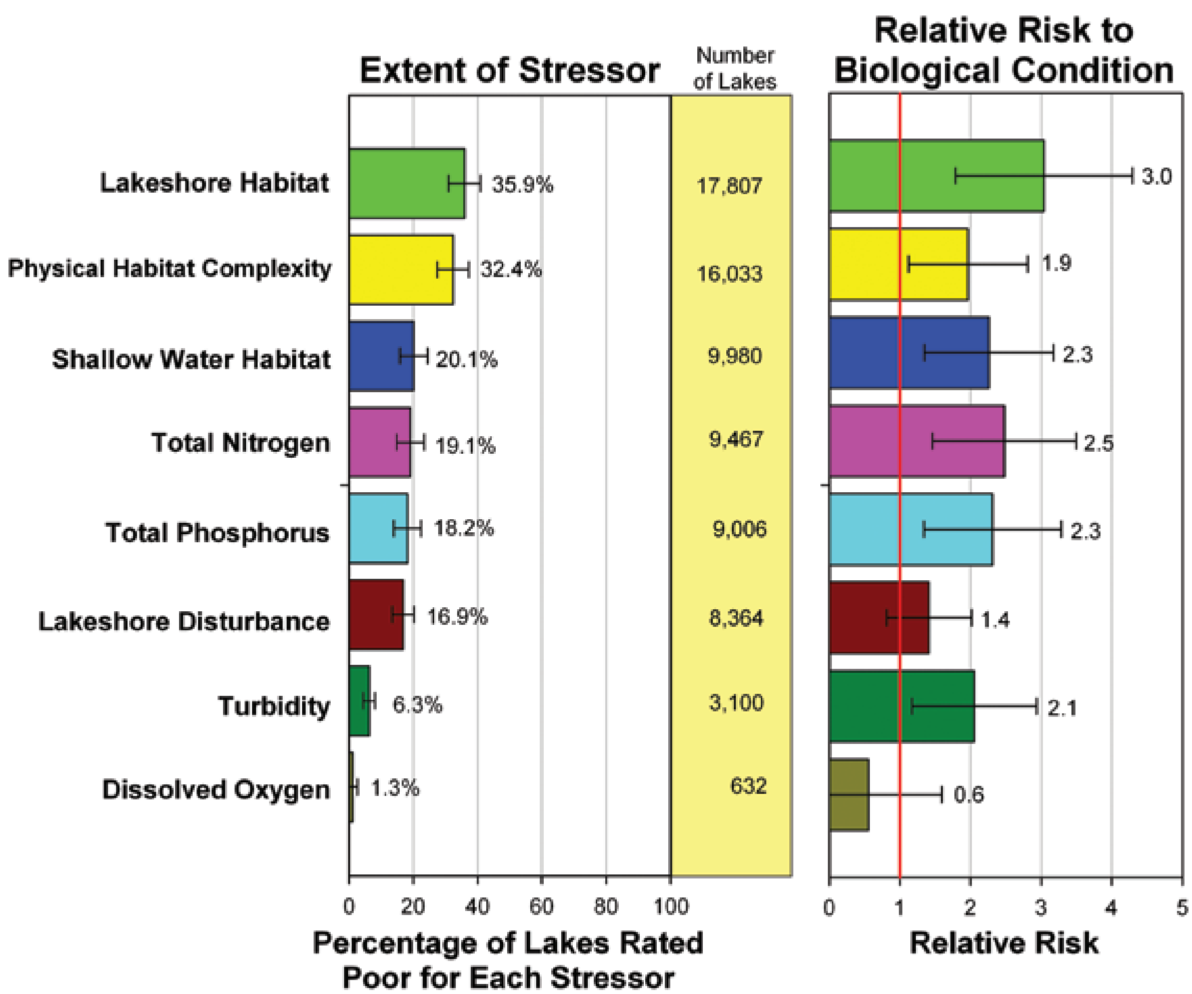


Figure ES-2. Extent of stressor and relative risk of stressor to biological condition.

Trophic Condition - The NLA establishes the first nationally consistent baseline of trophic status. Over 36% of the nation's lakes are mesotrophic, based on chlorophyll-*a* concentrations.

Changes in Trophic Condition - When compared to a subset of wastewater-impacted lakes sampled 35 years ago, trophic status improved in one-quarter (26%) and remained stable in over half (51%) of those lakes (Figure ES-3). This could indicate that, when considering rising populations in these areas, investments in wastewater pollution control are working.

Implications

As these results show, EPA and its state and tribal partners have begun to answer important national questions about the condition of the country's lakes. The results establish a national baseline status for future monitoring efforts which can be used to track scientifically credible trends in lake conditions. Successive surveys will help answer the question "Are our lakes getting better?"

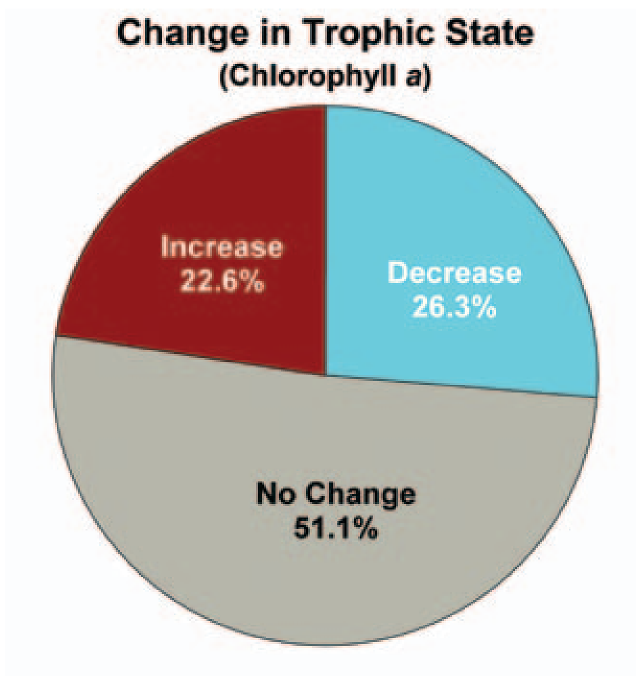


Figure ES-3. Proportion of National Eutrophication Survey (NES) lakes that exhibited improvement, degradation, or no change in trophic state based on the comparison of the 1972 National Eutrophication Survey and the 2007 National Lakes Assessment.

For water resource managers, policymakers, boaters, swimmers, and others, the NLA findings suggest:

- Poor lakeshore habitat condition imparts a significant stress on lakes and suggests the need for stronger management of shoreline development, especially as development pressures on lakes keep steadily growing.
- Effective nutrient management continues to be needed in the nation's lakes. Excess levels of nutrients contribute to algae bloom, weed growth, reduced water clarity, and other lake problems. The adverse impact of nutrients on aquatic life, drinking water, and recreation remains a concern.
- Local, state and national initiatives to protect the integrity of lakes should center on restoring the natural state of shoreline habitat – particularly vegetative cover and nutrient loading. Managers, residents, businesses, and community leaders should work together and enhance their efforts to preserve, protect, and restore their lakes and the natural environment surrounding them.

CHAPTER 1.
INTRODUCTION

Phelps Lake, Grand Teton National Park, WY. Photo courtesy of Great Lakes Environmental Center.

IN THIS CHAPTER

Chapter 1
Introduction

A Highly Valued and Valuable Resource

For anyone who went fishing as a child, water-skiing as a teen, or bird-watching as an adult, lakes are special places. Healthy lakes enhance the quality of life. In addition to supplying people with essential needs like drinking water, food, fiber, medicine, and energy, a lake's ecosystem is important in providing habitat for wildlife, recreation, aesthetics, reducing the frequency and severity of floods, shaping landscapes, and affecting local and regional climates. Lakes provide habitat for wildlife and enjoyment for people while supporting intrinsic ecological integrity for all living things.

It is difficult to put a price on a natural treasure. Certainly, from a vacationer's perspective, lakes are invaluable, providing endless enjoyment and relaxation year-round. According to the U.S. Fish and Wildlife Service, 30 million Americans went fishing in 2006 and $42.2 billion was spent on recreational fishing. Locally, this translates into important economic and recreational benefits. For example, Lake Champlain, on the border of Vermont and New York, has over 65 beaches and 98 fishing-related businesses. According to the 2003 Lake Champlain Management Plan, in 1998 a total of $3.8 billion was generated from tourism. As more and more people use lakes for their livelihood and recreation, the competition for lake resources will continue.

Protecting lake ecosystems is crucial not only to protecting this country's public and economic health, but also to preserving and restoring the natural environment for all aquatic and terrestrial living things. Lake protection and preservation can only be achieved by making informed lake management policy decisions at and across all jurisdictional levels.

Why a National Survey?

Water resource monitoring in the U.S. has been conducted by many different organizations over many decades using a variety of techniques. States and tribes conduct monitoring to support many Clean Water Act (CWA) programs. Section 305(b) of the CWA requires the U.S. Environmental Protection Agency (EPA) to report periodically on the condition of the nation's water resources by summarizing information provided by the states. Yet approaches to collecting and assessing data vary from state to state, making it difficult to compare the information across states or on a nationwide basis. Each of these monitoring efforts provides useful information relative to the goals of the individual programs, but integrating the data into a nationwide assessment has been difficult.

In recent years, a number of independent reports have identified the need for improved water quality monitoring and analysis at a national scale. Among these, the General Accounting Office (2000) reported that EPA and states cannot make statistically valid assessments of water quality and lack the data to support key management decisions. The National Research Council (2001) recommended that EPA and states promote a uniform, consistent approach to water monitoring and data collection to better support core water management programs. The National Academy of Public Administration, in its 2002 report entitled, *Understanding What States Need to Protect Water Quality*, concluded that improved water quality monitoring is necessary to help state agencies make better decisions and use limited resources more effectively. These reports underscore the need for more efficient and cost-effective ways to understand the magnitude and extent of water quality problems, the causes of these problems, and practical ways to address the problems.

State Water Quality Reports

Under section 305(b) of the Clean Water Act the states must submit biennial reports on the quality of their water resources. According to the most recently published National Water Quality Inventory Report (2004) the states assessed just over a third of the nation's waters — 37% or 14.8 million acres of the nation's 40.6 million acres of lakes, ponds and reservoirs. Of the lakes that were assessed, over half, 58% or 8.6 million acres, were identified as impaired or not supporting one or more of their designated uses such as fishing or swimming. The states cited nutrients, metals (such as mercury), sewage, sedimentation and nuisance species as the top causes of impairment. Leading known sources of impairment included agricultural activities and atmospheric deposition, although for many lakes, the sources of impairment remain unidentified.

The National Aquatic Resource Surveys

To bridge this information gap, EPA, other federal agencies, states and tribes are collaborating to provide the public with improved environmental information. Statistical surveys are one way of addressing water resource assessment needs. By choosing a statistical design with standardized field and laboratory protocols, the EPA, states and tribes are able to collect and analyze data that are nationally consistent and representative of waterbodies throughout the U.S. These statistical surveys offer a cost-effective and scientifically valid way to fulfill statutory requirements, complement traditional monitoring programs, and support a broader range of management decisions.

The surveys are designed to answer such questions as:

- What is the extent of waters that support a healthy biological condition, recreation, and fish consumption?
- How widespread are major stressors that impact water resource quality?
- Are we investing in water resource restoration and protection wisely?
- Are our waters getting cleaner?

The help of state partners was essential.
Photo courtesy of Frank Borsuk.

The specific goals of NARS are to generate scientifically valid information on the condition of water resources at national and ecoregional scales, establish baseline information for future trends assessment, and assist states and tribes in enhancing their water monitoring and assessment programs.

The focus of NARS is on waterbodies as groups or populations, rather than as individual waters. For example, a state or local manager may be interested in nutrient levels in a given lake over time. NARS, on the other hand, allows one to examine the percentage of the nation's lakes that have experienced changes in nutrient levels over time. Findings such as these help drive national water quality management decisions.

By generating population estimates of condition, the national statistical surveys and other statistical surveys have begun to provide answers to water resource questions with a known level of confidence. Working with its partners in states, tribes, territories, and other federal agencies, EPA has in recent years conducted statistical surveys of coastal waters, wadeable streams, and contaminants in lake fish tissue. The Agency's plans are to survey each of the five waterbody types, (lakes, rivers, streams, wetlands, and estuaries), on a 5-year rotating basis. EPA and its partners anticipate that the national surveys will continue to foster collaboration across jurisdictional boundaries, build state and tribal infrastructure and capacity for enhanced monitoring efforts, and achieve a robust set of statistically-sound data for better, more informed water resource quality management policies and decisions.

The National Lakes Assessment (NLA) is one component of the National Aquatic Resource Surveys. This report summarizes the first-ever assessment of lakes across the continental United States using consistent protocols and a modern, scientifically-defensible statistical survey approach.

Using the National Aquatic Resource Surveys

Because of their scientific credibility, results from these surveys are being used in other scientific contexts. Most notably is the recent Heinz Center Report, *The State of the Nation's Ecosystems, 2008*. The Heinz Center's report is designed to provide a high level, comprehensive and scientifically sound account on the state of the nation's ecosystems. The Heinz Center uses data derived from EPA's Wadeable Streams Assessment report and National Coastal Condition Report to answer a number of outstanding questions about surface water health in our country. Information from on-going and upcoming national surveys will help fill gaps identified for other water resources and show trends in national water quality.

HIGHLIGHT

Think Globally — Act Locally. Restoring Mousam Lake

"Every little bit helps" is perhaps the fundamental tenet of the estimated 3,000 to 4,000 local watershed groups across the country. Many communities are proving that they can make a noticeable difference in their neighborhood water resource. In York County, Maine, the Soil and Water Conservation District (SWCD) and the Mousam Lake Regional Association (MLRA) together with residents, townships, state agencies and others embarked on the Mousam Lake Water Quality Improvement Project. With widespread collaboration and some funding, they were able to clean up an impaired lake.

Confronting Environmental Challenges

Mousam Lake, a 863-acre lake located at the southern point of Maine, is a popular spot for boaters, anglers, and vacationers with its sandy shores and excellent cold and warm water trout fisheries. However, this 21- square mile watershed suffered from suburbanization and the conversion of forested land to driveways and parking lots. The lake's shoreline is heavily developed with over 700 seasonal and year-round homes and a heavily used boat ramp. For the past several decades, Mousam Lake has endured increased soil erosion and pollution from stormwater runoff from home construction, lawns and roads, and from failing septic systems. Higher levels of phosphorus have led to increased algal growth, decreased water clarity and lower levels of dissolved oxygen. In the 2003 Total Maximum Daily Load (TMDL) assessment, excess phosphorus was identified as the major impairment. This downward trend in water quality resulted in a steady decline in the lake's once viable ecology and that of its surrounding aquatic habitats. Maine's Department of Environmental Protection (MDEP) attributes the problem to soil erosion and polluted runoff from residential properties and camp roads and effluent from inadequate septic systems located in the sandy soils around the lake. The TMDL assessment estimated that to meet Maine water quality standards, the annual amount of phosphorus reaching the lake would need to be reduced by 27%.

A Decade of Effort

Since 1997, the York County SWDC, MLRA, MDEP, and the towns of Acton and Shapleigh have been working together to address sources of pollution in Mousam Lake and foster long-term watershed stewardship. In 1999, the Mousam Lake Water Quality Improvement Project began. With help from EPA, the Maine Department of Transportation and the Maine Department of Agriculture negotiated cost share agreements with public and private landowners, and best management practices were initiated at 45 priority sites. Technical assistance was provided to another 77 landowners. Projects included stabilizing shoreline erosion, improving gravel road surfaces and installing and/or upgrading roadside drainages. Twenty-one roads were repaired. In 2001, the Lake Youth Conservation Corps program was established to help with the implementation of best management practices, raise local awareness and commitment to lake protection, and involve local youth in environmental stewardship. Since 2007, the youth have completed over 115 projects and continue to repair an average of 18 sites each year with annual support from the towns of Acton and Shapleigh. The total cost for the project was $1.1 million with local townspeople and others contributing over $400,000 in matching funds or in-kind services.

A Cleaner, Healthier Lake

In 1998 MDEP designated Mousam Lake as impaired and added it to the state's section 303(d) list of waters not meeting water quality standards, a requirement of the federal Clean Water Act. From 1999 through 2006, a galvanized community tackled the problem and in 2007, monitoring results indicated that pollution loads in the lake were reduced by more than 150 tons/per year of sediment and 130 pounds/per year of phosphorus. Water clarity depth has increased by a full meter from what it was ten years ago. Today, erosion control projects continue, thus keeping an estimated 76 tons of sediment and 64 pounds of phosphorus out of the lake each year. In 2006, Mousam Lake was removed from the state's 303(d) list of impaired waters.

Staff and a small cadre of local leaders are continuing their campaign to keep the lake in good health. Community outreach and education activities are ongoing to inform residents on how they can help. As part of the project, numerous newsletters have gone to every household in the watershed; MLRA holds annual meetings; the SWCD conducts workshops and delivers presentations; 30 construction sites have been acknowledged with "Gold Star" signs for environmental stewardship; and more than 200 homeowners attended one of the thirteen "Septic Socials" to learn about septic system function, proper maintenance and water conservation.

Every Little Bit Helps

In many, many instances, small, local efforts can provide incentives and moral support for others. The success of the Mousam Lake project has inspired protection efforts on several neighboring lakes. The Acton Wakefield Watershed Alliance, the Square Pond Association, and the Loon Pond Association are now busy with their own restoration activities. For more information or tips from the people at Mousam Lake, contact Joe Anderson at York County SWCD at (207) 324-0888, janderson@yorkswcd.org or Wendy Garland (MDEP) at (207) 822-6320, wendy.garland@maine.gov.

Vegetated buffer planting by Master Gardeners.
Photo courtesy of Deborah Kendall.

CHAPTER 2.

DESIGN OF THE LAKES SURVEY

Photo courtesy of Washington Department of Ecology

IN THIS CHAPTER

Photo courtesy of Great Lakes Environmental Center

Chapter 2
Design of the Lakes Survey

Lakes in the U.S. are as varied and unique as the landscape surrounding them. Receding glaciers formed thousands of lakes in the northwestern, upper midwestern, and northeastern parts of the country. Glacial action formed the Finger Lakes in New York, the Adirondack region, the kettle ponds in New England, as well as numerous lakes and "prairie potholes" located in Minnesota, Wisconsin, Iowa, and the Dakotas. In contrast, Oregon's Crater Lake is a water-filled volcanic depression, as is Yellowstone Lake in Wyoming. Lake Tahoe in California and Pyramid Lake in Nevada were formed by tectonic action. Along major rivers, like the Mississippi, oxbow lakes were formed from meandering river channels. Similarly, damming of the Columbia River and the Colorado River has created large man-made lakes and reservoirs. Smaller previously impounded streams comprise thousands of man-made lakes that provided energy for mills during industrialization. Natural lakes are scarce across the southern U.S. Many of the lakes in the arid southwestern and the humid southeastern U.S. are man-made lakes or reservoirs. The NLA survey included examples of all of these lake types.

Areas Covered By the Survey

The NLA encompasses the lakes, ponds and reservoirs of the continental U.S. including private, state, tribal and federal land. Although not included in this report, a lake-sampling project is underway in Alaska. Hawaii was not included in the national survey design. Information from the NLA is also presented for both natural and man-made lakes to present any difference in biological condition or responses to stressors.

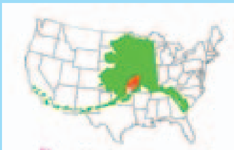
NLA results are reported for the continental U.S. and for 9 ecological regions (ecoregions). Areas are included in an ecoregion based on similar landform and climate characteristics (see Chapter 6 and Figure 20). Assessments were conducted at the ecoregion level because the patterns of response to stress are often best understood in a regional context. Some states participating in the NLA assessed lake condition at an even finer state-scale resolution than the ecoregional scale by sampling additional random sites within their state boundaries. Although these data are included in the analysis described in this report, state-scale results are not presented.

Selecting Lakes

Since a census of every lake in the country is cost prohibitive and beyond the reach of any program, EPA used a statistical sampling approach incorporating state-of-the-art survey design techniques. The first step, to ascertain the number of lakes in the country, was challenging because there is no comprehensive list or source for all lakes in the U.S. The best resource available is the USGS/EPA National Hydrography Dataset or NHD. The NHD is a multi-layered series of digital maps that reveal topography,

Alaska's Lake Assessment

By Terri Lomax, AK Department of Environmental Conservation



The State of Alaska is about one-fifth the land mass of the continental U.S. Most of it is sparsely populated with extremely limited access. This limited access has helped preserve its rugged beauty and abundant natural resources. But Alaska is facing pressure from climate change and natural resource development. In the populated areas, the main causes of waterbody pollution are urban runoff and agricultural activity.

There are an estimated 3 million lakes in Alaska. Instead of being a full participant in the National Lakes Survey, the State of Alaska opted to conduct a regional assessment. It focused on the Cook Inlet Basin, an area located in the southcentral part of the state; at 39,325 square miles, it is slightly smaller than the state of Kentucky. The State selected this area because the only agricultural activity of significance occurs within the Cook Inlet Basin.

Alaska's lake assessment began in 2007 with a pilot study of four lakes. This pilot study was focused on access and coordinating logistics of sampling, procedures, and analysis. In 2008, the full project was completed with sampling of 50 lakes in the Cook Inlet ecoregion. The field crew was from the Alaska Department of Environmental Conservation and the University of Alaska Anchorage Environment & Natural Institute. In addition to the National Lakes Assessment indicators, fish tissue for metals and mercury, sediment trace metals, and core dating were added to the study.

To date, all water chemistry, habitat, and lake profile data has been analyzed. Biological indicators, sediment metals and mercury, and fish tissue samples are currently being analyzed. All data collected must undergo quality assurance review before a final release of the data. However, initial results indicate that lakes in the Cook Inlet ecoregion of Alaska are healthy.

area, flow, location, and other attributes of the nation's surface waters. When queried, NHD has 389,005 features listed that could potentially be lakes, ranging in size from less than 2.4 acres (1 hectare) up to the largest lakes in the country. Figure 1 illustrates the sample framework for the survey.

Initial discussion by states and EPA regarding the scope of the survey focused on the size of lakes that were to be considered in the target population. It was agreed that, to be included, the site had to be a natural or man-made freshwater lake, pond or reservoir, greater than 10 acres (4 hectares), at least 3.3 feet (1 meter) deep, and with a minimum of a quarter acre (0.1 hectare) open water. 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 the criteria, 68,223 waterbodies were considered lakes by the NLA definition and thus comprised the target population (Figure 1, 3rd bar).

Other factors in lake selection included accessibility. In some cases, crews were either denied permission by the landowner or unable to reach the lake for safety reasons, such as sharp cliffs or unstable ridges. Using data from the crews' experience and pre-sampling reconnaissance, it was estimated that 27% or 18,677 lakes fell into the inaccessible category. This left 49,546 lakes which could be assessed - inference

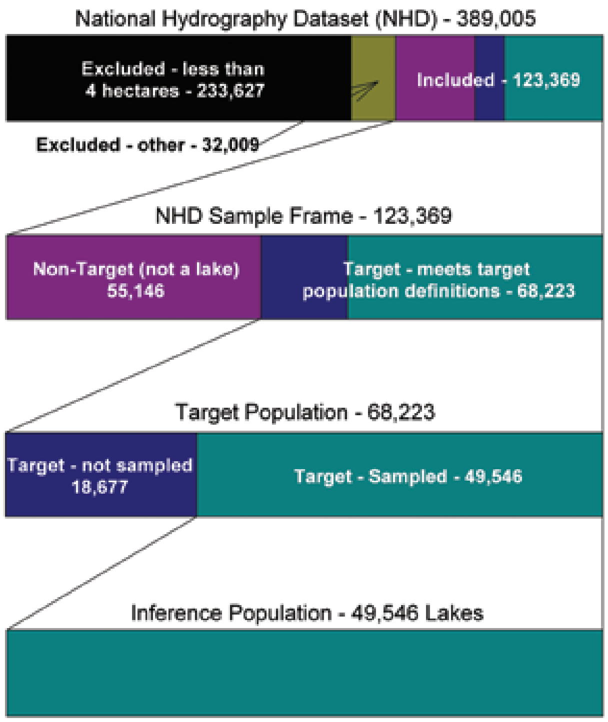


Figure 1. The process of lake selection. Starting with the NHD list of waterbodies, potential lakes are eliminated due to not meeting set criteria for inclusion in the survey (top bar), not being a lake (2nd bar), and inaccessibility (3rd bar) leaving the number of sampleable lakes or inference population (4th bar).

population (bottom bar). In the end, a total of 1,028 lakes were sampled in the survey. These 1,028 lakes represent the population. For quality assurance purposes, 10%, of the target lakes were randomly selected for a second sampling later in the summer.

Due to the selection process, the sampled NLA lakes represent 49,546 lakes or 73% of the target population. Thus, throughout this report, percentages reported for a given indicator are relative to the 49,546 lakes. For example, if the condition is described as poor for 10% of lakes nationally, this means that the number of lakes estimated to be poor for that indicator is 4,955 lakes.

As an added feature, the design specifically included some sites from EPA's 1972 National Lake Eutrophication Study (NES). By including this subset of lakes EPA hoped to be able to evaluate changes that occurred between the 1970s and 2007.

In conjunction with the national survey, a number of states opted to sample additional lakes to achieve a state-wide probabilistic survey. EPA provided a list of additional lakes to the states so that any state wishing to conduct a state-scale statistical survey could do so. Sampling and processing methods from these additional lakes had to adhere to both the national field and laboratory protocols. Eight states (MI, WI, IN, MN, TX, OK, ID, and WA) took advantage of the opportunity and the results from the additional sites were analyzed along with the national data. Some states increased the number of sites, but only collected a subset of indicators. Still other states opted to expand the list of indicators to address issues specific to their state; for example, Minnesota used its state-scale survey to assess pesticides.

Figure 2 shows the location of the lakes that were sampled for the NLA. The surveyed lakes cover an area of 3.8 million acres of surface water spread across the national landscape.

The site selection for the survey ensures that EPA can make unbiased estimates concerning the health of the target population of lakes with statistical confidence. The greater the number of sites sampled, the more confidence in the results. The number of sites included in the survey allows EPA to determine the percentage of lakes nationwide and within predetermined ecoregions that exceed a threshold of concern with 95% confidence. In the graphs throughout this report, the margin of error is provided as thin lines on either side of the bars and represent the 95% confidence interval for the estimate.

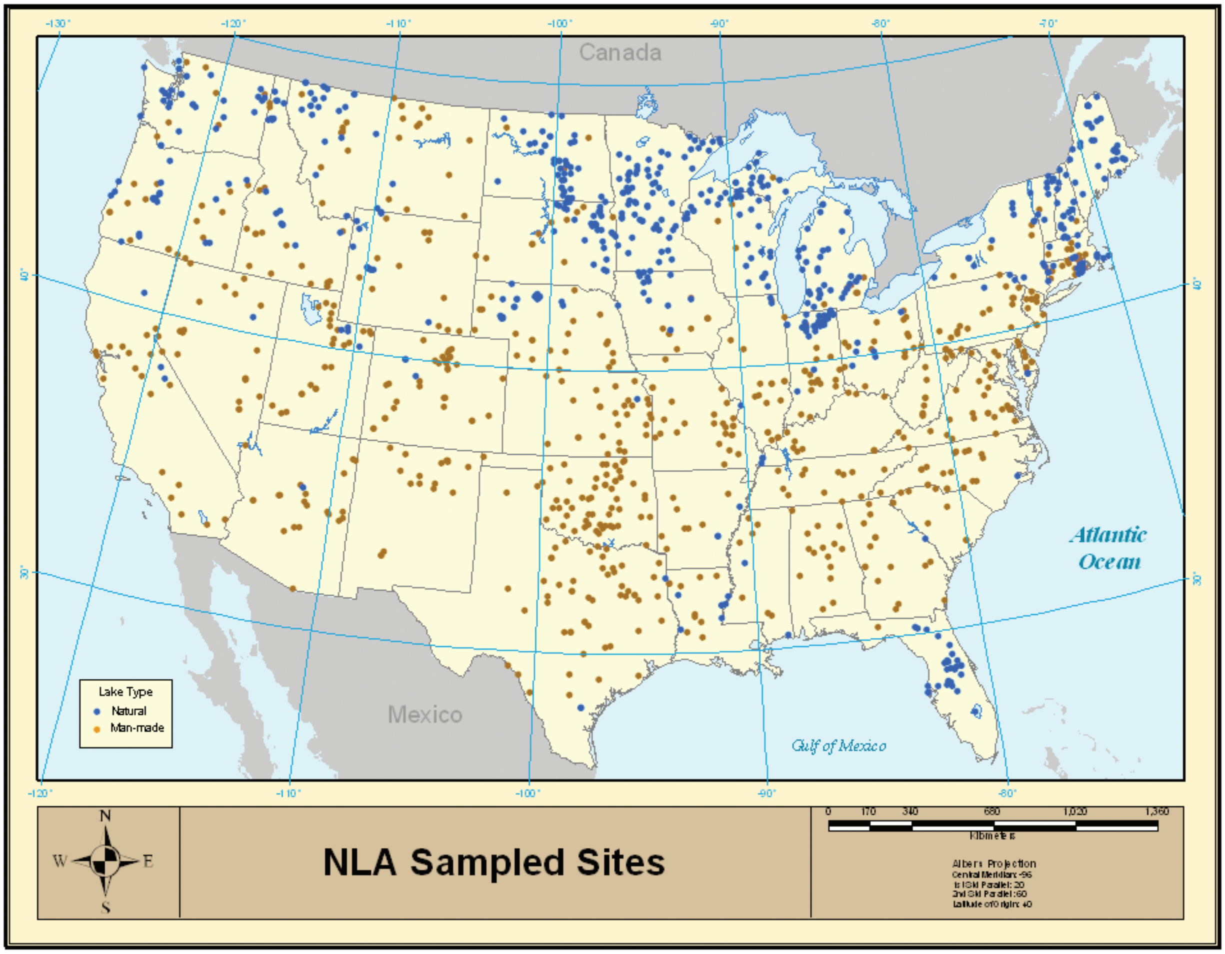


Figure 2. Location of lakes sampled in the NLA. Natural lakes are the blue dots; Man-made lakes are brown.

For national estimates, the margin of error around the NLA findings is approximately ±5% and for ecoregions the margin of error is approximately ±15%. For example, for the national biological condition findings, the NLA estimates that 22.4% of the nation's lakes are in poor condition and that the margin of error is +/- 4%. This means that there is a 95% certainty that the true value is between 18.4% and 26.4%.

Lake Extent - Natural and Man-made Lakes

NLA analysts, comprised of lake science experts both within and outside the Agency, examined available records for each sampled lake to determine its origin. They considered natural lakes as those that existed pre-European settlement, even if presently augmented by means of an impoundment or other earthworks. Using this operational definition, 41% of the estimated 49,546 lakes are man-made reservoirs, while 59% are of natural origin. This means that nearly one-half of today's lakes were not here when the colonists arrived.

While natural lakes come in many different sizes, most man-made lakes are relatively small. A total of 52% of man-made lakes are 10-25 acres (4-10 hectares) in size compared with only 34% of the natural lakes in that small lake size category. Large lakes, over 12,500 acres (5,000 hectares), are rare in the U.S., comprising only 0.3% of natural lakes and 0.6% of man-made lakes (Figure 3).

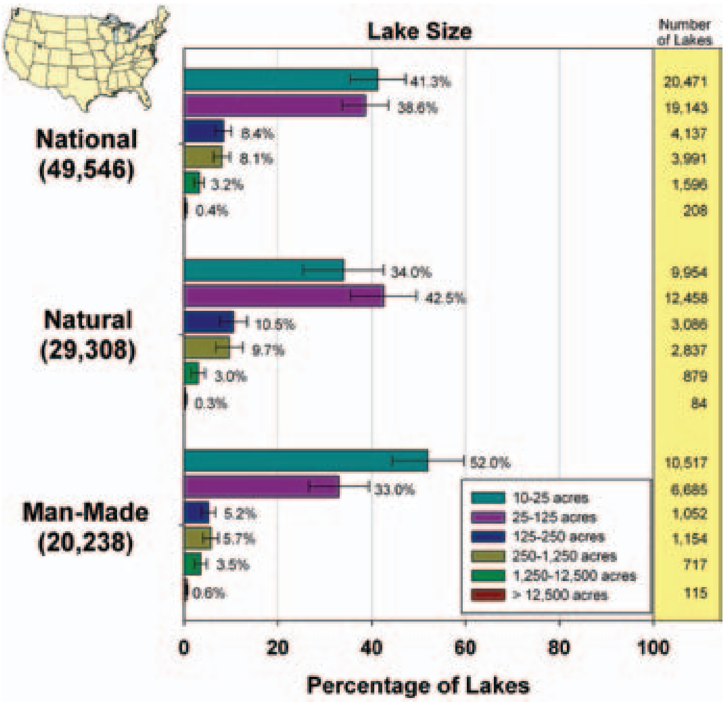


Figure 3. Size distribution of lakes in the U.S. overall and for natural and man-made lakes.

Choosing Indicators

Scientists and lake managers recognize that lake ecosystems are dynamic and indicators selected to characterize lakes must represent important aspects of water resource quality. For the NLA, a suite of chemical, physical and biological indicators were chosen to assess biological integrity, trophic state, recreational suitability, and key stressors impacting the biological quality of lakes.

Although there are many more indicators and/or stressors that affect lakes, NLA analysts believe these to be among the most representative at a national scale. The NLA survey marks the first time all these indicators have been applied consistently and simultaneously to lakes on a national scale.

For this assessment, NLA analysts looked at data of phytoplankton, zooplankton and sediment diatoms in an effort to characterize the biological condition of lakes. It was during the analysis that it was decided that the results of the phytoplankton and zooplankton assessment would serve as the primary biological indicator. To address recreational/human health related concerns, the NLA looked at actual levels of the algal toxin microcystin, along with cyanobacterial cell counts and chlorophyll-*a* concentrations as indicators of the potential for the presence of algal toxins. The presence and concentration of microcystin were used as the primary indicators for recreational condition. Chlorophyll-*a* was used as the primary indicator of trophic status. Although fish samples were not collected in the survey, NLA analysts also looked at the findings of a parallel study of contaminants in fish tissue.

Both physical and chemical stressor indicators were measured. For example, shorelines affect biological communities in many ways, such as providing food and

Biological	Recreational	Chemical	Physical
• Sediment diatoms • Phytoplankton (algae) • Zooplankton • Benthic macroinvertebrates* • Algal density (chlorophyll-*a*) • Invasive species*	• Pathogens* *(enterococci)* • Algal toxin (microcystins) • Algal cell counts (Cyanobacteria) • Algal density (chlorophyll-*a*)	• Nutrients (phosphorus & nitrogen) • Water column profile (dissolved oxygen, temperature, pH, turbidity, acid neutralizing capacity, salinity) • Sediment mercury*	• Lakeshore habitat cover and structure • Shallow water habitat cover and structure • Lakeshore human disturbance

* These indicators are still under evaluation and are not included in this report. Results will be published at a later date.

shelter for aquatic wildlife, and by moderating the magnitude, timing, and pathways of water, sediment, and nutrient inputs. Shorelines also buffer the lake from human activities. Water quality characteristics, such as nutrient levels and dissolved oxygen, create environments essential for aquatic organisms to survive and grow. At the bottom of the lake, sediment diatoms, a type of algae that live on the bottom and leave fossil remains, allow examination of current water quality conditions, such as phosphorus levels, along with historical conditions. These indicators of stress were selected because water quality stressors impact the biological health of lakes– from primary producers (phytoplankton or algae) to small openwater animals (zooplankton) to macroinvertebrates (insects, mollusks and crustaceans) and fish.

Launching a field survey boat in Kansas.
Photo courtesy of Ben Potter.

Lake Habitats

Lakes are highly interactive systems. The physical and chemical make-up of a lake supports a specialized community of biological organisms unique to the surrounding environment. Lakes and ponds are still-water habitats that host a large array of floating organisms that cannot survive in flowing water. For many organisms, shoreline and shallow water habitats provide refuge from predation, living and egg-laying substrates, and food. In addition to aquatic inhabitants, a wide number of terrestrial animals rely on lakes for their food. For example, in a typical summer, a moose can eat over 17½ lbs of aquatic plants per day. A 3½ lb adult osprey can consume some 270 lbs of fish in one year

The indicators include both the vegetation and physical features along shorelines and adjacent upland areas. Shoreline structure affects nutrient cycling, biological production, and even sedimentation rates within the lake. The zone of transition between the lakeshore and the water's edge is an area where considerable biological interactions occur and is critically important to benthic communities, fish, and other aquatic organisms. The relationship between the terrestrial and aquatic environments is characterized by the movement of nutrients/food from the shore to the water (*e.g.,* fish making use of emergent plants for food or shelter), and the reverse movement from the water back to the shore (*e.g.,* seasonal flooding of shorelines, shore birds feeding on aquatic insects and crustaceans).

Human activities along lakeshores often adversely affect ecosystem functions by lessening the amount and type of optimal habitat available. Habitat cover or protection, in the form of woody snags, overhanging trees, and aquatic plants, becomes markedly reduced. A poor habitat cover adversely impacts aquatic plants, fish, and other living things in and around the lake. Alterations of these and other types of habitat features can affect biological integrity even in lakes where the water is not polluted. Therefore, the physical habitat condition of the land-water interface is critically important to overall lake condition.

Field Sampling

In preparation for the survey, each target lake was screened to verify that it met the established criteria for inclusion in the survey. Throughout the summer of 2007, 86 field crews, consisting of 2 to 4 people each, sampled lakes from Maine to California. To ensure consistency in data collection and quality assurance, the crews attended a three-day training session, used standardized field methods and data forms, and followed strict quality control protocols including field audits.

At each lake site, crews collected samples at a single station located at the deepest point in the lake and at ten stations around the lake perimeter (Figure 4). At the mid-lake station, depth profiles for temperature, pH, and dissolved oxygen were taken with a calibrated water quality probe meter or multi-probe sonde. A Secchi disk was used to measure water clarity and depth at which light penetrates the lake (the euphotic zone). NLA analysts used these vertical profile measurements to determine the extent of stratification and the availability of the appropriate temperature regime and level of available oxygen necessary to support aquatic life. Single grab water samples were collected to measure nutrients, chlorophyll-*a*, phytoplankton, and the algal toxin microcystin. Zooplankton samples were collected using a fine mesh (80μm) and course mesh (243μm) conical plankton net.

A sediment core was taken to provide data on sediment diatoms and mercury levels. The top and bottom layers of the sediment core were analyzed to detect possible changes in diatom assemblages over a period of time.

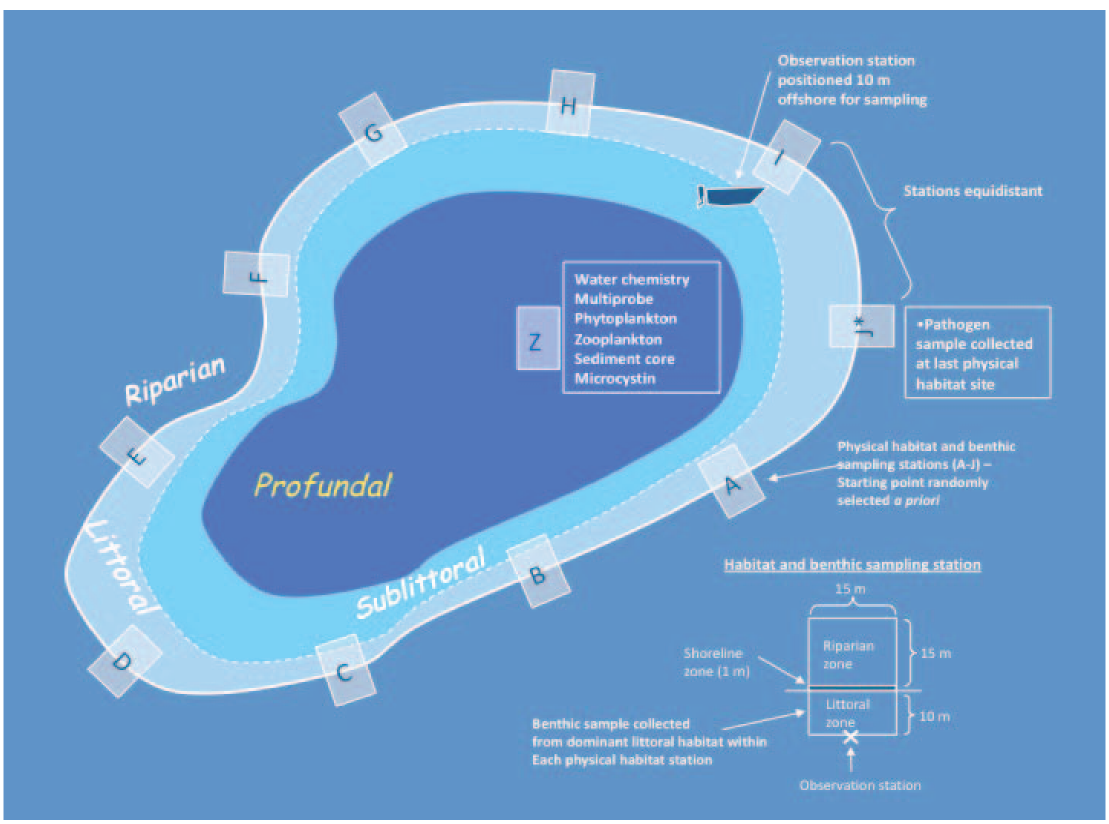


Figure 4. NLA sampling approach for a typical lake. Sampling locations are denoted by letters A-J and Z. Riparian, littoral, sublittoral, and profundal lake zones are depicted, as is the schematic design of a shoreline physical habitat station.

Along the perimeter of the lake, crews collected data and information on the physical characteristics that affect habitat suitability. Information on substrate composition was recorded along the ten pre-determined stations. Benthic macroinvertebrates, collected with a 500µm D-frame net, and water samples for pathogen analysis were collected at the first and last station, respectively. Filtering and other sample preparations took place back on shore. Sampling each lake took a full day and many crews spent weeks in the field. At the end of the season, field crews collected 8,536 water and sediment samples; took over 5,800 direct measurements; and recorded in excess of 620,000 observations.

Setting Expectations

Two types of assessment thresholds were used in the NLA. The first is fixed thresholds. Fixed thresholds are based on longstanding accepted values from the peer reviewed scientific literature. They are well established, and widely and consistently used. An example of this is standard chlorophyll-a thresholds which are used to classify lakes into the different trophic categories.

The second type of threshold is based on the distribution (*i.e.,* the range of values) of a particular indicator derived from the reference lakes data.

Selecting Reference Lakes

In order to assess the condition of the country's lakes, results were compared to conditions in a suite of "reference lakes." A reference lake in the NLA is a lake (either natural or man-made) with attributes (such as biological or water quality) that come as close as practical to those expected in a natural state, *i.e.*, least-disturbed lake environment. NLA analysts used the reference distribution as a benchmark for setting thresholds for good, fair, and poor condition for each of the indicators.

EPA's experience with past surveys showed that only a small portion of the sampled population of lakes will be of reference quality. EPA used both identified lakes that were thought to be of high quality as well as high quality lakes from the random site selection process to serve as candidate reference lakes that might ultimately serve as "least-disturbed" benchmark reference sites. The candidate lakes were sampled identically to, and in addition, to the target lakes. Subsequently, data results from all sampled lakes were evaluated against the reference screening criteria to determine the final set of lakes that would be used to characterize the reference condition. NLA analysts used a number of independent variables reflecting human influence as classification and screening criteria, *e.g.*, limnological shoreline index, chloride content, total water column calcium, and others. Two parallel groups of reference lakes were set, one for biological condition, and another for

Retrieving a sediment core.
Photo courtesy of Great Lakes Environmental Center.

nutrient stressors. The latter set of reference sites was developed so that nutrient levels could be used in screening reference lakes for biological condition.

When considering reference condition, it is important to remember that many areas in the United States have been altered - with natural landscapes transformed by cities, suburban sprawl, agricultural development, and resource extraction. To reflect the variability across the American landscape, these least-disturbed lakes diverge from the natural state by varying degrees. For example, highly remote lakes like those in the upper elevation wilderness areas of Montana may not have changed in centuries and are virtually pristine, while the highest quality, least-disturbed lakes in other parts of the country, especially in urban or agricultural areas, may exhibit different levels of human disturbance. The least-disturbed reference sites in these widely influenced watersheds display more variability in quality than those in watersheds with little human disturbance. Thus in reference conditions across the country, *i.e.,* the "bar" for expectations may be different. The resulting reference lakes represent the survey team's best effort at selecting lakes that are the least disturbed nationally and in specific regions across the country.

Thresholds – Good, Fair, and Poor

After the reference lakes were selected and reference condition was determined, thresholds against which the target lakes are compared were set. For NLA, each indicator for a lake was classified as either "good," "fair," or "poor" relative to the conditions found in reference lakes. That is, "good" denotes an indicator value similar to that found in reference lakes, "poor" denotes conditions definitely different from reference conditions, and "fair" indicates conditions on the borderline of reference conditions. Specifically, these thresholds are then applied to the results from the target lakes and are classified as follows: lake results above 25% of the reference range values are considered "good;" below the 5% of the reference range value are "poor;" and those between the 5% and 25% are "fair" (Figure 5). These "good," "fair," "poor" designations however are not intended to be a replacement for the evaluation by states and tribes of the quality of lakes relative to specific water quality standards.

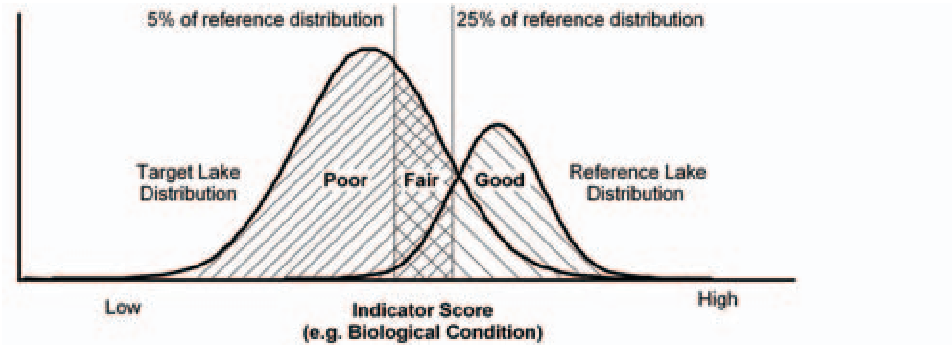


Figure 5. Reference condition thresholds used for good, fair, and poor assessment.

HIGHLIGHT

Surveying the Nation's Lakes for Invasive Aquatic Species

Amy P. Smagula
New Hampshire Department of Environmental Services

On every continent, in nearly all aquatic habitat types, at all levels of the food web, invasive species have made an impact. Invasive aquatic species can be described as those species that live in water but are generally not native to a particular waterbody. In general they have traits or characteristics that suggest a competitive ecological advantage over native species. Invasive species grow rapidly and/or aggressively, so that they can eventually dominate a habitat to the detriment of native creatures that already live there. Invasive aquatic species include a whole range of organisms, including plants, animals, pathogens, and others.

Invasive Aquatic Species:

- Grow very quickly and spread rapidly to occupy large areas;
- Have various strategies for reproduction;
- Survive in a range of conditions;
- Have no natural predators to control them;
- Take over areas from native plants/animals and can thus be ecologically devastating;
- Pose serious economic problems in terms of control costs and costs attributable to habitat loss and recreational impairments to waterbodies, including reductions in property values on infested waterbodies;
- Are very difficult if not impossible to control; and
- Threaten nearly half of the species listed under the Endangered Species Act.

The types of invasive aquatic species in our lakes are numerous and diverse, and can include aquatic plants that either root in substrate (like Eurasian watermilfoil or Hydrilla) or that float on the surface of the water (like the giant salvinia). They include larger animals such as fish (like the snakehead fish), and macroinvertebrates (like the zebra mussel). They also include those seen only with the aid of a microscope, such as filamentous algae or the spiny water flea.

The pathways for invasive aquatic species introductions are varied, and include ballast water discharges from large vessels, retail industries like the aquarium and home water garden trades, and even internet suppliers of aquatic species. Once a species becomes established in a waterbody, either by accidental (*e.g.*, contaminated boat) or intentional means (*e.g.*, dumping of an aquarium or direct planting), it is transient recreational equipment (motor boats, kayaks, diving gear, *etc.*) that causes the lake-to-lake spread of these species.

Depending on the point of introduction and transport pathways, species can become widely distributed or remain as localized infestations. Unfortunately, many invasive aquatic species are highly adaptive, and can survive and thrive in a wide range of environmental conditions. Big or small, plant or animal, invasive aquatic species in our lakes can have detrimental effects on the very attributes of those waterbodies that scientists, citizens, and environmental stewards are trying to evaluate and preserve.

How Can Data from the NLA Survey Help?

One of the goals of the National Lakes Assessment (NLA) is to provide citizens and governments with current information on the health of our lakes so that they can take action to prevent further degradation. Data on invasive aquatic species can be used to help determine which of these species has been documented in a state or region, and if those are well established populations or if they are pioneering and can be eliminated or halted before other waterbodies in the area are affected. These data may also be used to assist with risk assessments for an area, based on what has been found in neighboring states, coupled with tourism and recreational data for that region.

The Key is Prevention, Early Detection, & Rapid Response

Preventing the introduction of invasive aquatic species is paramount to protecting a waterbody. Many states and regional working groups have established education campaigns to alert lake users and others about the threats posed by invasive aquatic species and to hopefully prevent a new infestation by proper care of transient recreational vessels and gear. Additionally, many states have developed prohibited species lists in an effort to prevent overland transport and sale of these invasive species.

When prevention fails and an infestation does occur, early detection is critical. Individual lake associations, special interest groups, and homeowners are encouraged to look for new infestations on a regular basis during the growing season, particularly if they live on a waterbody that receives a high level of use by transient boaters. A small new infestation is much more easily contained or eradicated than a dense and large-scale infestation. A network of volunteer monitors around a waterbody can look for signs of invasive species and report to key officials who can effectively deal with a potentially new infestation.

State officials should be knowledgeable and poised for a rapid response to contain and control an infestation. They should be aware of appropriate management actions for the species in question and how to best approach the problem. Fortunately, many states have developed specific plans for aquatic nuisance species management, so that an immediate response can be made.

Hydrilla ***(Hydrilla verticillata)***	**First Identified in US:** 1960 **Native Range:** Africa **U.S. Distribution:** Widespread throughout the east and southeast, CA as well as occurrence in other states in the U.S. **Description:** Narrow leaves whorled around the 20 ft main stem. It is the most invasive submergent plant in the U.S., and can even out-compete invasive watermilfoil by canopying over the surface. It has been observed to grow up to a half-inch per day in optimum conditions. **Impacts:** This plant forms thick impenetrable growth in the water column of lakes. It can impact native aquatic plants and animals and cause problems for recreation and navigation on waterbodies that it infests.	
Zebra mussel ***(Dreissena polymorpha)***	**First Identified in US:** 1988 **Native Range:** Eurasia **U.S. Distribution:** All of the Great Lakes and many associated tributaries, plus other states throughout the U.S. **Description:** Sticky strands secreted from one side of shell. Can grow very thick on surfaces. **Impacts:** Documented to grow very thick on surfaces, foul marine engines, clog intake pipes, wash up in windrows on beaches, and alter the aquatic food web by reducing the amount of algae in the water due to high filter-feeding rates.	

Photos credits: Hydrilla, Amy P. Smagula, NH DES. Zebra mussels, NH SeaGrant.

CHAPTER 3. THE BIOLOGICAL CONDITION OF THE NATION'S LAKES

IN THIS CHAPTER

- Lake Health – The Biological Condition of Lakes
- Stressors to Lake Biota
- Ranking of Stressors

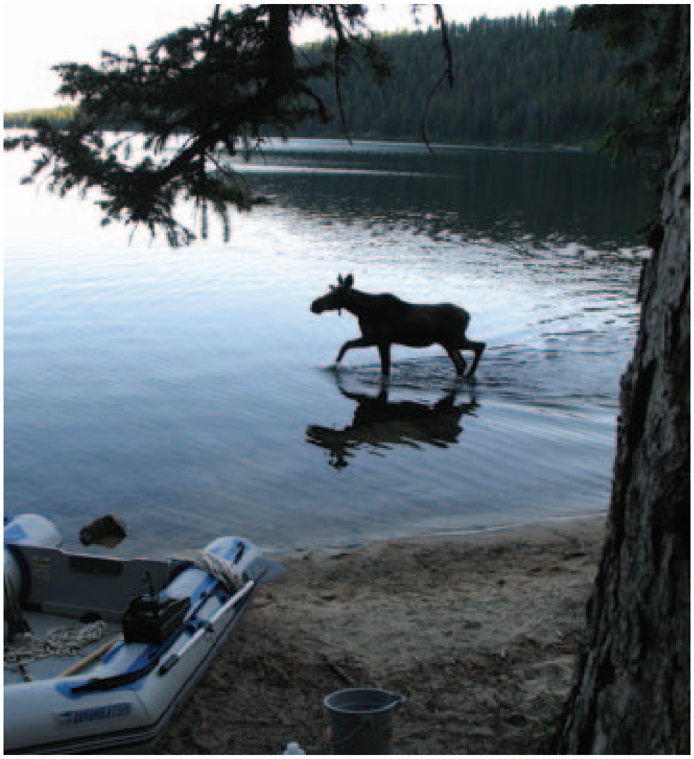


Photo courtesy of Great Lakes Environmental Center

Chapter 3

The Biological Condition of the Nation's Lakes

The Clean Water Act explicitly aims "to restore and maintain the chemical, physical and biological integrity of the nation's waters". Although the NLA report does not include all aspects of biological integrity or review all possible chemical, physical or biological stressors known to affect water quality, it does present the findings of some important indicators for estimating the condition of the nation's lakes and characterizing the key influences.

This and the following two chapters describe the results of the NLA using three approaches to assess lake condition. The first approach evaluates whether lakes are able to support healthy aquatic plant and animal communities. Analysts evaluated key stressors to lake biota, such as chemical and physical habitat attributes, and ranked the stressors in order of importance. In the second approach, the recreational suitability of lakes was assessed and the risk of exposure to algal toxins was evaluated (Chapter 4). The third approach was to evaluate trophic state based on chlorophyll-*a* levels (Chapter 5).

Lake Health – The Biological Condition of Lakes

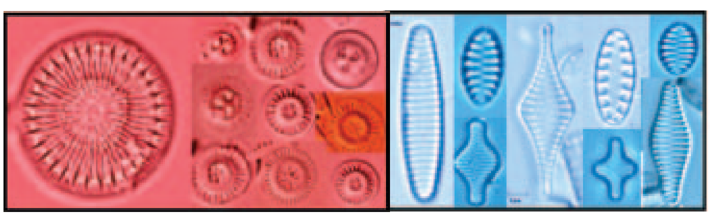
The biology of a lake is characterized in terms of the presence, number, and diversity of fish, insects, algae, plants and other organisms that together provide accurate information about the health and productivity of the lake ecosystem. The number and kinds of plant and animal species present in a lake system are a direct measure of a lake's overall well-being.

The biological condition assessment is based on information from two biological communities or assemblages – phytoplankton and zooplankton — in its evaluation of lake condition. The primary basis for assessing biological health is an index of taxa loss which is applied to the phytoplankton and zooplankton data. The NLA uses a measure of planktonic taxa loss as the predominant measure of overall lake condition because it is based on both plant and animal data and thus will reflect a broader perspective of trends in lakes. A second method to assess biological health uses an index of biotic integrity that is applied to sediment diatoms, a distinct type of phytoplankton. Both models use the biological reference conditions developed from the set of reference lakes.

Biological Indicators

Phytoplankton. Phytoplankton are microscopic plants (algae) that float in the water and are usually responsible for both the color and clarity of lakes. Because of their ability to photosynthesize (*i.e.,* they use the sun's energy to turn carbon dioxide and water into food and energy), they are a primary source of energy in most lake systems, providing the food source for higher order organisms such as zooplankton or small fishes. Phytoplankton are remarkably diverse. For example, certain phytoplankton can regulate the depth at which they reside, optimizing their ability to access both nutrients and light. Others are specific to certain habitats within lakes, and to certain nutrient and chemical conditions.

Zooplankton. Zooplankton are small free-floating aquatic animals. The zooplankton community constitutes an important element of the aquatic food chain. These organisms serve as an intermediary species in the food chain, transferring energy from planktonic algae (primary producers) to larger invertebrate predators and fish. Both phytoplankton and zooplankton are highly sensitive to changes in the lake ecosystem. The effects of environmental disturbances can be detected through changes in species composition, abundance, and body size distribution of these organisms.



Centrate (left) and pinnate (right) diatoms.
Image courtesy of J. Smol as provided by D. Charles.

Diatoms. Diatoms are a group of algae. Typically abundant in marine and freshwater habitats, diatoms account for at least 20% of the primary production of energy on earth. Unique among the algae, diatoms have cell walls composed of silica (glass), which are intricate and beautiful as well as useful

Collecting a zooplankton sample in Texas.
Photo courtesy of Texas Commission of Environmental Quality.

for identifying individual species. In lakes, diatoms grow suspended in water as well as attached to substrates. Biologists use the diatoms in the water column and those on the lake bottom as a reflection of conditions in the lake. When diatoms die, they settle to the bottom and their silica shells remain intact. Over time their silica shells are preserved in layer upon layer of lake sediments enabling researchers to look at conditions that existed in the past. Similar to other biological indicators, diatoms integrate the physical and chemical conditions of the lake and surrounding watershed in which they reside. The environmental conditions under which particular diatom species flourish vary greatly and have been well described, making them a useful indicator.

Index of Taxa Loss – The Observed/Expected (O/E) Ratio

NLA analysts used the planktonic O/E taxa loss model to assess the condition of the planktonic community, combining data from both phytoplankton and zooplankton. The O/E measure looks at whether or not organisms (taxa) one would expect to find, based on reference lakes, are in fact present. The model allows a precise matching of the taxa found in the sample — in this case phytoplankton and zooplankton taxa — with those that should occur under the specified natural environmental conditions defined by the reference sites. The list of expected taxa (or "E") at individual sites are predicted from a model developed from data collected at reference sites. By comparing the list of taxa observed (or "O") at a site with those expected to occur, one can quantify the proportion of taxa that have been lost presumably due to stressors present in the lake. The O/E model is widely used nationally and internationally to assess the condition of aquatic communities. The index is particularly attractive because it allows a direct comparison of conditions across the different types of aquatic systems (*e.g.*, lakes, wetlands, streams, and estuaries) that will be assessed by the national aquatic resource surveys.

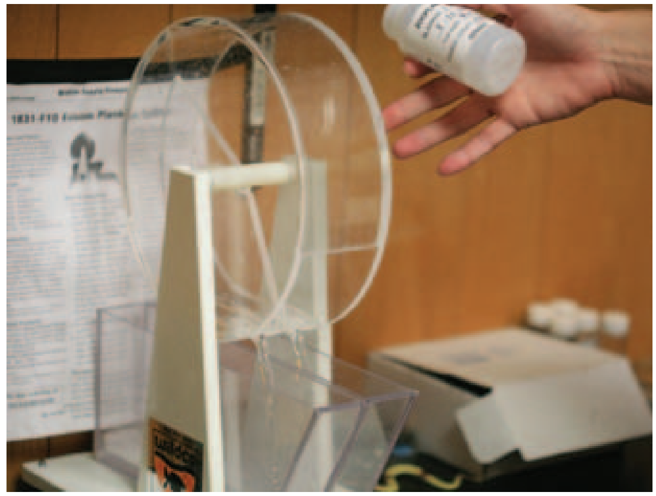
Measuring physical habitat data with flooded terrestrial vegetation. Photo courtesy of Dave Mercer.

Typically O/E values are interpreted as the percentage of the expected taxa present. Each tenth of a point less than 1 represents a 10% loss of taxa at the site; thus, an O/E score of 0.9 indicates that 90% of the expected taxa are present and 10% are missing. The higher the percentage, the healthier the lake. As with all indicators, O/E values must be interpreted in context of the quality of reference sites because the quality of reference sites available in a region sets the bar for what taxa may be expected. Regions with lower-quality reference sites may have fewer taxa or different taxa and thus will have a lower bar. Although an O/E value of 0.8 means the same thing regardless of a region, *i.e.*, 20% of taxa have been lost relative to reference conditions in each region, the true amount of taxa loss will be under-estimated if reference sites are of lower quality, meaning more disturbed than reference sites in comparable regions.

For the phytoplankton and zooplankton data, NLA analysts developed regionally-specific O/E models to predict the extent of taxa loss across lakes of the United States. They defined three categories of plankton taxa loss: good (<20% taxa loss), fair (20-40% taxa loss), and poor (>40% taxa loss).

Index of Biological Integrity - The Lake Diatom Condition Index

The Lake Diatom Condition Index (LDCI) — or the Diatom IBI — is similar in concept to an economic indicator (*e.g.*, the Consumer Confidence Index) in that the total index score is the sum of scores for a variety of individual measures. To calculate economic indicators, economists look at a number of metrics, including new orders for consumer goods, building permits, money supply, and others that reflect economic growth. To determine the LDCI, ecologists looked at taxonomic richness, habit and trophic composition, sensitivity to human disturbance, and other aspects of the assemblage that are reflective of a natural state. For the LDCI, NLA analysts calculated regionally-specific thresholds that were based on percentages of reference lake distributions of LDCI values.[2]



Subsampling zooplankton samples.
Photo courtesy of EcoAnalysts.

The development of the LDCI is a groundbreaking addition to the tools available to perform lake assessments. The metrics used to develop the LDCI for the NLA covered five characteristics of diatom assemblages that are routinely used to evaluate biological condition:

Taxonomic richness: This characteristic represents the number of distinct taxa, or groups of organisms, identified within a sample. A greater number of different kinds of taxa, particularly those that belong to pollution-sensitive groups, indicate a variety of physical habitats and an environment exposed to generally lower levels of stress.

Taxonomic composition: Ecologists calculate composition metrics by identifying the different taxa groups, determining which taxa in the sample are ecologically important, and comparing the relative abundance of organisms in those taxa to the whole sample. Healthy (good quality) lake systems have diatoms from across a larger number of taxa groups, whereas stressed (poor quality) lakes are often dominated by a high abundance of organisms in a small number of taxa that are tolerant of pollution.

Taxonomic diversity: Diversity metrics look at all the taxa groups and the distribution of organisms among those groups. Healthy lakes should have a high level of diversity of diatoms present.

Morphology: Organisms are characterized by certain adaptations, including how they move and where they live. These habits are captured in morphological metrics. For example, some are designed to move freely up and down within the water column to maximize nutrient uptake or light exposure, while others may develop adaptations, such as coloration, to avoid predation. A diversity of such attributes is reflective of a lake that naturally includes a diversity of habitat niches.

Pollution tolerance: Each taxa can tolerate a specific range of chemical contamination, which is referred to as their pollution tolerance. Once this range is exceeded, the taxa are no longer present. Highly sensitive taxa, or those with a low pollution tolerance, are found only in lakes with good water quality.

[2] The numerical threshold for the diatom index and many of the other NLA indicators can be found in the Technical Appendix.

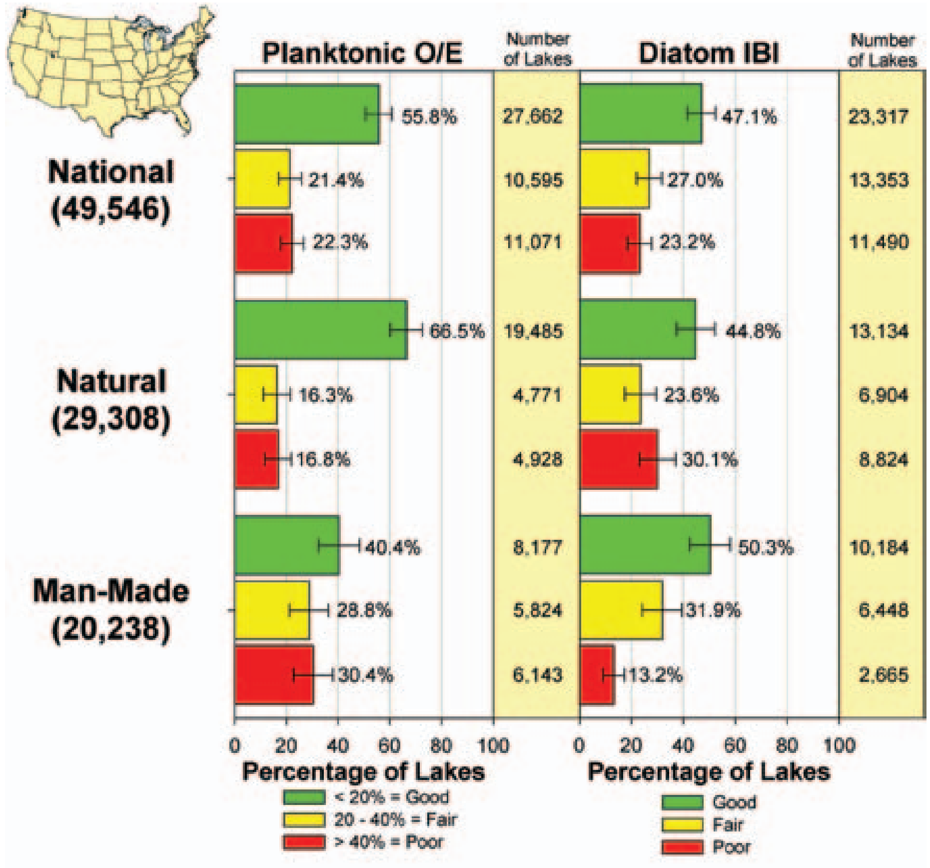


Figure 6. Assessment of quality using the Planktonic O/E Taxa Loss and Lake Diatom Condition Index.[3]

Findings of the Biological Assessments

Using the planktonic O/E, or taxa loss model, 56% of the nation's lakes are in good condition, while 21% are in fair condition, and 22% are in poor condition (Figure 6). The LDCI shows similar results with 47% of lakes in good condition, 27% in fair condition, and 23% in poor condition. For the continental U.S., this means about half of the country's lakes are in good condition, while the other half are experiencing some level of stress that is negatively affecting the aquatic biological communities.

Natural lakes in general exhibit slightly lower overall plankton taxa loss than man-made lakes. Sixty-seven percent of natural lakes are in good condition as compared to 40% of man-made lakes - a statistical difference. The LDCI, on the other hand, indicates that the proportion of lakes exhibiting good conditions does not vary significantly between natural and man-made lakes. However, 30% of natural lakes as compared to 13% of man-made lakes exhibit poor biological condition based on the diatom LDCI.

Although in many cases the results of the planktonic O/E analysis are similar to the results of the diatom LDCI analysis, such agreement will not always occur. The taxa loss index examines a specific aspect of biological condition (biodiversity loss) and the index of biological integrity analysis

[3]For this and all figures in this report, values for good, fair and poor may not add to one hundred percent. Lakes sites that were not assessed and indicators for which no data was recorded are not included. Please refer to the Technical Appendix for further discussion.

combines multiple characteristics to evaluate biological condition. In this instance, the two communities may be responding differently to the stresses impacting lakes or to different stresses.

Stressors to Lake Biota

In the aquatic environment, a stressor can be anything (chemical, biological or physical) that has the potential to impact its inhabitants by altering their surroundings outside their normal ecological range. There are many external occurrences that can alter a creature's ability to thrive, both natural and otherwise. Drought or rapid draw-down can be a stressor; contaminant (*e.g.,* metals) can be a stressor; and human activity can be a stressor. An important dimension of the national lakes assessment is to evaluate key chemical and physical stressors of lake quality that, when altered, have the potential to impact lake biota.

1. Chemical Stressors

For the assessment, five of the eight chemical indicators of lake stress were evaluated. These are total phosphorus concentration, total nitrogen concentration, turbidity, acid neutralizing capacity (ANC), and dissolved oxygen concentration (DO).

Phosphorus, Nitrogen, and Turbidity

Phosphorus and nitrogen are critical nutrients required for all life. In appropriate quantities, these nutrients support the primary algal production necessary to support lake food webs. 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 in lakes. This also means that modest increases in available phosphorus can cause very rapid increases in algal growth. Some lakes are limited by nitrogen. In these lakes, modest increases in available nitrogen will yield the same effects. When excess nutrients from human activities enter lakes, cultural eutrophication is often the result. The culturally-accelerated eutrophication of lakes has a negative impact on everything from species diversity to lake aesthetics.

Turbidity is a measure of light scattering, specifically, murkiness or lack of clarity. Lakes that are characterized by high concentrations of suspended soil particles and/or high levels of algal cells will have high measured turbidity. Turbidity in lakes is natural in some instances, resulting from natural soil deposition and resuspension within the lakes themselves. When human activities in lake watersheds and riparian zones increase soil erosion, increased turbidity often results in smothering of nearshore habitats by sediments and/or changing algae growth patterns. These changes affect biological and recreational conditions.

Boat fully loaded for a day on an Oklahoma lake.
Photo courtesy of Paul Koenig.

Findings for Nutrients and Turbidity

Phosphorus, nitrogen, and turbidity are linked indicators that jointly influence both the clarity of water and the concentrations of algae in a lake. The levels of these three indicators vary regionally, as do the relationships between nutrients and turbidity, and between nutrients and algal growth. For phosphorus, nitrogen, and turbidity, lakes were assessed in relation to regionally-specific thresholds based on the distributions in a distinct set of reference lakes.

Survey results show that slightly over half of the nation's lakes are in good condition with respect to phosphorus and nitrogen (Figure 7). Fifty-eight percent and 54% of lakes are not stressed for the two nutrients, respectively. For all lake classes there was no significant difference between phosphorus and nitrogen indicators. For both nutrients, there are no significant differences between natural lakes and man-made lakes.

For turbidity, 78% of lakes are in good condition, 16% are in fair condition, and 6% are in poor condition. When comparing the natural lakes to the man-made lakes for this indicator, 75% of natural lakes are in good condition as compared to 81% of man-made lakes.

Lake Acidification

While not a widespread problem, lake acidification continues to be an important indicator of lake condition in a small number of areas around the country. Acid rain and acid mine drainage are major sources of acidifying compounds and can change the pH of lake water, impacting fish and other aquatic life. Acid neutralizing capacity

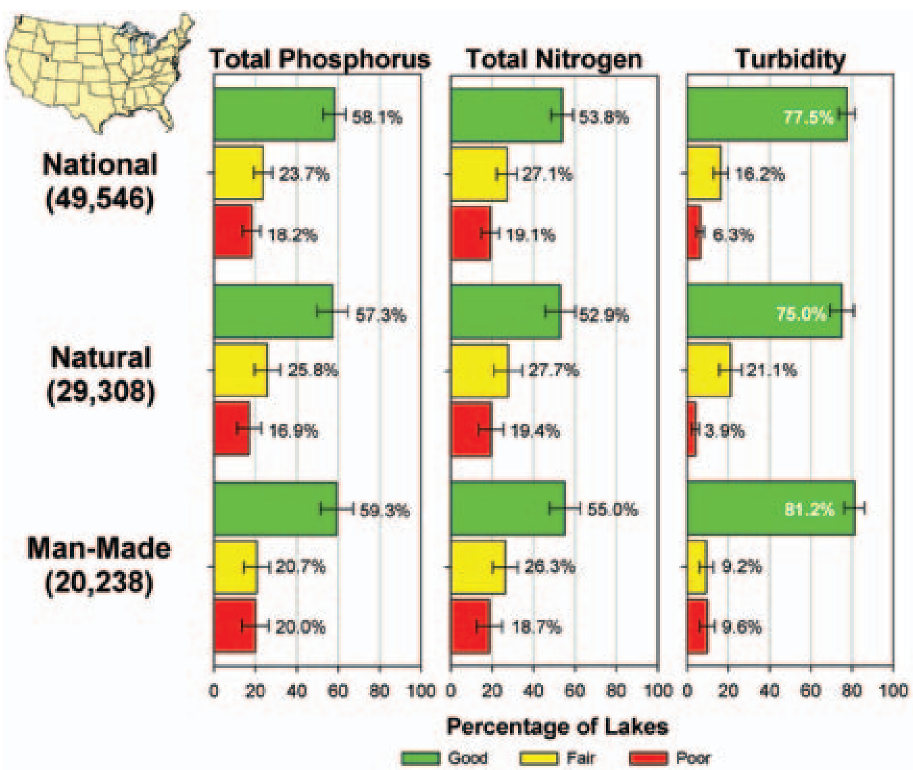


Figure 7. Phosphorus, nitrogen, and turbidity in three lake classes.

ANC Assessment Thresholds	
Non-acidic	>50 µeq ANC
Acidic-natural	≤ 50 µeq ANC and DOC ≤ 5 mg/L
Anthropogenically acidified	≤0 µeq ANC and DOC < 5 mg/L

(ANC) serves as an indicator for 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 and contain fewer acid-neutralizing ions have low ANC and therefore a predisposition to acidification.

Maintaining stable and sufficient ANC is important for fish and aquatic life because ANC protects or buffers against drastic pH changes in the waterbody. Most living organisms, especially aquatic life, 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.

Findings for Lake Acidification

Results from the NLA indicate that almost all, or 99%, of the nation's lakes can be classified as in good condition with respect to ANC (Figure 8). When looking at these results, however, it is also important to note that although the NLA indicates that lake acidification is not a widespread problem, acidification on a smaller scale, *i.e.*, "hot spots," do occur. While only a relatively small proportion of lakes may be impacted by acidification, the effects of acidification in the impacted lakes, and the contribution of acidity to other stressors, can be severe in specific geographic regions.

Dissolved Oxygen

Dissolved oxygen, or DO, is considered one of the more important measurements of water quality and is a direct indicator of a lake's ability to support aquatic life. Aquatic organisms have different DO requirements for optimal growth and reproduction. Decreases in DO can occur during winter or summer when the available dissolved oxygen is consumed by aquatic plants, animals, and bacteria during respiration. While each organism has its own DO tolerance range, generally levels below 3 mg/L are of concern. Conditions below 1 mg/L are referred to as hypoxic and are often devoid of life.

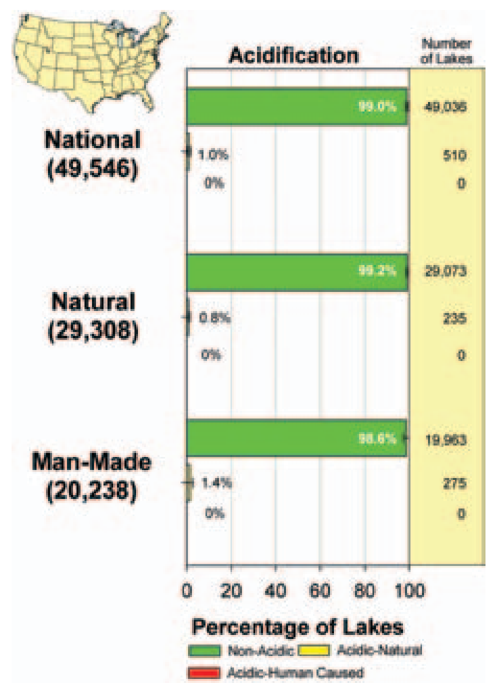


Figure 8. Acid neutralizing capacity for lakes of the U.S.

Findings for Dissolved Oxygen

For the NLA, DO assessment thresholds were established as high (≥ 5 mg/L), moderate (>3 to <5), and low (≤3 mg/L), and were based on measurements from the top two meters in the middle of the lake (Figure 9). Eighty-eight percent of the country's lakes display high levels of DO and are in good condition based on the surface waters sampled (Figure 9). Natural lakes perform slightly better than the nation as a whole with 94% in good condition. Man-made lakes results show 80% with high levels of DO.

These findings indicate that, in general, low DO is not a chronic problem near the lake surface, which was not surprising given the sampling approach used in the survey. Future surveys may be able to more adequately address DO conditions in the bottom waters of lakes where low DO conditions are more likely to occur first.

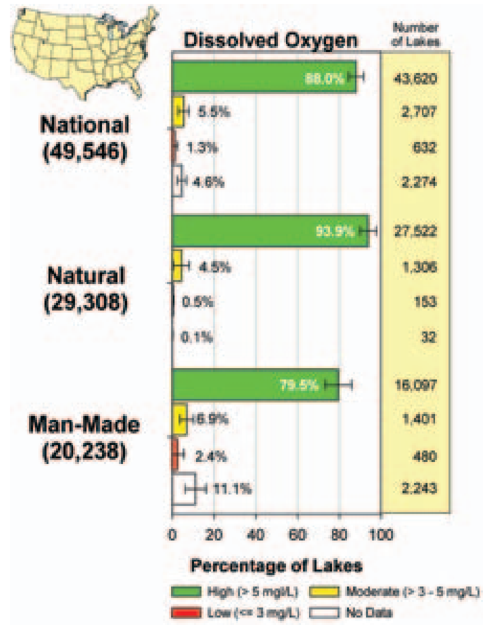


Figure 9. Dissolved oxygen for lakes of the U.S.

2. Physical Stressors

The condition of lakeshore habitats (Figure 10) provides important information relevant to lake biological health. For the NLA, physical habitat condition was assessed based on observations for four indicators: 1) lakeshore habitat, 2) shallow water habitat, 3) physical habitat complexity (an index of habitat condition at the land-water interface), and 4) human disturbance (extent and intensity of human activity). In assessing the physical habitat complexity indicator, NLA analysts looked at not only the total amount of cover present but also the diverse types of cover and the complex nature of potential ecological niches. For each lake habitat indicator, values were compared to the distribution of the indicator value in the reference sites.

Lakeshore Habitat

The lakeshore habitat indicator examines the amount and type of shoreline vegetation. It is based on observations of three layers of coverage (understory grasses and forbs, mid-story non-woody and woody shrubs, and overstory trees). In general, lakeshores are in better condition when shoreline vegetation cover is high in all three layers. It is important to note, however, that not all three layers naturally occur in all areas of the country. For example, in the Northern Plains areas, there is typically no natural overstory tree cover. Similarly, in some areas of the intermountain west, steep rocky shores are the norm for high-mountain and/or canyon lakes. These natural features have been factored into the calculation of the lakeshore habitat indicator.

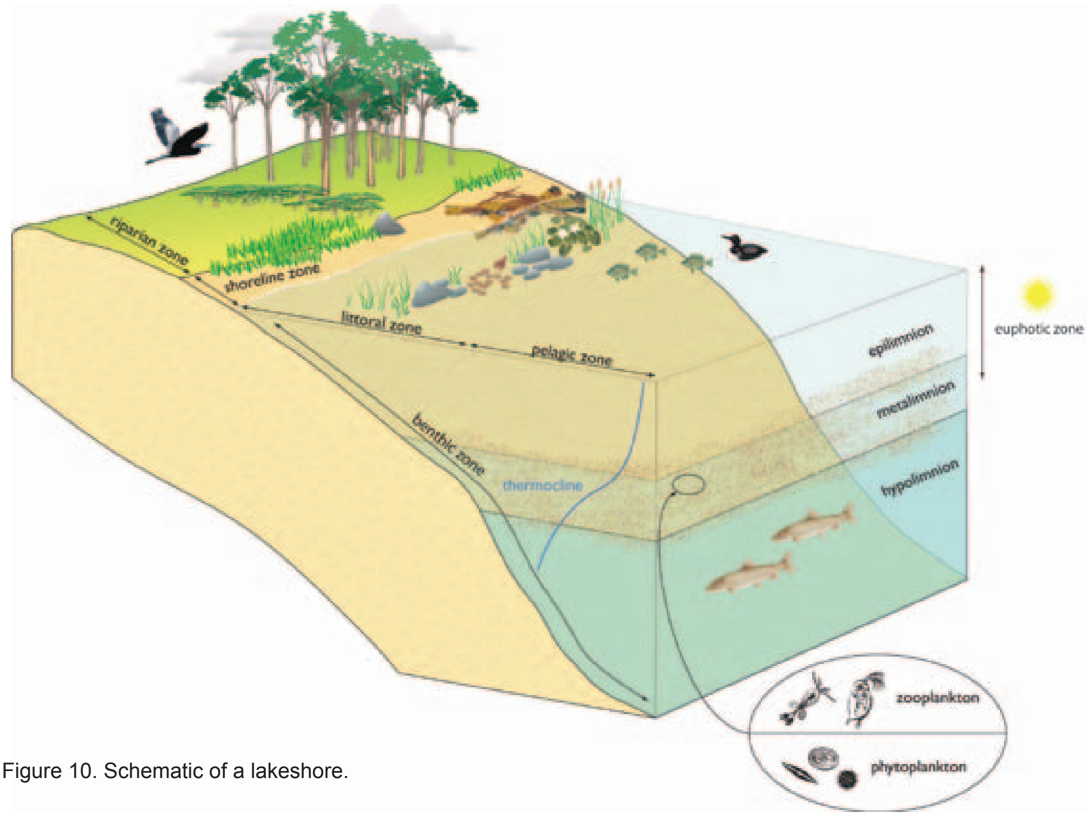


Figure 10. Schematic of a lakeshore.

Shallow water habitat

The shallow water habitat indicator examines the quality of the shallow edge of the lake by utilizing data on the presence of living and non-living features such as overhanging vegetation, aquatic plants (macrophytes), 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, and more complex, ecological niches. Like the 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.

Physical habitat complexity

The third indicator, physical habitat complexity, combines data on from the lakeshore and shallow water interface. This indicator estimates the amount and variety of all cover types at the water's edge. Like the other indicators, this index is related to conditions in reference lakes and is modified regionally to account for differing expectations of natural condition.

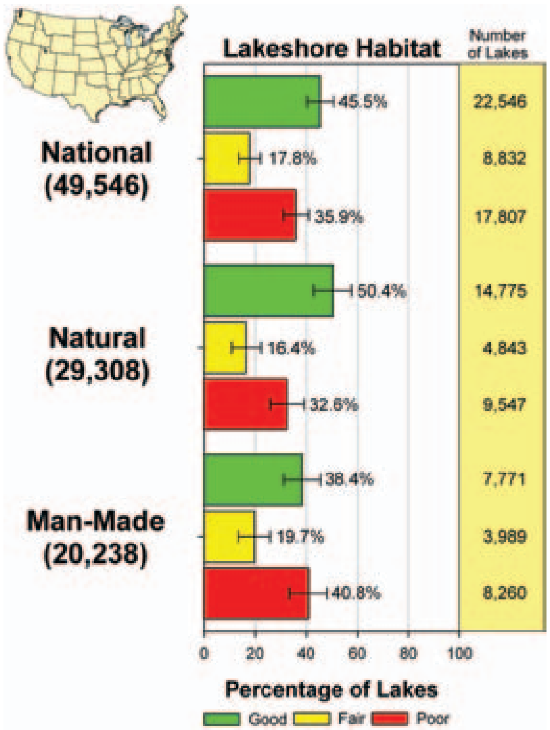


Figure 11. Lakeshore habitat for lakes of the U.S. as percent of lakes in three condition classes.

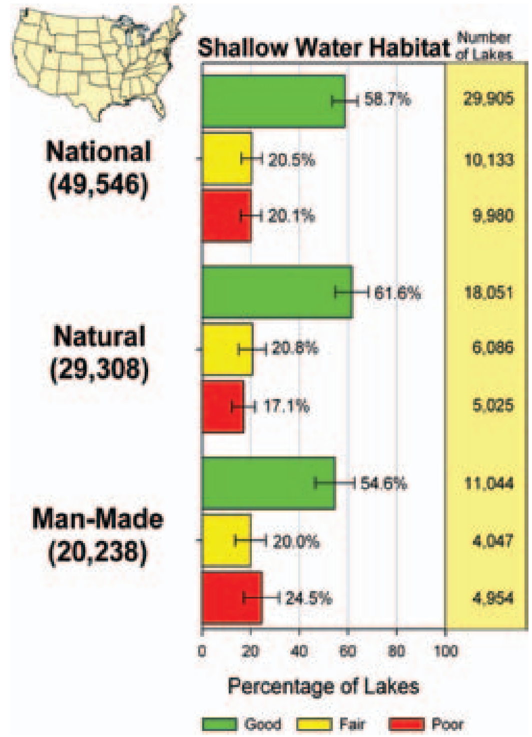


Figure 12. Shallow water habitat for lakes of the U.S. as percent of lakes in three condition classes.

Findings for Habitat Integrity

The findings for the three habitat stressor indicators are depicted in Figures 11, 12 and 13. Nationally, 46% of lakes exhibit good lakeshore habitat condition, while 18% of lakes are in fair condition and 36% are in poor condition. With respect to the shallow water areas of lakes, 59% of lakes exhibit good habitat condition, while 21% of lakes are in fair condition, and 20% are in the most disturbed, or poor condition. For physical habitat complexity of the land/water interface, 47% of lakes are in good condition, 20% of lakes are in fair condition, and 32% are in poor condition. For all three habitat indicators, more natural lakes support healthy combined habitat condition than man-made lakes.

Lakeshore Human Disturbance

In the above discussion of the lakeshore environment, the condition of lakes was described in terms of habitat integrity in both the lakeshore and shallow water areas of the lake. The fourth indicator of physical habitat is lakeshore human disturbance and reflects direct human alteration of the lakeshore itself. These disturbances can range 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 retaining walls and artificial beaches). The effects of lakeshore development on the quality of lakes include excess sedimentation, loss of native plant growth, alteration of native plant communities, loss of habitat structure, and modifications to substrate types. These impacts, in turn, can negatively affect fish, wildlife, and other aquatic communities.

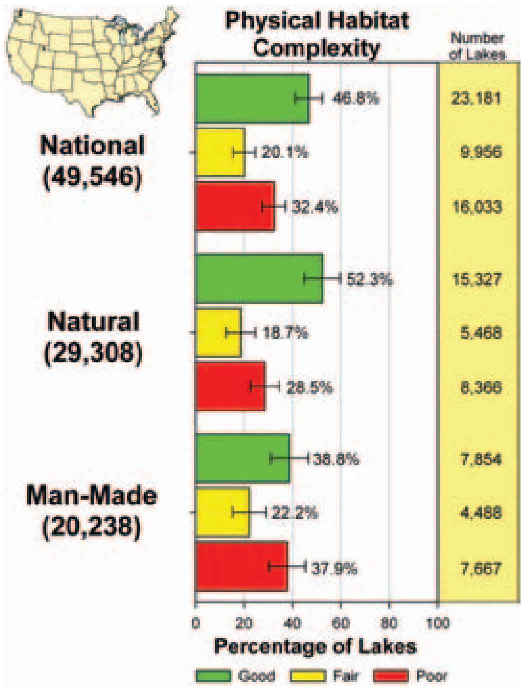


Figure 13. Physical habitat complexity for the lakes of the U.S. as percent of lakes in three condition classes.

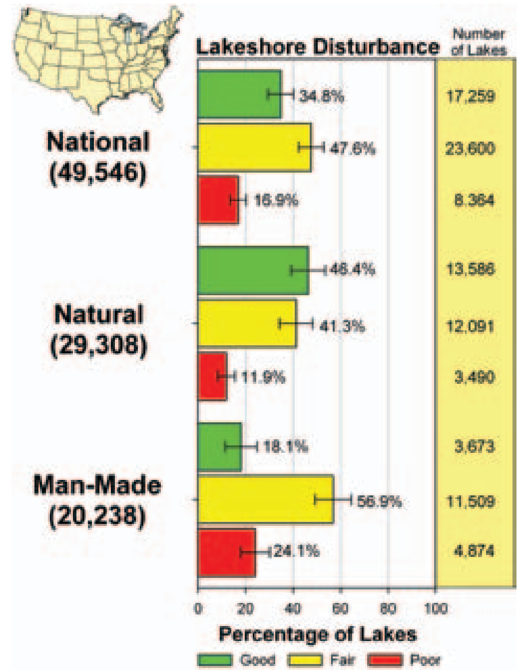


Figure 14. Lakeshore disturbance for lakes of the U.S. as percent of lakes in three conditions classes.

Findings for Lakeshore Disturbance

Across the lower 48 states, 35% of lakes exhibit good conditions representative of relatively low human disturbance levels, while 48% of lakes exhibit moderate disturbance, and 17% exhibit poor, or highly disturbed conditions (Figure 14). In contrast to the other three habitat indicators, the percentage of natural lakes that have minimal lakeshore disturbance is substantially higher than that of man-made lakes. Forty-six percent of natural lakes are in good condition compared to 18% of man-made lakes. These findings also show that there are twice as many man-made lakes with high lakeshore disturbance (poor condition) as natural lakes.

Ranking of Stressors

An important key function of the national assessments is to provide a perspective on key stressors impacting biological condition in lakes and rank them in terms of the benefits expected to be derived from reducing or eliminating these stresses. For the NLA, analysts used three approaches to rank stressors. The first looks at how extensive or widespread any particular stressor is, *e.g.*, how many 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 is 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, the stressors are assessed and reported independently and as such do not sum to 100%. Most lakes are likely to experience multiple stressors simultaneously which can result in cumulative effects rather than those elicited by a single stressor.

Relative Extent

Relative extent is a way of evaluating how widespread and common a particular stressor is among lakes. A stressor with a high relative extent indicates a significant concern. Conversely, stressors that occur over a small area (*i.e.,* hot spots) or that occur over a wide area but are spread out have a low relative extent. It is important for water resource managers to take into account the extent of the stressor when setting priority actions at the national, regional, and state scale.

Nationally, the most widespread stressors measured as part of the NLA are those that affect the shoreline and shallow water areas, which in turn can affect biological condition. Results from the NLA show that the most widespread of these is the alteration of lakeshore habitat.

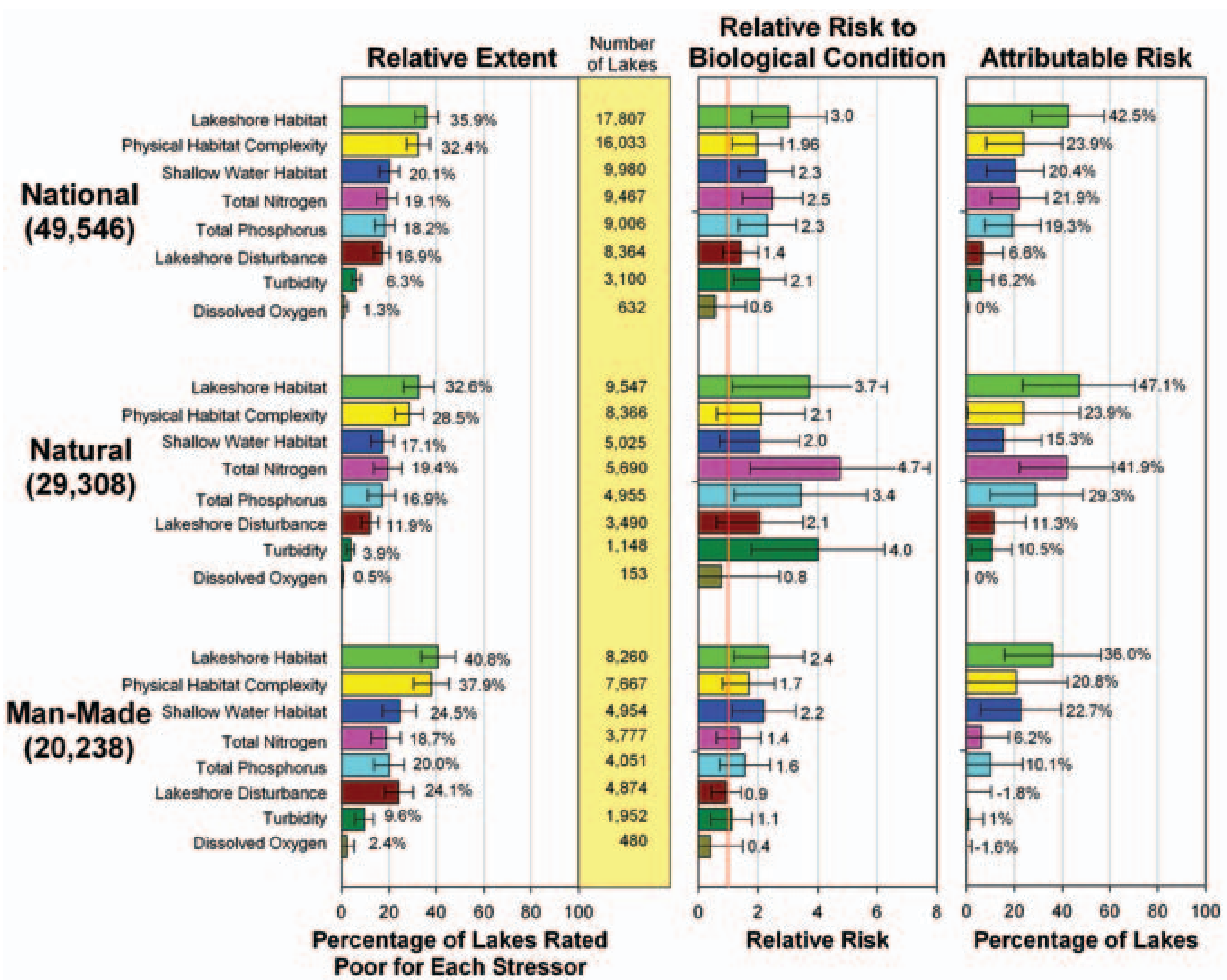


Figure 15. Relative extent of poor stressors conditions. Relative risks of impact to plankton O/E and Attributable risk (combining Relative extent and Relative risk).

Thirty-six percent of lakes nationally have poor lakeshore habitat (Figure 15, left graph). The second most prevalent stressor is physical habitat complexity, which is poor in 32% of lakes nationally. Total nitrogen and total phosphorus ranked fourth and fifth, respectively, in terms of how widespread excess levels are across the country.

The ranking of these stressors according to extent is similar across natural and man-made lakes with most stressors being more widespread in man-made lakes (*e.g.*, lakeshores with poor habitats occurring at 41% of man-made lakes compared with 33% of natural lakes).

Relative Risk

The evaluation of relative risk is a way to examine the severity of the impact of a stressor when it occurs. Relative risk is used frequently in the human health field. For example, a person who smokes is 10-20 times more likely to get and die of lung cancer[4]. Similarly, 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. When these two likelihoods are quantified, their ratio is called the relative risk. For the NLA, only the relative risk of stressor to poor conditions is presented.

Results of the relative risk analyses are presented in the middle graph of Figure 15. The highest relative risk nationally was found for lakeshore habitat disturbance with a relative risk just over 3. This means that lakes with poor surrounding vegetation are about 3 times more likely to also have poor biological conditions, as defined for this assessment. The remaining stressors, with the exception of

Survey crew member records shoreline habitat data.
Photo courtesy of Texas Commission of Environmental Quality.

dissolved oxygen and lakeshore disturbance, have relative risks near 2 (*i.e.*, twice as likely to have poor biological conditions). The relative risks for stressors in natural lakes appear consistently greater than the relative risk values for man-made lakes.

Attributable Risk

As mentioned, attributable risk is derived by combining the relative extent and the relative risk into a single number for the purposes of ranking. Conceptually, attributable risk provides an estimate of the proportion of poor biological conditions that could be reduced if poor conditions of a particular stressor were eliminated. This risk value represents the magnitude or importance of a potential stressor and one that can be ranked and prioritized for policy makers and managers.

Estimates for attributable risk based on the planktonic O/E indicator of biological condition are presented in right graph of Figure 15. Lakeshore habitat alteration has the highest attributable risk for plankton taxa loss while other stressors (with the exception of lakeshore disturbance, turbidity and

[4] Centers for Disease Control. http://www.cdc.gov/cancer/lung/risk_factors.htm

dissolved oxygen) have similar attributable risk values. Thus one might expect that to improve lake condition to the greatest extent, lakeshore vegetative habitat would have to be increased to the point that it is no longer a stressor. Natural lakes show a slightly different pattern in attributable risk with lakeshore habitat being a high priority followed closely by total nitrogen, total phosphorus and physical habitat complexity. For man-made lakes, three of the four habitat indicators rank the highest in attributable risk.

Human shoreline disturbance is an important stressor in lakes. Photo courtesy of Great Lakes Environmental Center.

Lakeshore Alteration Stress

By Kellie Merrell, VT Department of Conservation

Transformation of lakeshores from natural forested and wetland cover to lawns and sandy beaches, accompanied by residential homes development (and redevelopment) is a stressor to many lakes. In a survey of 345 lakes in the Northeast during the early 1990s, the U.S. Environmental Protection Agency and U.S. Fish and Wildlife Service determined that stress from shoreline alteration was a more widespread problem than eutrophication and acidification. In recent years, many state agencies have documented the effects of shoreline development on nearshore and shallow water habitat quality with notable results.

As lakeshores are converted from forests to lawns, lakes are impacted by impervious surfaces, enhanced runoff, less shading, and in most cases, more abundant aquatic plant growth in shallow areas. Shallow water habitat is further simplified by the direct removal of woody structure, and interruption in the resupply of this critical habitat component. The Wisconsin Department of Natural Resources has estimated that unbuffered developed sites contribute five times more runoff, seven times more phosphorus and 18 times more sediment to a lake than the naturally forested sites.

This alteration of the nearshore and shallow water habitat affects a variety of both terrestrial and aquatic wildlife and has been described in the literature. Green frog, dragonfly, and damselfly populations decline. The nesting success and diversity of fish species also declines, with sensitive native species being replaced by more tolerant species. Turtles lose basking sites and corridors to inland nest sites. Bird composition shifts from insect-eating to seed-eating species. Even white-tailed deer are affected, with reduction in winter browse along shorelines reducing winter carrying capacity. The removal of conifers along shores also reduces shoreline mink activity. Ultimately, the cumulative effects of lakeshore development have negative implications for many species of fish and wildlife.

CHAPTER 4.
SUITABILITY FOR RECREATION

Photo courtesy of Washington Department of Ecology

IN THIS CHAPTER

- ► Algal Toxins
- ► Contaminants in Fish Tissue
- ► Pathogen Indicators

Chapter 4
Suitability for Recreation

Another perspective on lake condition views the quality of a lake in terms of its suitability or safety for recreational use. Lakes are used for a wide variety of recreational opportunities that include swimming, waterskiing, windsurfing, fishing, boating, and many other activities. However, a number of microbial organisms, algal toxins, and other contaminants present in lakes can make people sick. NLA analysts assessed three indicators with respect to recreational condition: 1) microcystin – a type of algal toxin, 2) cyanobacteria – a type of algae that often produces algal toxins, and 3) chlorophyll-*a* — a measure of all algae present. Results from a companion study of contaminants in fish tissue are also discussed. Samples were also collected for pathogens and sediment mercury; however, results for these two indicators are unavailable as of publication of this report and will be presented in a supplemental report available on http://www.epa.gov/lakessurvey/.

Algal Toxins

One group of phytoplankton, cyanobacteria, (also called blue-green algae) are a natural part of all freshwater ecosystems. Eutrophication in lakes often results in conditions that favor their growth and cyanobacterial blooms frequently occur. Cyanobacterial blooms can be unsightly, often floating in a layer of decaying, odiferous, gelatinous scum. Many types of cyanobacteria have the potential to produce cyanotoxins, and several different cyanotoxins may be produced simultaneously. In assessing the risk of exposure to algal toxins for recreational safety, it is important to remember that algal density, *i.e.*, chlorophyll-*a* concentrations and cyanobacteria cell counts, serve as proxies for the actual presence of algal toxins. This is because not all phytoplankton are cyanobacteria and not all cyanobacteria produce cyanotoxins.

Although there are relatively few documented cases of severe human health effects, exposure to cyanobacteria or their toxins may produce allergic reactions such as skin rashes, eye irritations, respiratory symptoms, and in some cases gastroenteritis, liver and kidney failure, or death. The most likely exposure route for humans is through accidental ingestion or inhalation during recreational activities, though cyanotoxins are also cause for concern in drinking water. Cyanotoxins can also kill livestock and pets that drink affected water. While many varieties of cyanotoxin exist, microcystin, produced by *Microcystis* taxa, is currently believed to be the most common in lakes. Microcystin is a potent liver toxin, a known tumor promoter, and a possible human carcinogen.

Because of the potential for human illness, several states have issued guidelines for recreational use advisories associated with the presence of microcystin or associated indicators. These guidelines vary and rely on visual observations of algal scums, measured chlorophyll-*a* concentrations, cyanobacteria cell counts, and/or direct measurements of microcystin. While EPA does not presently have water quality criteria for microcystin, cyanotoxin, or any other algal toxins, the World Health Organization (WHO) has established recreational exposure guidelines for chlorophyll-*a*, cyanobacterial cell counts, and microcystin (Table 1).

Table 1. World Health Organization thresholds of risk associated with potential exposure to cyanotoxins.

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

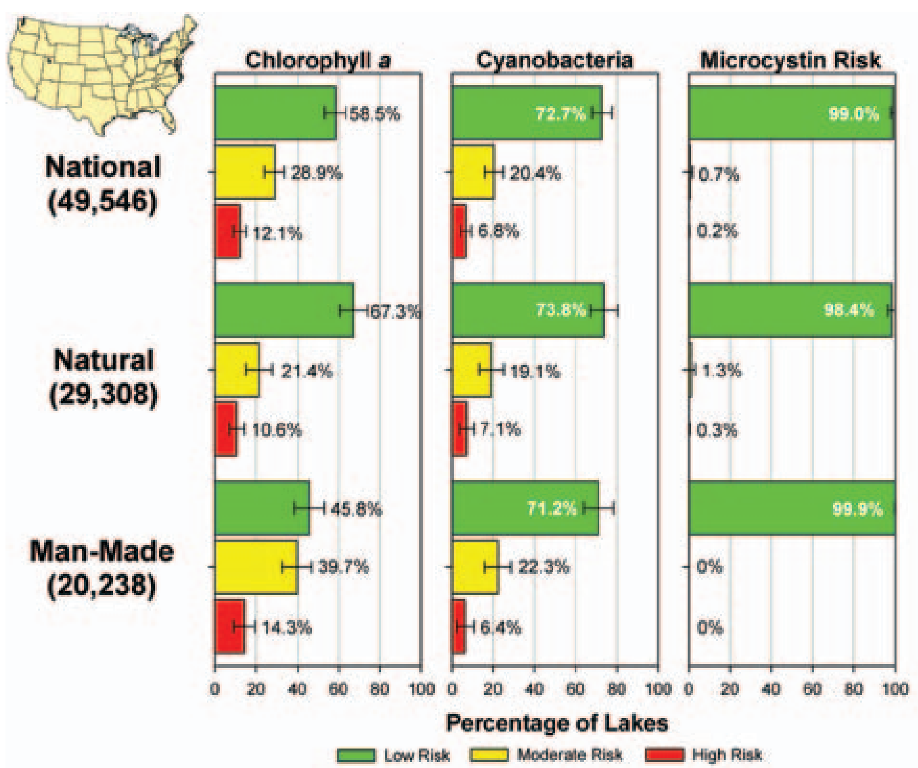


Figure 16. Percent of lakes, using three algal toxin indicators. In the first two graphs the percentage numbers indicate the risk or exposure to algal toxins associated with the presence of chlorophyll-*a* and cyanobacteria, not the risk of exposure to cholorphyll-*a* and cyanobacteria *per se*.

These thresholds, along with the presence or absence of microcystin, were used to assess the condition of lakes of the nation with respect to this indicator suite. A lake that is in good condition exhibits a low risk of potential exposure. Conversely, a lake in poor condition has a high exposure potential.

Using the WHO thresholds, the level of risk associated with the exposure to algal toxins varied and by indicator (Figure 16). Using the cyanobacteria cell count as the indicator, 27% of lakes nationwide pose a high or moderate risk for potential exposure to algal toxins. There was no significant difference in the proportion of natural and man-made lakes with high or moderate exposure risks for cyanobacteria. Based on chlorophyll-*a* concentration, 41% of lakes pose a high or moderate exposure potential to algal toxins.

It is important to note, however, that while the risk of exposure is extremely low, microcystin was present in 30% of lakes nationally (Figure 17). This could potentially have wide ranging impacts on human health and the swimmability of many lakes. When interpreting the data of this first ever national-scale study of microcystin in lakes, it is necessary to consider how the sampling was conducted. During the 2007 survey, microcystin samples were collected at mid-lake, in open water. However, large windblown accumulations of cyanobacteria often occur at nearshore areas in lakes and it is the concentrations along the lake's edge that are of most concern to municipal health officials. Some studies indicate that cell counts and cyanotoxin concentrations are greater in nearshore scums than in open water areas. However, concentrations large enough to cause human health concerns may still occur in open waters (with or without surface accumulations or scums). Sampling at mid-lake provides a conservative estimate

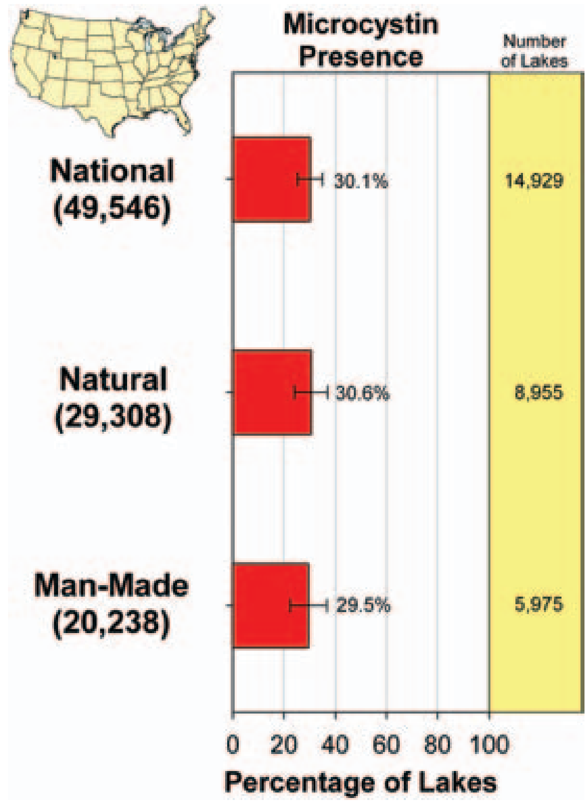


Figure 17. Occurrence of microcystin in lakes.

and because of this, the NLA results may underestimate certain types of recreational exposure when accumulations or scums are present.

Another important point to consider when looking at the data is whether the single sample of microcystin truly represents what is in the lake. Chlorophyll-*a* levels, cyanobacteria densities, and cyanotoxin concentrations may change quite rapidly, depending on bloom intensity and weather conditions. The concentrations of microcystin measured on one particular day may over or underestimate season-wide central tendencies. The NLA is not intended to assess the specific condition of any given lake, but rather provide information on the general conditions across the population of lakes. Finally, it is currently unknown how well microcystin occurrence correlates with the occurrence of other classes of cyanotoxins that were not measured, or how human health risks might be altered because of toxin mixtures. While the survey results are a good start in our understanding, much more is to be learned about algal toxins in lakes.

Contaminants in Lake Fish Tissue

Fish acquire contaminants and concentrate them in their tissues by uptake from water (bioconcentration) and through ingestion (bioaccumulation). Fish can often bioaccumulate chemicals at levels of more than a million times the concentration detected in the water column.

In a study conducted by the Office of Water's Office of Science and Technology, EPA surveyed contaminants in lake fish tissue. *The National Study of Chemical Residues in Lake Fish Tissue* characterized contaminant levels in fillet tissue for predators and in whole bodies for bottom-dwelling fish species. The study targeted pollutants that were classified as persistent, bioaccumulative, and toxic (PBT) chemicals, including mercury, arsenic, PCBs, dioxins and furans, DDT, and chlordane. This survey provided data to develop national estimates for 268 PBT chemicals in fish tissue from lakes and reservoirs in the 48 continental states (excluding the Great Lakes and the Great Salt Lake).

The study focused on fish species that are commonly consumed in the study area, have a wide geographic distribution, and potentially accumulate high concentrations of PBT chemicals. Fish samples were collected over a 4-year period (2000-2003) from 500 randomly selected lakes and reservoirs, which ranged in size from 2.5 acres (1 hectare) to 900,000 (365,000 hectares), were at least 3 feet (1 meter) deep, and had permanent fish populations.

The data show that mercury, PCBs, dioxins and furans, and DDT are widely distributed in lakes and reservoirs across the country. Mercury and PCBs were detected in all fish samples (Figure 18). Dioxins and furans were detected in 81% of the predator samples and 99% of the bottom-dwelling fish samples. DDT was detected in 78% of the predator samples and 98% of the bottom-dwelling samples. Cumulative frequency distribution plots showed that established human consumption limits were exceeded in 49% of the sampled lakes for mercury, in 17% of the lakes for total PCBs, and in 8% of the lakes for dioxins and furans. In contrast, 43 targeted chemicals were not detected in any sample. Full results from this study can be found at http://www.epa.gov/waterscience/fishstudy.

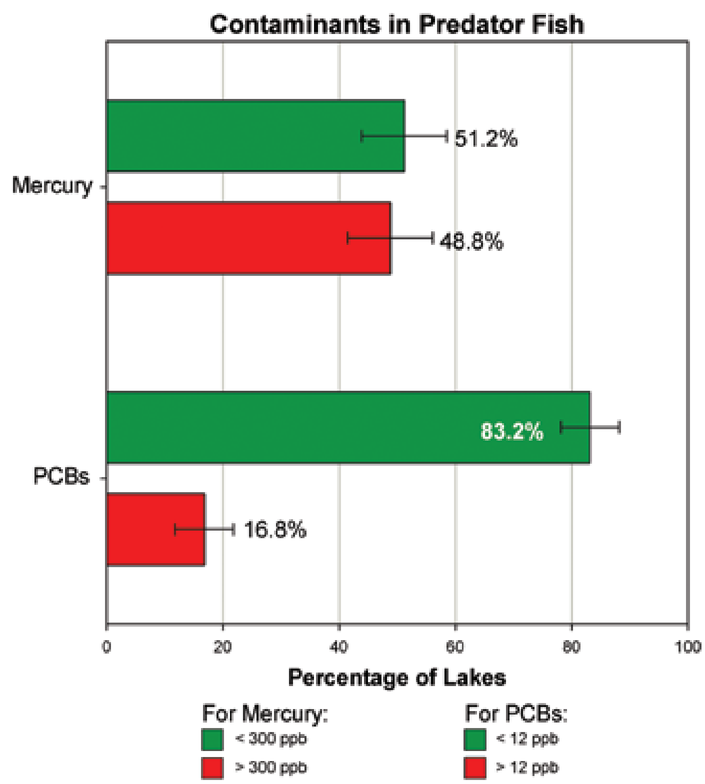


Figure 18. Percentage predator fish with mercury and PCB levels above (red) and below (green) EPA recommended limits.

Pathogen Indicators

Enterococci are believed to provide a better indication of the presence of pathogens than more traditional indicators for fecal coliform. *Enterococci* are bacteria that live in the intestinal tracts of warm-blooded creatures, including humans.

They are most frequently found in soil, vegetation, and surface water because of contamination by animal excrement. Most species of *enterococci* are not considered harmful to humans. However, the presence of *enterococci* in the environment indicates the possibility that other disease-causing agents also carried by fecal material may be present. Epidemiological studies of marine and freshwater beaches have established a relationship between the density of *enterococci* in the water and the occurrence of gastroenteritis in swimmers.

For the NLA, *enterococci* were measured using a method to assess ambient concentrations. This Quantitative Polymerase Chain Reaction (qPCR) method quantifies DNA that is specific to *enterococci*. Published epidemiological studies report a clear relationship between levels of qPCR-measured *enterococci* and sickness. EPA research is still underway to develop health-based thresholds for interpreting qPCR results.

Analyzing phytoplankton samples.
Photo courtesy of EcoAnalysts.

HIGHLIGHT

Atmospheric Contaminants: Mercury and Acid Rain

Neil C. Kamman
Vermont Department of Environmental Conservation

Of the many stressors that affect lakes, atmospheric contaminants are perhaps the most difficult to address. This is because sources of atmospheric contaminants are often hundreds or even thousands of miles from the lakes into which the contaminants are ultimately deposited. The intertwined issues of freshwater acidification and mercury contamination are not new. The popular press began reporting on acid rain in the 1970s. It took another 10-15 years for the press to also focus on mercury. Today, many people are aware of both issues, yet often do not fully comprehend nor appreciate the degree to which the two are linked. In the case of both these pollutants, the cycle is initiated by emissions into the air.

Mercury is a naturally occurring metal that is found in the environment in many forms, all of which are toxic to aquatic life in varying degrees. The release of mercury to the environment is enhanced by human activities such as the combustion of fossil fuels, such as coal and petroleum. In the U.S. the largest sources of mercury are coal-fired generation or utility boilers, followed by waste incinerators. Mercury is present in many household items, notably thermostats and fluorescent lamps, and is released when these items end up in landfills or incineration facilities. Depending on its chemical form, air-borne mercury may remain in the atmosphere for a period of minutes (as reactive gaseous mercury), days (as particulate mercury), or weeks or years (as gaseous elemental mercury).

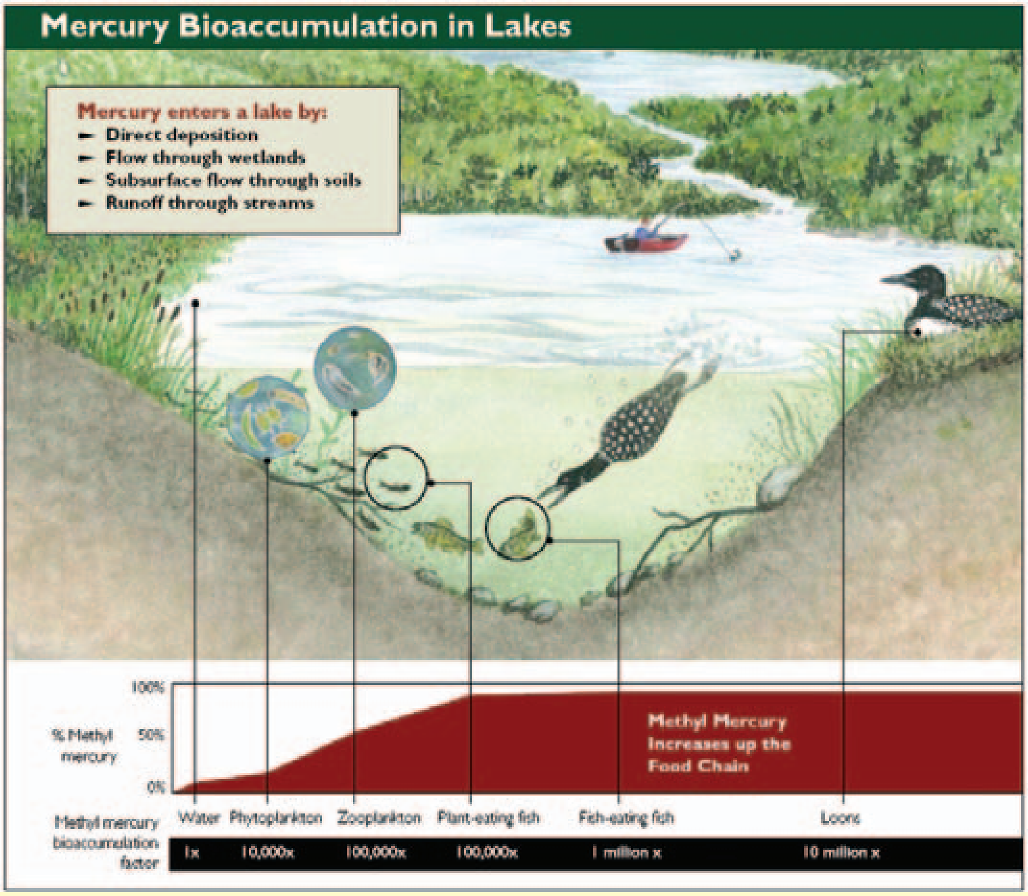
Methylmercury, one of the most toxic forms of mercury, can be prevalent in fish and has documented adverse health effects on humans. The U.S. Centers for Disease Control and Prevention estimates that up to 6% of women of childbearing age have blood mercury levels in excess of established safety levels. Fish and fish-eating wildlife such as the common loon and American bald eagle are also at risk from mercury toxicity. While the mercury cycle in lakes is quite complex, there are five basic stages: emission, deposition, methylation[*], bioaccumulation, and finally sequestration to lake sediments.

Lake acidification is most commonly caused by acidic deposition (rain, snow and dust). The acidic deposition pathway begins with the release into the air of acid-forming chemicals, most notoriously sulfur dioxide and nitrogen oxides, and ends when sulfuric and nitric acids are deposited to the landscape. Sulfur dioxide, like mercury, results largely from the burning of fossil fuels. Some forms of coal are very rich in sulfur, and poorly controlled facilities released massive quantities, particularly during the period 1960-1992. Both sulfur dioxide and nitrogen oxides are common components of vehicular emissions. Once emitted, these two compounds undergo complex atmospheric transformations, resulting in rain and snow that contain dilute concentrations of nitric and sulfuric acids. Thankfully, the Clean Air Act Amendments of 1990 have resulted in profound reductions in acid-forming precursors. In very sensitive regions, however, lakes remain at risk for acidification even with reduced levels of acid rain.

In one sense, the process of lake acidification is not as complex as that of mercury accumulation in that there is neither methylation nor bioaccumulation of the acids. Yet acidification has more pernicious effects that can exacerbate mercury problems. Acidification of watersheds renders the watersheds more efficient at creating and transporting methylmercury to lakes, along with other soil-bound toxic metals such as aluminium. Moreover, acidification of the lakes themselves renders the bioaccumulation of methylmercury more efficient. Therefore, acidic lakes: 1) receive more mercury from their watershed, 2) have more of the mercury in the toxic methylated form, and 3) have more efficient bioaccumulation of the methylmercury.

[*]The natural and biologically-mediated process by which mercury is transformed into toxic organic methylmercury.

Studies throughout the United States, Canada, Russia, and Scandinavia all show a very strong connection between lake acidification and mercury bioaccumulation. Researchers have documented the occurrence of mercury hotspots in various parts of the U.S. and attribute these to one of three basic causes — proximity to poorly-controlled emissions sources, water level management in reservoirs, or acid sensitive landscapes. In regions of North America where lake acidification is in fact already improving, minor reductions in mercury in fish and fish-eating wildlife can be anticipated. Much more consequential reductions in environmental mercury contamination are expected as EPA and states strive to control mercury emissions from coal-fired utilities and other sources.



Graphical depiction of methylmercury bioaccumulation in lake biota. This figure is reproduced from the Hubbard Brook Research Foundation's ScienceLinks publication Mercury Matters: Linking Mercury Science with Public Policy in the Northeastern United States. Used with permission.

CHAPTER 5. TROPHIC STATE OF LAKES

Photo courtesy of USEPA Region 10

IN THIS CHAPTER

- Findings for Trophic State

Photo courtesy of Great Lakes Environmental Center

Chapter 5
Trophic State of Lakes

The third approach to assessing the condition of lakes is to look at lakes with respect to their primary production. Trophic state depicts 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 biomass are termed oligotrophic. Lakes that fall in between are mesotrophic, and those on the extreme ends of the scale are termed hypereutrophic or ultra-oligotrophic. Lakes exist across all trophic categories; however hypereutrophic lakes are usually the result of excessive human activity and can be an indicator of stress conditions.

There is no ideal 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. Eutrophic lakes can be biologically diverse with abundant fish, plants, and wildlife. For anglers, increased concentrations of nutrients, algae, or aquatic plant life generally result in higher fish production.

Eutrophication is a slow, natural part of lake aging, but today human influences are significantly increasing the amount of nutrients entering lakes. Human activities such as poorly managed agriculture or suburbanization of lakeshores can result in excessive nutrient concentrations reaching lakes. This can lead to accelerated eutrophication and related undesirable effects including nuisance algae, excessive plant growth, murky water, odor, and fish kills.

Findings for Trophic State

For NLA, the trophic state is characterized using nationally-consistent chlorophyll-*a* concentrations (Figure 19). Based on these thresholds, 13% of lakes are oligotrophic, 37% are mesotrophic, 30% are eutrophic, and 20% are hypereutrophic. The results also show that natural lakes tend towards mesotrophic conditions and man-made lakes towards eutrophic conditions.

Many states and lake associations classify their lakes by trophic state using a variety of thresholds for nutrients (phosphorus or nitrogen), Secchi disk transparency, or chlorophyll-*a*, depending on the data available. For this assessment, NLA analysts, in consultation with a number of state and local lake experts, decided to base trophic state on chlorophyll-*a* concentrations. The group considered this indicator the most relevant and straightforward estimate of trophic state because it is based on direct measurements of live organisms, yet acknowledges that other indicators also could be used. Table 2 illustrates the percentages that would fall into the different trophic categories if different indicators were used. Total nitrogen and total phosphorus, (which ranked fourth and fifth in terms of how widespread excess levels are across the country) together or individually are primary drivers of eutrophication.

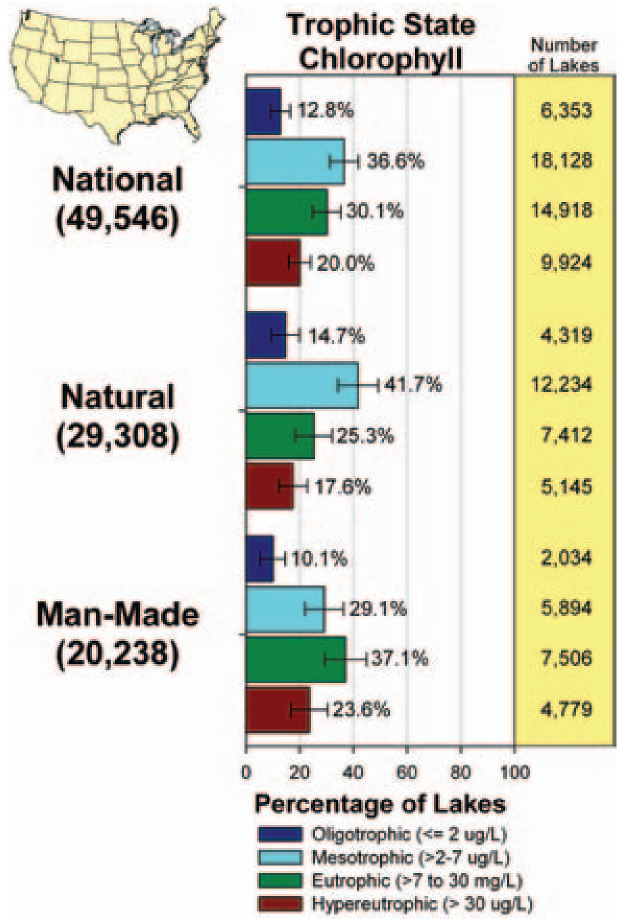


Figure 19. Trophic state of lakes in the lower continental U.S.

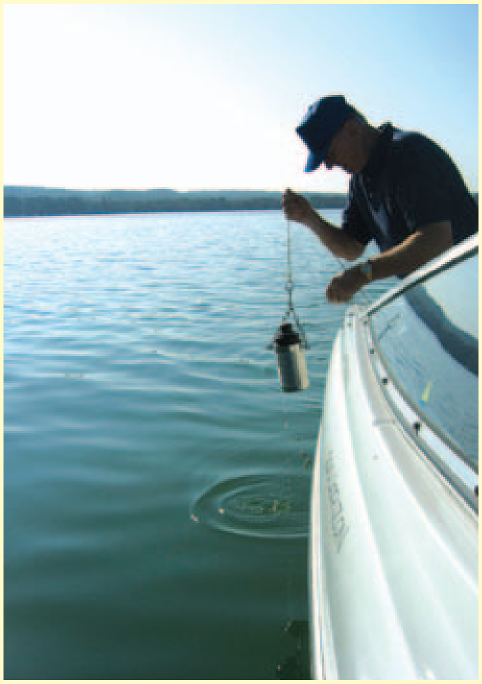
Table 2. Percent of U.S. lakes (natural and man-made) by trophic state, based on four alternative trophic state indicators.

Indicator	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Chlorophyll-*a*	12.8	36.6	30.1	20
Secchi transparency	10.5	22.5	39.8	18.4
Total Nitrogen	22.1	37.5	22.0	18.4
Total Phosphorus	25.0	28.8	24.7	21.4

HIGHLIGHT

Volunteer Power: Monitoring Lakes with Volunteers

Hundreds of organizations monitor lakes in the U.S. using trained volunteers. Some volunteer groups are run by state environmental agencies. Others are managed by local residential lake associations determined to protect the quality of their local lake, pond or reservoir. Universities, often as part of U.S. Department of Agriculture Cooperative Extension, manage a number of statewide lake volunteer monitoring programs. In some states, trained volunteers are the leading source of consistent, long-term lake data. Volunteer-collected lake data are widely used in state water quality assessment reports, identification of impaired waters, local decision making, and scientific study.



A volunteer with the Michigan Cooperative Lakes Monitoring Program collects a water sample for chlorophyll analysis.
Photo courtesy of Ralph Bednarz.

One national program designed to promote the use of volunteers in lake monitoring is the Secchi Dip-In (http://dipin.kent.edu/index.htm). Run by limnologist Dr. Robert Carlson of Kent State University since 1994, the Dip-In encourages individuals who are members of a volunteer monitoring program to measure lake transparency on or around the 4th of July and report their results on a national website. These values are used to assess the transparency of volunteer-monitored waters in the U.S. and Canada. One goal of the Dip-In is to increase the number and interest of volunteers in environmental monitoring and to provide national level recognition of the work that they perform.

Volunteer Monitoring and the National Lakes Assessment

The relationship between lake volunteer monitoring and the National Lakes Assessment (NLA) is in its earliest stages. However, volunteers did participate in a few states where links between volunteer programs and state monitoring staff were strong. The Vermont Department of Environmental Conservation (DEC) conducted its own statistically valid assessment of 50 lakes including NLA-selected lakes, about half of which are also routinely sampled by volunteers in the DEC-managed Vermont Lay Monitoring Program. Volunteers were informed ahead of time when NLA sampling crews were going to arrive, and in some cases were able to provide boats for the crews as well as welcome local advice regarding lake navigation and access. In Rhode Island, some volunteers conducted side-by-side sampling with the NLA crews for later analysis and comparison using Rhode Island Watershed Watch methods. Volunteers observed the sampling, assisted crews with equipment, provided firsthand knowledge of local lakes, and contacted news media to provide publicity. In Michigan, at two lakes also monitored by Michigan's Cooperative Lake Monitoring Program, volunteers sampled side-by-side with Michigan Department of Environmental Quality staff and NLA survey crews. Local newspaper reporters observed these monitoring events and provided press coverage of the volunteers working alongside the survey crews.

Volunteer monitors are important partners in the assessment and protection of the nation's lakes, and state agencies and EPA should continue to explore pathways for improved communication and cooperation with volunteer programs in future surveys of the nation's lakes.

CHAPTER 6. ECOREGIONAL RESULTS

Photo courtesy of Tetra Tech

IN THIS CHAPTER

- Nationwide Comparisons
- Northern Appalachians
- Southern Appalachians
- Coastal Plains
- Upper Midwest
- Temperate Plains
- Southern Plains
- Northern Plains
- Western Mountains
- Xeric

Chapter 6
Ecoregional Results

Taken individually, each lake is a reflection of its watershed. The characteristics of the watershed, *i.e.*, its size relative to the lake, topography, geology, soil type, land cover, and human activities, together influence the amount and nature of material entering the lake. For example, a deep alpine lake located in a Rocky Mountain watershed will likely have clear, pristine water and little biological productivity. Conversely, a lake in a coastal plains watershed of the mid-Atlantic region, an area of nutrient-rich alluvial soils and a long history of human settlement, will more likely be characterized by high turbidity, high concentrations of nutrients and organic matter, prevalent algal blooms, and abundant aquatic weeds and other plants. Atmospheric deposition of airborne pollutants, as well as nutrients traveling in groundwater from hundreds of miles away, can affect the watershed and influence the lake condition.

Lakes in high population areas are especially vulnerable. Combined sewer overflow and stormwater runoff can carry marked amounts of pollutants such as metals, excess sediment, bacteria, and most recently, pharmaceuticals. As a result, expectations and lake condition vary across the country.

Because of the diversity in landscape, it is important to assess waterbodies in their own geographical setting. The NLA was designed to report findings on an ecoregional scale. Ecoregions are areas that contain similar environmental characteristics and are defined by common natural characteristics such as climate, vegetation, soil type, and geology. By looking at lake conditions in these smaller ecoregions, decision-makers can begin to understand patterns based on landform and geography, and whether the problems are isolated in one or two adjacent regions or are widespread.

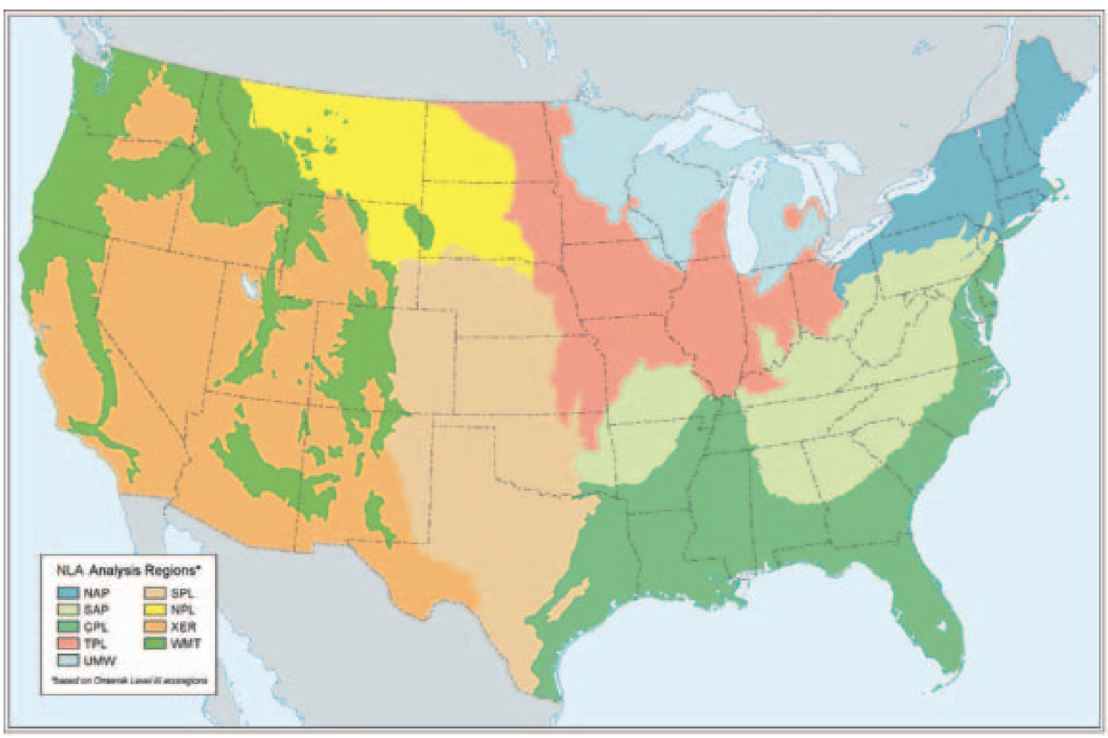


Figure 20. Ecoregions used as part of the National Lakes Assessment.

EPA has defined ecoregions at various scales, ranging from coarse ecoregions at the continental scale (Level I) to finer ecoregions that divide the land into smaller units (Level III or IV). The nine ecoregions used in this assessment are aggregations of the Level III ecoregions delineated by EPA for the continental U.S. These nine ecoregions as shown in Figure 20 are:

- Northern Appalachians (NAP)
- Southern Appalachians (SAP)
- Coastal Plains (CPL)
- Upper Midwest (UMW)
- Temperate Plains (TPL)
- Southern Plains (SPL)
- Northern Plains (NPL)
- Western Mountains (WMT)
- Xeric (XER)

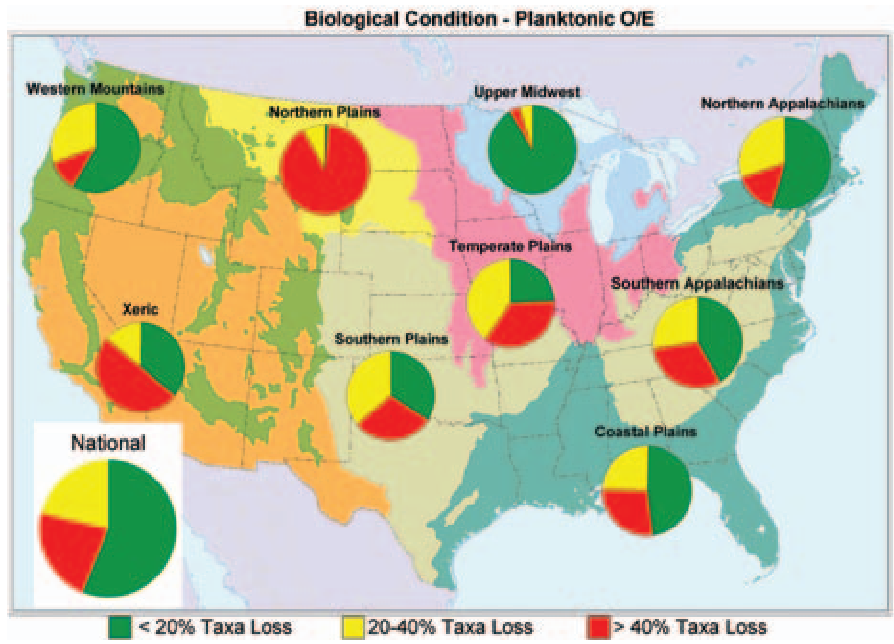


Figure 21. Biological condition (based on planktonic O/E taxa loss) across nine ecoregions.

To assess waters within each ecoregion, the NLA captures the geographic variation in lakes using regionally-specific reference conditions. The resulting set of reference lakes all share common characteristics and occur within a common geographic area.[5] This approach not only allows lakes in one region to be compared with the particular reference lakes of that region, but also allows for the comparison of one ecoregion to another. This means that lakes in the arid west are not being assessed against lakes in the Southern Plains. Yet, at the same time, this also means that if 10% of the Xeric west lakes were in poor condition and 20% of the Southern Plains lakes were relatively poor, one can compare the two ecoregions and say that the Southern Plains have twice the proportion of lakes in poor condition.

Nationwide Comparisons

Biological Condition – Taxa Loss

Regionally, the proportion of lakes with good biological condition ranges from 91% in the Upper Midwest to < 5% in the Northern Plains (Figure 21). In general, the glaciated and/or mountainous regions have the highest proportion of lakes exhibiting good biological condition, followed by Coastal Plains lakes. The Xeric west and Northern Plains exhibit the highest proportions of lakes in poor condition biologically. Forty nine percent of lakes are in poor biological condition in the Xeric region, while just under 85% of Northern Plains lakes are in poor biological condition.

[5] It is important to note that the geographic boundaries of the regionally-specific reference areas do not specifically match those of the nine ecoregions. More detailed information about how regional reference lakes were determined can be found in the Technical Report.

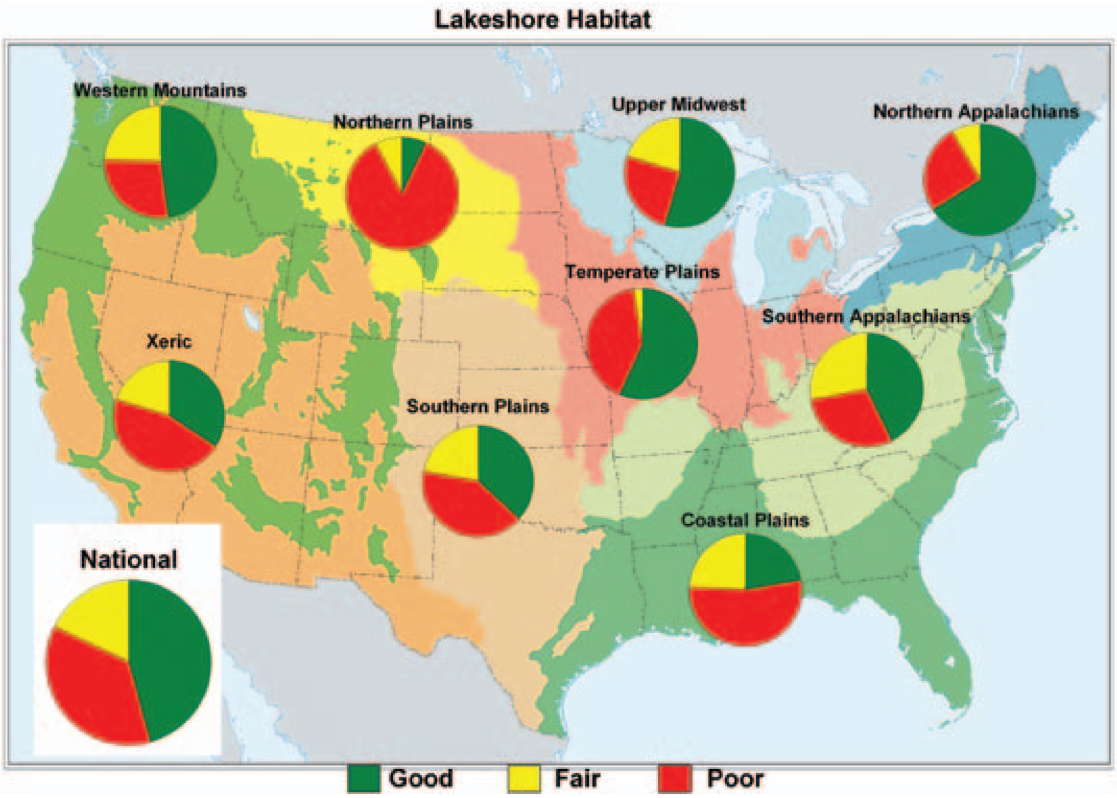


Figure 22. Habitat condition of the nation's lakes across nine ecoregions based on lakeshore habitat.

Habitat Stressors – Lakeshore Habitat

In the NLA, habitat stress was assessed using four indicators: lakeshore habitat, shallow water habitat, physical habitat complexity and human disturbance. Of these, the most revealing indicator, based on the relative and attributable risk analyses, is lakeshore habitat. This analysis indicates that biological integrity of lakes is three times more likely to be poor when the lakeshore habitat area is classified as poor. Regionally, the proportion of lakes with poor lakeshore habitat ranges from a low of 25% in the Northern Appalachians to a high of 84% in the Northern Plains (Figure 22). Poor lakeshore habitat is most prevalent in the Plains and Xeric ecoregions.

Trophic Status

Regionally, the proportion of lakes classified as oligotrophic, based on measures of chlorophyll-*a*, ranges from 54% in the Western Mountains to < 5% in the Temperate Plains (Figure 23). The highest proportion of mesotrophic waters are found in the Northern and Southern Appalachians, and the Upper Midwest. The proportion of eutrophic lakes is highest in the Coastal and Southern Plains. Hypereutrophic lakes are most prevalent in the Temperate Plains, where nearly 50% of lakes are classified hypereutrophic.

Recreational Suitability – Cyanobacteria (blue-green algae)

Over 75% of lakes in the Western Mountains, Xeric west, Upper Midwest, and Northern and Southern Appalachians pose minimal risk of exposure to cyanobacteria-produced toxins. The greatest proportions of lakes at high exposure risk (> 100,000 cells/L) occur in the Southern, Coastal, and Temperate Plains. The Northern Plains have over 50% of lakes in the moderate exposure risk category (Figure 24).

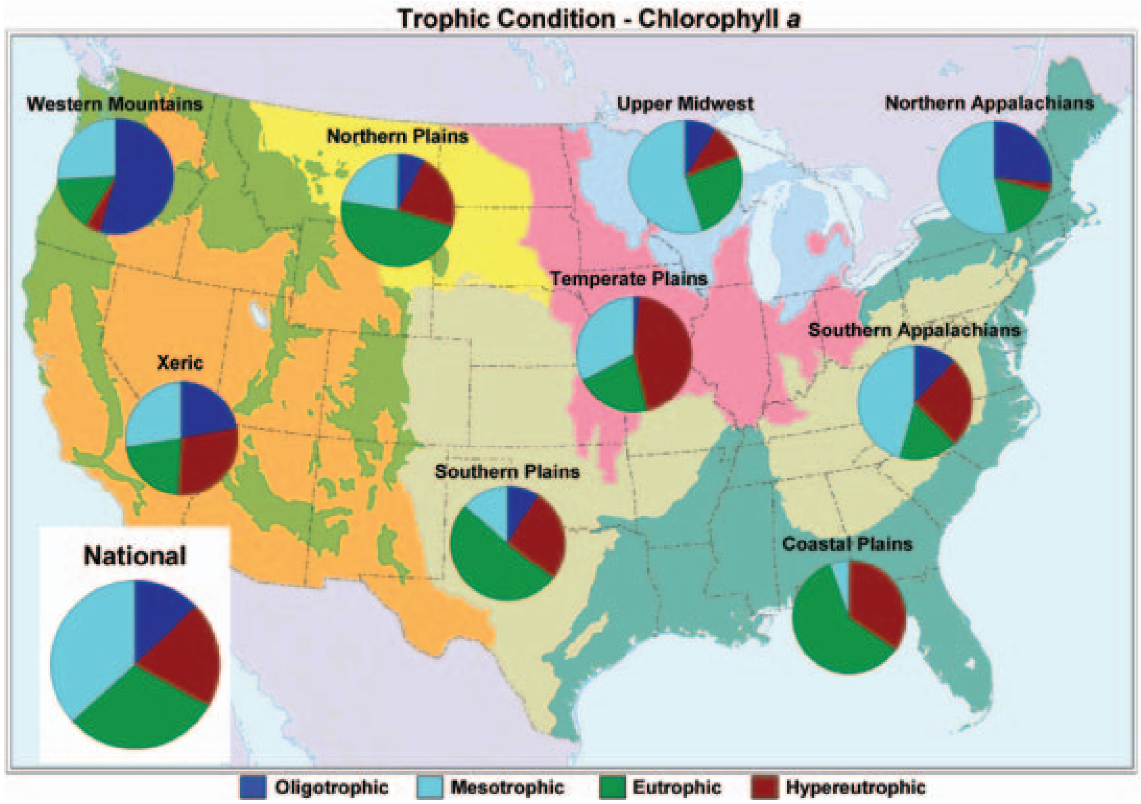


Figure 23. Trophic state across nine ecoregions (based on chlorophyll-*a.)*

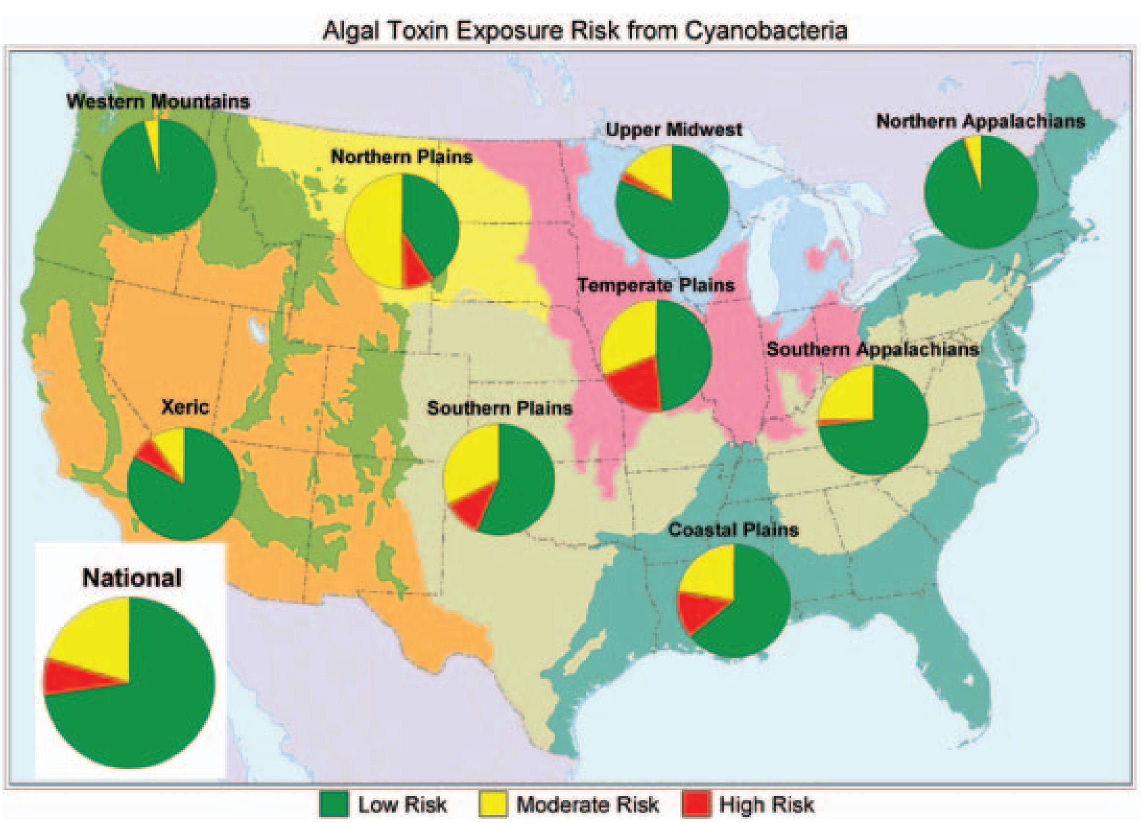


Figure 24. Comparison of exposure to cyanobacteria risk across nine ecoregions.

Northern Appalachians
The Landscape

The Northern Appalachians ecoregion covers all of the New England states, most of New York, the northern half of Pennsylvania, and northeast Ohio. It encompasses New York's Adirondack and Catskill Mountains and Pennsylvania's mid-northern tier, including the Allegheny National Forest. Major waterbodies include Lakes Ontario and Erie, New York's Finger Lakes, and Lake Champlain. There are 5,226 lakes in the Northern Appalachians that are represented by the NLA, 54% of which are constructed reservoirs. The ecoregion comprises some 139,424 square miles (4.6% of the United States), with about 4,722 square miles (3.4%) under federal ownership. Based on satellite images in the National Land Cover Dataset (1992), the distribution of land cover is 69% forested and 17% planted/cultivated, with the remaining 14% of land in other types of cover.

Many lakes in the region were created for the purpose of powering sawmills. During the 18th and early 19th centuries, lakes were affected by sedimentation caused by logging, farming, and damming of waterways. When agriculture moved west and much of eastern farmland converted back into woodlands, sediment yields declined in some areas. In many instances, lakes in what appears to be pristine forested settings are in fact still recovering from prior land use disturbances. In the mountainous regions of the Northern Appalachian ecoregion, many large reservoirs were constructed throughout the early 20th century for hydropower generation and/or flood control.

Dick's Pond in Massachusetts.
Photo courtesy of USEPA Region 1.

Findings

A total of 93 of the selected NLA sites were sampled during the summer of 2007 to characterize the condition of lakes throughout the ecoregion. An overview of the NLA findings for Northern Appalachian lakes is shown in Figure 25.

Biological Condition

Fifty-five percent of lakes are in good biological condition based on planktonic O/E, and when using the diatom IBI, 67% of lakes in the ecoregion are in good biological condition relative to reference condition. Conversely, the percentages of lakes in poor condition are 15% and 10% based on the two analyses, respectively.

Trophic Status

Based on chlorophyll-*a*, 26% of lakes are oligotrophic, 54% are mesotrophic, 17% are eutrophic, and only 3% are considered hypereutrophic.

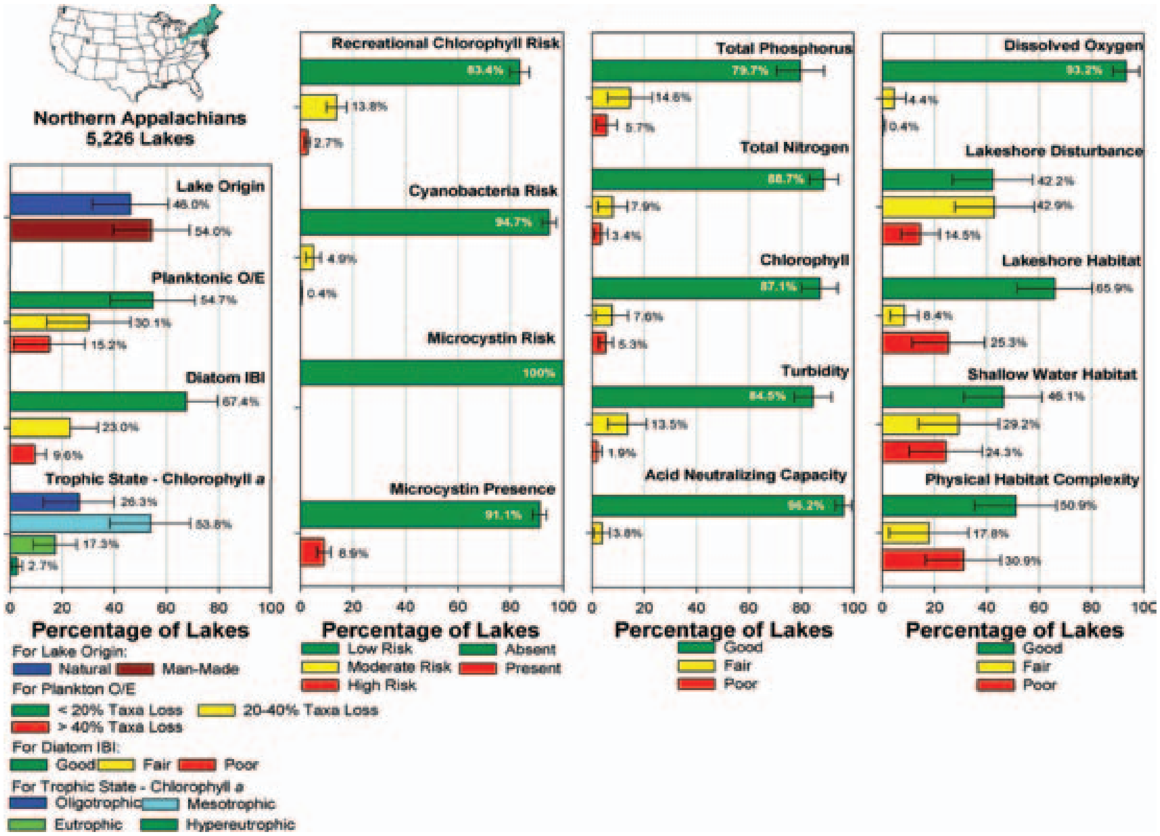


Figure 25. NLA results for the Northern Appalachians. Bars show the percentage of lakes within a condition class for a given indicator. For Recreational Chlorophyll risk and Cyanobacteria risk, the percentage numbers indicate the risk of exposure to algal toxins associated with the presence of cholorphyll-*a* and cyanobacteria, not the risk of exposure to chlorophyll-*a* and cyanobacteria *per se*.

Recreational Suitability

Using the indicators and World Health Organization guidelines described in Chapter 3, most lakes in the Northern Appalachian ecoregion exhibit relatively low risk of exposure to cyanobacteria and associated cyanotoxins. Based on cyanobacterial counts, 95% of lakes exhibit low exposure risk. Microcystin was present in 9% of lakes.

Physical Habitat Stressors

Lakeshore habitat is considered good in 66% of the lakes in this ecoregion. Given the long history of land use and settlement in this ecoregion, the shorelines of Northern Appalachian lakes exhibit relatively disturbed conditions due to human activities. Fifty-seven percent of lakes show moderate to high levels of lakeshore disturbance.

Chemical Stressors

In contrast to physical habitat conditions, the majority of Northern Appalachian lakes exhibit high-quality waters based on the NLA chemical stressor indicators. Relative to regionally-specific reference expectations, total phosphorus and nitrogen, chlorophyll-*a*, and turbidity levels are considered good in 80% or more of lakes in this ecoregion. Lakes are in good condition based on ANC and surface water DO levels when compared to nationally-consistent thresholds.

Southern Appalachians
The Landscape

The Southern Appalachians ecoregion stretches over 10 states, from northeastern Alabama to central Pennsylvania. Also included in this region are the interior highlands of the Ozark Plateau and the Ouachita Mountains in Arkansas, Missouri, and Oklahoma. The region covers about 321,900 square miles (10.7% of the United States) with about 42,210 square miles (10.7%) under federal ownership. Many important public lands such as the Great Smoky Mountains National Park and surrounding national forests, the Delaware Water Gap National Recreation Area, the George Washington and Monongahela National Forests, and the Shenandoah National Park are located within the region. Topography is mostly hills and low mountains with some wide valleys and irregular plains. Piedmont areas are included within the Southern Appalachians ecoregion.

Natural lakes are nearly non-existent in this ecoregion. The 4,690 lakes in the Southern Appalachians ecoregion represented by the NLA are all man-made. The configuration of the Southern Appalachian valleys has proven ideal for the construction of man-made lakes, and some of the nation's largest hydro-power developments can be found in the Tennessee Valley.

Findings

A total of 116 of the selected NLA sites were sampled during the summer of 2007 to characterize the condition of lakes throughout the ecoregion. An overview of the NLA findings for lakes in the Southern Appalachians is shown in Figure 26.

Pennsylvania lake.
Photo courtesy of Frank Borsuk.

Biological Condition

Forty-two percent of lakes are in good biological condition based on planktonic O/E and when using the diatom IBI, 63% of lakes in the ecoregion are in good biological condition relative to reference condition. Conversely, the percentages of lakes in poor condition are 31% and 13% based on the two analyses, respectively. The apparent difference between these two biological indices may suggest that the two indicators are responding to different stressors in lakes in this particular ecoregion.

Trophic Status

Based on chlorophyll-*a*, 12% of lakes are oligotrophic, 46% are mesotrophic, 17% are eutrophic, and 26% are considered hypereutrophic.

Recreational Suitability

While many lakes in the Southern Appalachians ecoregion exhibit relatively low risk of exposure to cyanobacteria and associated cyanotoxins, a quarter of lakes exhibit moderate risk levels based on chlorophyll-*a* and cyanobacteria values. Microcystin was present in 25% of lakes.

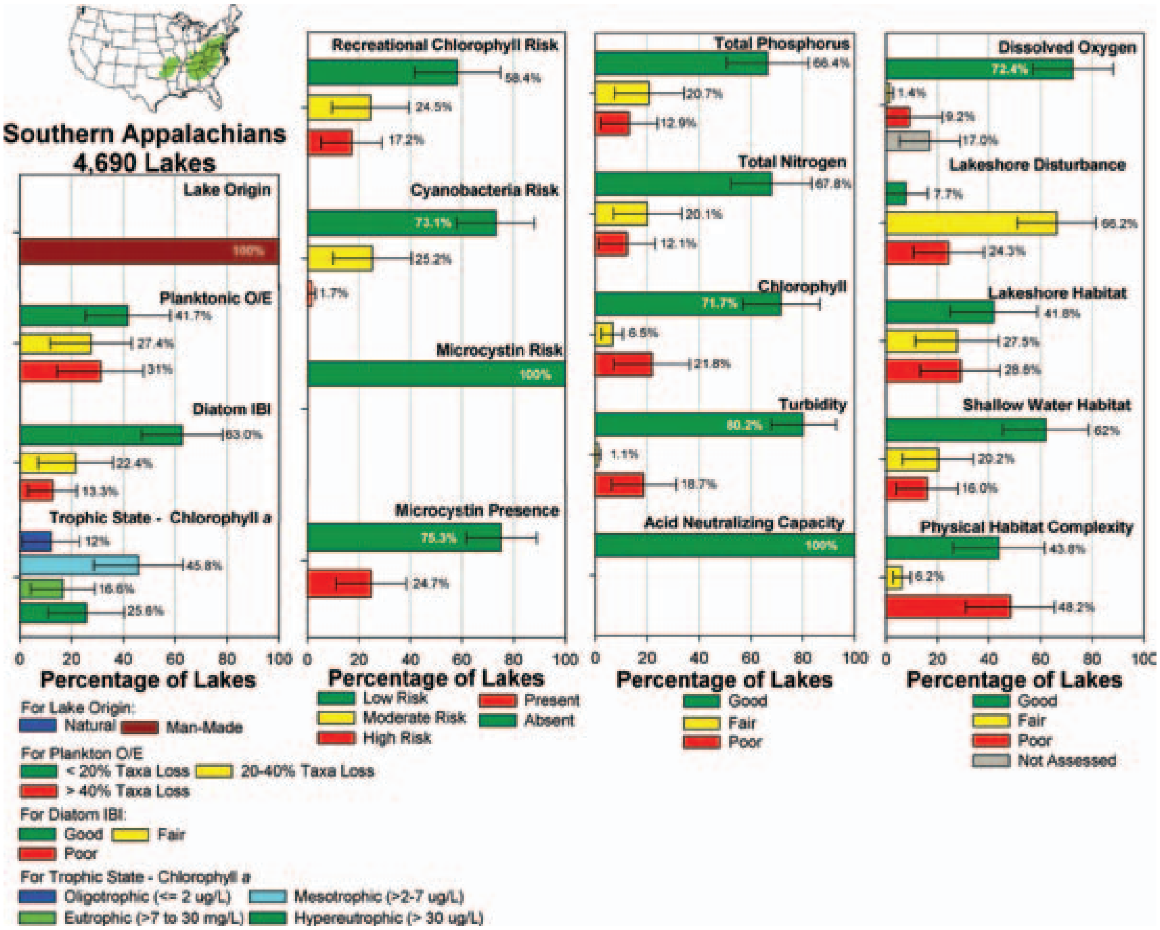


Figure 26. NLA results for the Southern Appalachians. Bars show the percentage of lakes within a condition class for a given indicator. For Recreational Chlorophyll risk and Cyanobacteria risk, the percentage numbers indicate the risk of exposure to algal toxins associated with the presence of cholorphyll-*a* and cyanobacteria, not the risk of exposure to chlorophyll-*a* and cyanobacteria *per se*.

Physical Habitat Stressors

Lakeshore habitat is considered good in 42% of the lakes in this ecoregion. Yet the shorelines of Southern Appalachians lakes indicate considerable lakeshore development pressure. Over 90% of lakes show moderate to high levels of lakeshore disturbance.

Chemical Stressors

Based on the NLA chemical stressor indicators, a considerable proportion of Southern Appalachians lakes exhibit good quality waters. Total phosphorus and nitrogen are considered good in 66% and 68% of lakes, respectively. Relative to regionally-specific reference expectations, chlorophyll-*a* and turbidity levels are considered good in 72% or more of the man-made lakes in this ecoregion. Man-made lakes are in good condition based on ANC and surface water DO levels when compared to nationally consistent thresholds, although 9% of lakes were ranked poor due to low dissolved oxygen.

Coastal Plains
The Landscape

The Coastal Plains ecoregion covers the Mississippi Delta and Gulf Coast, north along the Mississippi River to the Ohio River, all of Florida, eastern Texas, and the Atlantic seaboard from Florida to New Jersey. Total area is about 395,000 square miles (13% of the United States) with 25,890 square miles (6.6%) under federal ownership. Based on satellite images in the 1992 National Land Cover Dataset, the distribution of land cover is 39% forested, 30% planted/cultivated, and 16% wetlands, with the remaining 15% of land in other types of cover. Damming, impounding, and channelization in this ecoregion have altered the rate and timing of water flow and delivery to lakes.

A subset of major lakes of the region includes the Toledo Bend (TX) and Sam Rayburn Reservoirs (TX/LA), Lake Okeechobee (FL), Lake Marion (SC), and the massive lake-wetland complexes north of the Gulf Coast. The Coastal Plains is also home to a variety of lakes and ponds, such as Cape Cod kettleholes, New Jersey Pine Barren ponds, southeastern blackwater lakes, Carolina "Bays," and the limestone-rich clear lakes of the Florida peninsula. A total of 7,009 lakes and reservoirs in the Coastal Plains ecoregion are represented in the NLA, and 69% of these are man-made.

Findings

A total of 102 of the selected NLA sites were sampled during the summer of 2007 to characterize the condition of lakes throughout the ecoregion. An overview of the NLA findings for the Coastal Plains lakes is shown in Figure 27.

Biological Condition

Forty-seven percent of lakes are in good biological condition based on planktonic O/E, and when using the diatom IBI, 57% of lakes in the ecoregion are in good biological condition relative to reference condition. Conversely, the percentages of lakes in poor condition are 27% and 6% based on the two analyses, respectively

Trophic Status

Based on chlorophyll-*a*, 6% of the lakes are mesotrophic, 60% are eutrophic, and 34% are considered hypereutrophic.

Recreational Suitability

Lakes in the Coastal Plains ecoregion exhibit moderate risk of exposure to cyanobacteria and associated cyanotoxins. Based on cyanobacterial counts, 64% of lakes exhibited low exposure risk. Microcystin was present in 35% of lakes.

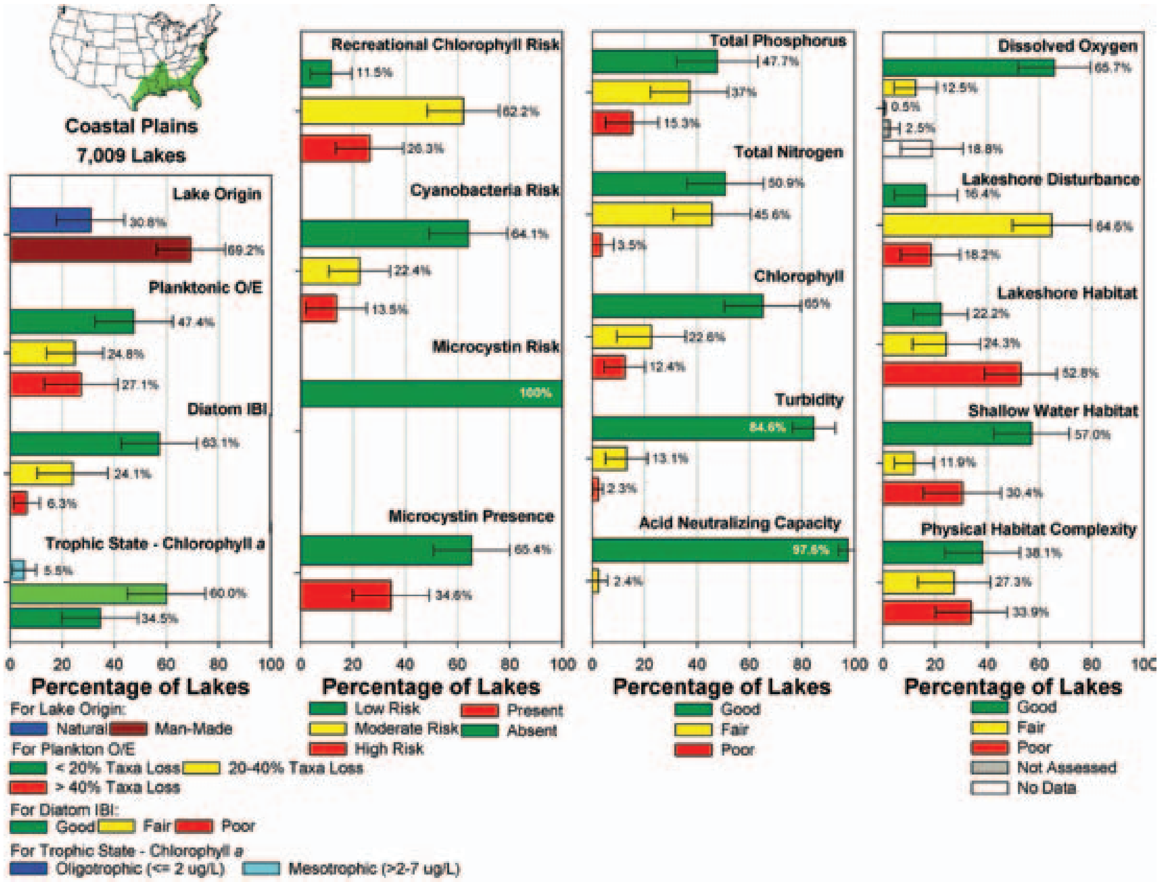


Figure 27. NLA findings for the Coastal Plains. Bars show the percentage of lakes within a condition class for a given indicator. For Recreational Chlorophyll risk and Cyanobacteria risk, the percentage numbers indicate the risk of exposure to algal toxins associated with the presence of cholorphyll-*a* and cyanobacteria, not the risk of exposure to chlorophyll-*a* and cyanobacteria *per se*.

Physical Habitat Stressors

Lakeshore habitat is considered good in 22% of the lakes in this ecoregion. Moreover, the shorelines of the Coastal Plains lakes are highly disturbed, indicating considerable lakeshore development pressure in this region. About 84% of lakes show moderate to high levels of lakeshore human disturbance.

Chemical Stressors

Based on the NLA chemical stressor indicators, water quality is somewhat variable across the Coastal Plains. Total phosphorus and nitrogen are considered good in 48% and 51% of lakes, respectively, and are poor in 15% and 4% of lakes, respectively. Relative to regionally-specific reference expectations, chlorophyll-*a* concentrations are considered good in 65% of lakes, and turbidity levels are considered good in 85% of lakes in this ecoregion. Lakes are in good condition based on ANC and surface water DO levels when compared to nationally-consistent thresholds, although 13% of lakes were ranked fair due to low dissolved oxygen.

Upper Midwest
The Landscape

The Upper Midwest ecoregion covers most of the northern half and southeastern part of Minnesota, two-thirds of Wisconsin, and almost all of Michigan, extending about 160,374 square miles (5.4% of the United States). A total of 15,562 lakes in the ecoregion are represented in the NLA, nearly all of which are of natural origin, reflecting the glaciation history of this region. Sandy soils dominate with relatively high water quality in lakes supporting warm and cold-water fish communities. Major lakes of the region include the Great Lakes (which, for design considerations, were not represented by the NLA), and also Lake of the Woods and Red Lake (MN). The glaciated terrain of this ecoregion is typically plains with some hill formations. The northern tier of this ecoregion has a very high number of smaller lakes, both drainage and seepage, which range widely in geochemical makeup. Much of the land is covered by national and state forest. Federal lands account for 15.5% of the area at about 25,000 square miles. Based on satellite images in the 1992 National Land Cover Dataset, the distribution of land cover is 40% forested, 34% planted/cultivated, and 17% wetlands, with the remaining 9% of land in other types of cover. Most of the landscape was influenced by early logging and agricultural activities.

Findings

A total of 148 of the selected NLA sites were sampled during the summer of 2007 to characterize the condition of lakes throughout the ecoregion. An overview of the NLA findings for the Upper Midwest lakes is shown in Figure 28.

Minnesota prairie pothole lake.
Photo courtesy of Steve Heiskary.

Biological Condition

Ninety-one percent of lakes are in good biological condition based on planktonic O/E, and when using the diatom IBI, 47% of lakes in the ecoregion are in good biological condition relative to reference condition. Conversely, the percentages of lakes in poor condition are 4% and 22% based on the two analyses, respectively. The difference between these two biological indices may suggest that the two indicators are responding to different stressors in lakes in this particular ecoregion.

Trophic Status

Based on chlorophyll-*a*, 9% of lakes are oligotrophic, 54% are mesotrophic, 26% are eutrophic, and 10% are considered hypereutrophic.

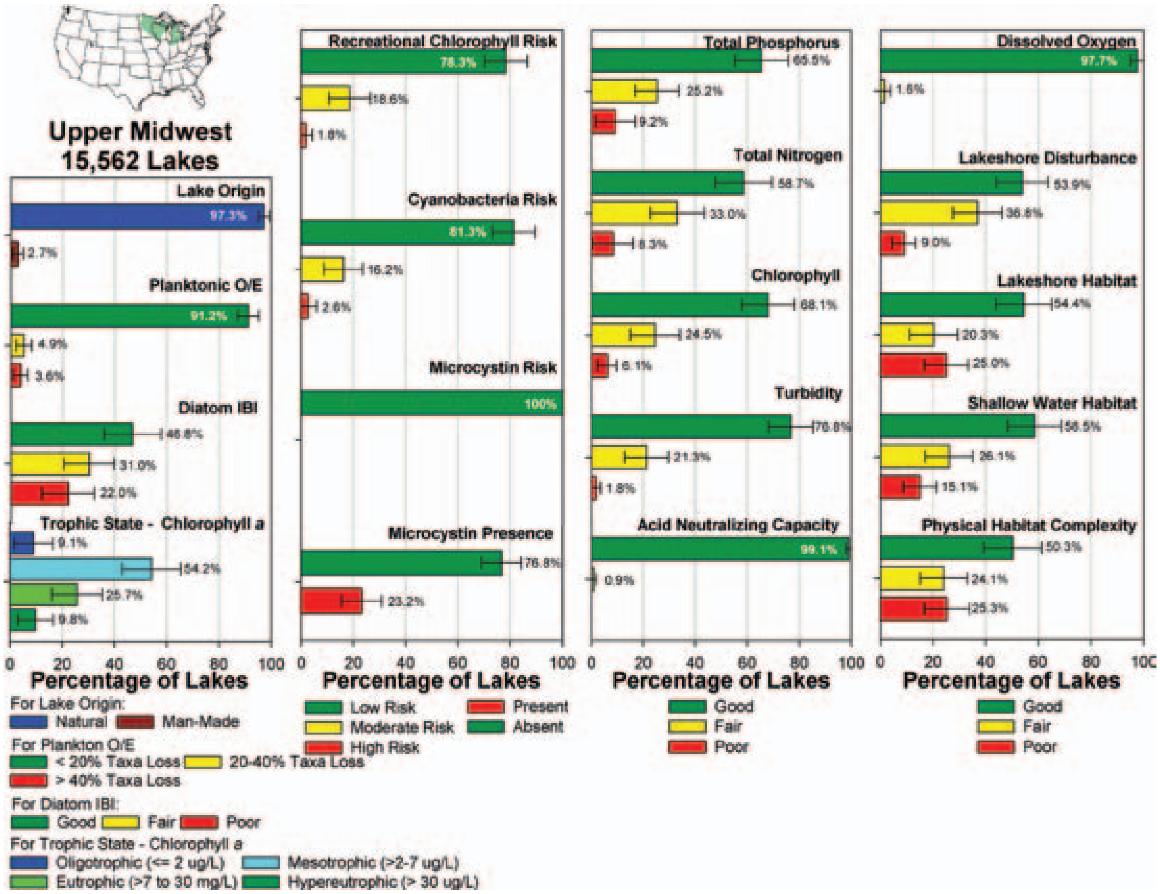


Figure 28. NLA findings for the Upper Midwest. Bars show the percentage of lakes within a condition class for a given indicator. For Recreational Chlorophyll risk and Cyanobacteria risk, the percentage numbers indicate the risk of exposure to algal toxins associated with the presence of cholorphyll-*a* and cyanobacteria, not the risk of exposure to chlorophyll-*a* and cyanobacteria *per se*.

Recreational Suitability

Lakes in the Upper Midwest exhibit relatively low risk of exposure to cyanobacteria and associated cyanotoxins. Based on cyanobacterial counts, 81% of lakes exhibited low exposure risk. Microcystin was present in 23% of lakes.

Physical Habitat Stressors

Lakeshore habitat is considered good in 54% of the lakes in this ecoregion. The shorelines of the Upper Midwest lakes, indicate considerable lakeshore development pressure. Forty-six percent of lakes show moderate to high levels of lakeshore human disturbance.

Chemical Stressors

Based on the NLA chemical stressor indicators, water quality is relatively good across the Upper Midwest. Total phosphorus and nitrogen are considered good in 66% and 59% of lakes, respectively, and are poor in 9% and 8%, of lakes respectively. Relative to regionally-specific reference expectations, chlorophyll-a concentrations are considered good in 68% of lakes, and turbidity levels are considered good in 77% of lakes in this ecoregion. Lakes are in good condition based on ANC and surface water DO levels when compared to nationally-consistent thresholds.

Temperate Plains
The Landscape

The Temperate Plains ecoregion includes the open farmlands of Iowa; eastern North and South Dakota; western Minnesota; portions of Missouri, Kansas, and Nebraska; and the flat farmlands of western Ohio, central Indiana, Illinois, and southeastern Wisconsin. This ecoregion covers some 342,200 square miles (11.4% of the United States), with approximately 7,900 square miles (2.3%) in federal ownership. The terrain consists of smooth plains, numerous small lakes, prairie pothole lakes, and wetlands. A total of 6,327 lakes in the Temperate Plains ecoregion are represented in the NLA, of which 75% are of natural origin. Lakes of this region are generally small, with over 60% of lakes smaller than 100 hectares in size. Agriculture is the predominant land use. Based on satellite images in the 1992 National Land Cover Dataset, the distribution of land cover is 9% forested and 76% planted/cultivated, with the remaining 15% of land in other types of cover.

Sampling with a D-net for benthic macroinvertebrates.
Photo courtesy of Great Lakes Environmental Center.

Findings

A total of 137 of the selected NLA sites were sampled during the summer of 2007 to characterize the condition of lakes throughout this ecoregion. An overview of the NLA findings for the Temperate Plains lakes is shown in Figure 29.

Biological Condition

One quarter, or 24%, of lakes are in good biological condition based on planktonic O/E, and when using the diatom IBI, 17% of lakes in the ecoregion are in good biological condition relative to reference condition. Conversely, the percentages of lakes in poor condition are 35% and 52% based on the two analyses, respectively.

Trophic Status

Based on chlorophyll-*a*, 2% of lakes are oligotrophic, 32% are mesotrophic, 21% are eutrophic, and 45% are considered hypereutrophic.

Recreational Suitability

Lakes in the Temperate Plains exhibit moderate risk of exposure to cyanobacteria and associated cyanotoxins. Based on cyanobacterial counts, 48% of lakes exhibited low exposure risk. Microcystin was present in 67% of lakes.

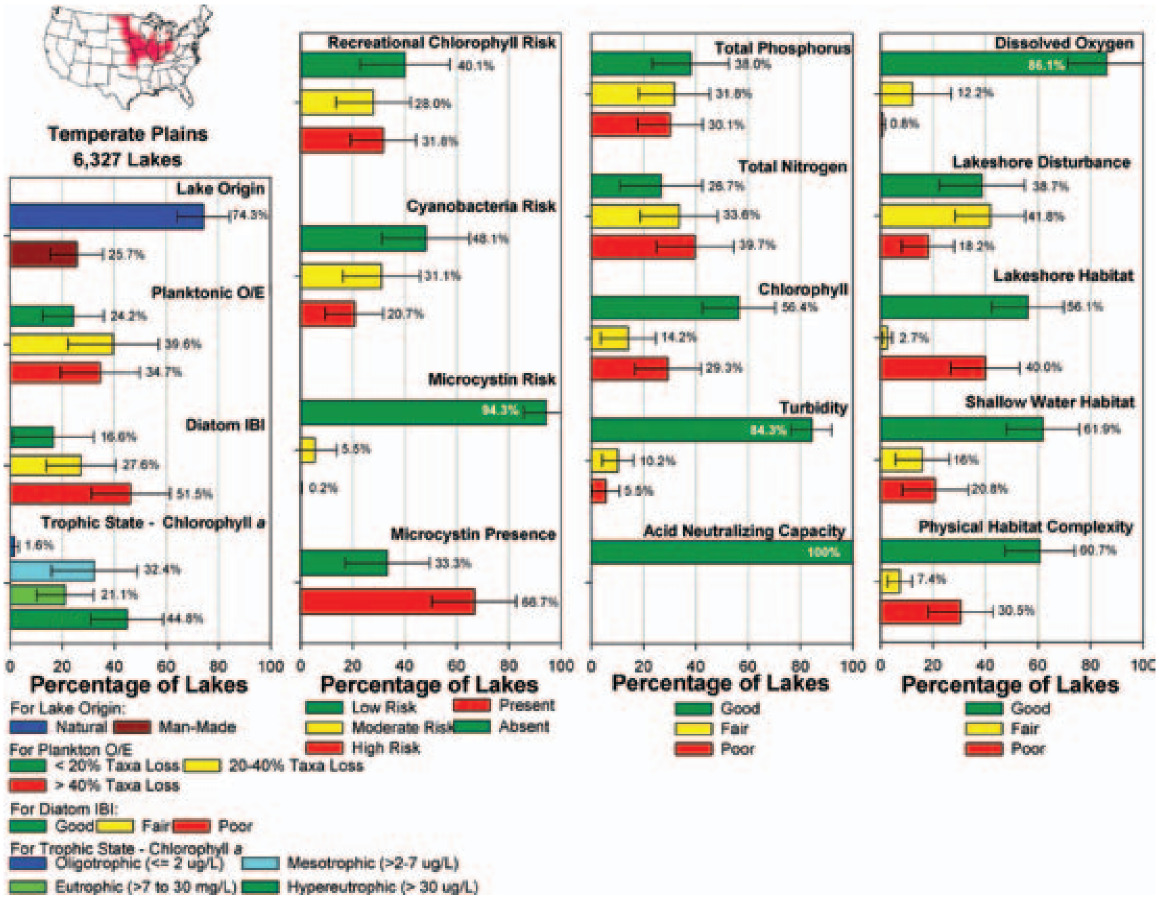


Figure 29. NLA findings for the Temperate Plains. Bars show the percentage of lakes within a condition class for a given indicator. For Recreational Chlorophyll risk and Cyanobacteria risk, the percentage numbers indicate the risk of exposure to algal toxins associated with the presence of cholorphyll-*a* and cyanobacteria, not the risk of exposure to chlorophyll-*a* and cyanobacteria *per se*.

Physical Habitat Stressors

Lakeshore habitat is considered good in 56% of the lakes in this ecoregion. The shorelines of the Temperate Plains lakes exhibit human activity disturbances, urban development, and agricultural pressures in this region. Sixty percent of lakes show moderate to high levels of lakeshore human disturbance.

Chemical Stressors

Based on the NLA chemical stressor indicators, water quality in the Temperate Plains is somewhat variable. Total phosphorus and nitrogen are considered good in 38% and 27% of lakes, respectively, and are poor in 30% and 40% of lakes, respectively. Relative to regionally-specific reference expectations, chlorophyll-*a* concentrations are considered good in 56% of lakes, and turbidity levels are considered good in 84% of lakes in this ecoregion. Lakes are generally in good condition based on ANC and surface water DO levels when compared to nationally-consistent thresholds. However, dissolved oxygen is fair in 12% of lakes.

Southern Plains
The Landscape

The Southern Plains ecoregion covers approximately 405,000 square miles (13.5% of the United States) and includes central and northern Texas; most of western Kansas and Oklahoma; and portions of Nebraska, Colorado, and New Mexico. The terrain is a mix of smooth and irregular plains interspersed with tablelands and low hills. Most of the great Ogallala aquifer lies underneath this region.

Based on satellite images in the 1992 National Land Cover Dataset, the distribution of land cover is 45% grassland, 32% planted/cultivated, and 14% shrubland, with the remaining 9% of land in other types of cover. The Great Prairie grasslands, which once covered much of the Southern Plains region, are considered the most altered and endangered large ecosystem in the United States. About 90% of the original tall grass prairie has been replaced by other vegetation or land use. Federal land ownership in the region totals about 11,980 square miles or approximately 3% of the total, the lowest share of all NLA aggregate ecoregions. A total of 3,148 lakes in the Southern Plains ecoregion are represented in the NLA, 97% of which are constructed reservoirs.

Findings

A total of 128 of the selected NLA sites were sampled during the summer of 2007 to characterize the condition of lakes throughout this ecoregion. An overview of the NLA findings for the Southern Plains lakes is shown in Figure 30.

Comanche Creek Reservoir.
Photo courtesy of Texas Commission of Environmental Quality.

Biological Condition

Thirty-four percent of lakes are in good biological condition based on planktonic O/E, and when using the diatom IBI, 41% of lakes in the ecoregion are in good biological condition relative to reference condition. Conversely, the percentages of lakes in poor condition are 29% and 23% based on the two analyses, respectively.

Trophic Status

Based on chlorophyll-*a*, 9% of lakes are oligotrophic, 14% are mesotrophic, 51% are eutrophic, and 26% are considered hypereutrophic.

Recreational Suitability

Lakes in the Southern Plains exhibit moderate risk of exposure to cyanobacteria and associated cyanotoxins. Based on cyanobacterial counts, 57% of lakes exhibit low exposure risk. Microcystin was present in 21% of lakes.

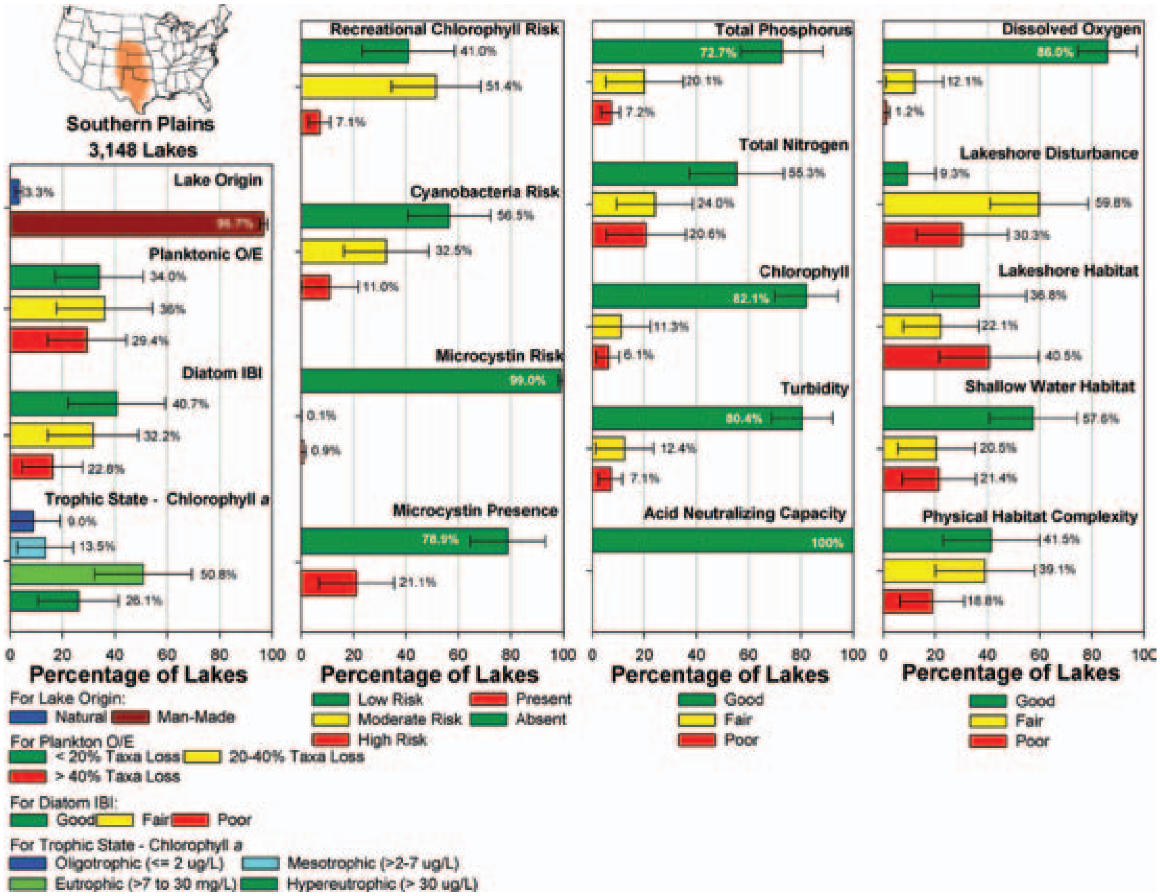


Figure 30. NLA findings for the Southern Plains. Bars show the percentage of lakes within a condition class for a given indicator. For Recreational Chlorophyll risk and Cyanobacteria risk, the percentage numbers indicate the risk of exposure to algal toxins associated with the presence of cholorphyll-*a* and cyanobacteria, not the risk of exposure to chlorophyll-*a* and cyanobacteria *per se*.

Physical Habitat Stressors

Lakeshore habitat is fair to poor in 63% of the lakes in this ecoregion. The shorelines of Southern Plains lakes exhibit considerable disturbed conditions due to human activities. Ninety percent of lakes show moderate to high levels of lakeshore human disturbance.

Chemical Stressors

Water quality, based on the NLA chemical stressor indicators, is relatively good in the Southern Plains. Total phosphorus and nitrogen are considered good in 73% and 55% of lakes, respectively, and are poor in 7% and 20% of lakes, respectively. Relative to regionally-specific reference expectations, chlorophyll-*a* concentrations and turbidity levels are considered good in over 80% of lakes in this ecoregion. Lakes are generally in good condition based on ANC and surface water DO levels when compared to nationally-consistent thresholds. However, dissolved oxygen is fair in 12% of lakes.

Northern Plains
The Landscape

The Northern Plains ecoregion covers approximately 205,084 square miles (6.8% of the United States), including western North and South Dakota, Montana east of the Rocky Mountains, northeast Wyoming, and a small section of northern Nebraska. Federal lands account for 52,660 square miles or a relatively large 25.7% share of the total area. Terrain of the area is irregular plains interspersed with tablelands and low hills. This ecoregion is the heart of the Missouri River system and is almost exclusively within the Missouri River's regional watershed. Several major reservoirs are along the Missouri River mainstem, including Lake Oahe and Lake Sacajawea. The total surface area of lakes in this region is growing owing to increased runoff coupled with flat topography. Devil's Lake (ND) is one example, which in 1993 had a surface area of 44,000 acres and presently covers in excess of 130,000 acres.

Based on satellite images in the 1992 National Land Cover Dataset, the distribution of land cover is 56% grassland and 30% planted/cultivated, with the remaining 14% of land in other types of cover. A total of 2,660 lakes in the Northern Plains ecoregion are represented in the NLA, 77% of which are of natural origin.

Findings

A total of 65 of the selected NLA sites were sampled during the summer of 2007 to characterize the condition of lakes throughout this ecoregion. An overview of the NLA findings for the Northern Plains ecoregion is shown in Figure 31.

A Northern Plains lake.
Photo courtesy of Tetra Tech.

Biological Condition

The Northern Plains has the highest proportion of lakes in poor biological condition of any of the ecoregions. Ninety percent of lakes are in poor biological condition based on planktonic O/E, and 88% are in poor condition based on the diatom IBI.

Trophic Status

Based on chlorophyll-*a*, 8% of lakes are oligotrophic, 22% are mesotrophic, 48% are eutrophic, and 22% are considered hypereutrophic.

Recreational Suitability

Lakes in the Northern Plains exhibit the greatest risk of exposure to cyanobacteria and associated cyanotoxins of all ecoregions. Based on cyanobacterial counts, 59% of lakes exhibit moderate to high exposure risk. Microcystin was present in 75% of lakes.

Physical Habitat Stressors

Lakeshore habitat cover is considered good in only 7% of the lakes in this ecoregion. Regionally-specific habitat reference condition for the Northern Plains

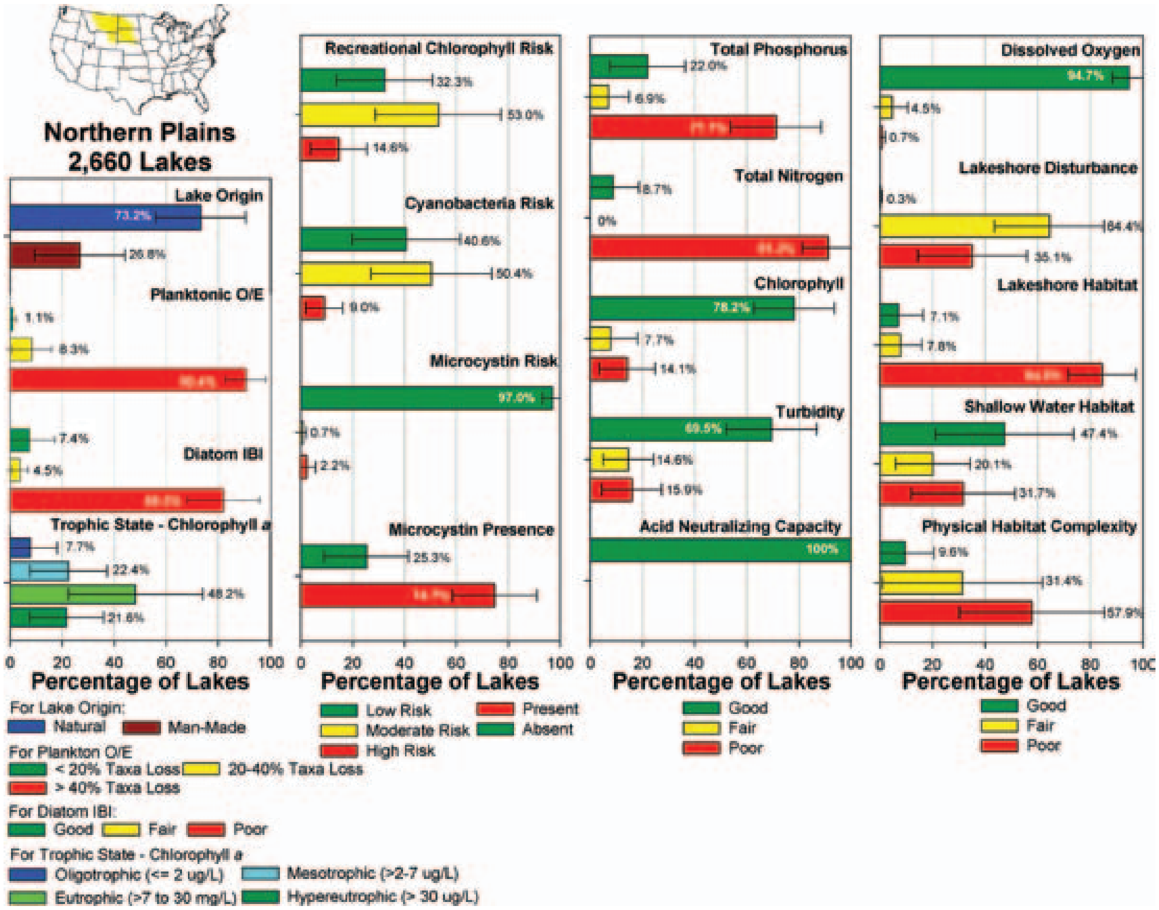


Figure 31. NLA findings for the Northern Plains. Bars show the percentage of lakes within a condition class for a given indicator. For Recreational Chlorophyll risk and Cyanobacteria risk, the percentage numbers indicate the risk of exposure to algal toxins associated with the presence of cholorphyll-*a* and cyanobacteria, not the risk of exposure to chlorophyll-*a* and cyanobacteria *per se*.

is comprised of grasses and shrubs and is different from many of the other ecoregions where expectations include a tree layer in addition to a middle and lower story. Even taking into account the regional-specific expectations, the NLA data show that the Northern Plains lake shorelines exhibit very high levels of disturbance due to human activities. Ninety-nine percent of lakes show moderate or high levels of lakeshore human disturbance.

Chemical Stressors

Based on the NLA chemical stressor indicators, water quality is variable in the Northern Plains. In general, lakes in this ecoregion tend to have high levels of nutrients. Relative to regionally-specific reference expectations, total phosphorus concentrations are considered poor in 71% of lakes, while total nitrogen concentrations are considered poor in 91% of lakes. By contrast, based on chlorophyll-*a*, 78% of lakes are considered in good condition, and turbidity levels are good in 70% of lakes.

In the Northern Plains ecoregion, the traditional limnological concept that biomass production is controlled simply by nutrient concentrations may not apply. Lakes are generally in good condition based on ANC and surface water DO levels when compared to nationally-consistent thresholds.

Western Mountains
The Landscape

The Western Mountains ecoregion includes the Cascade, Sierra Nevada, Pacific Coast ranges in the coastal states; the Gila Mountains in the southwestern states; and the Bitterroot and Rocky Mountains in the northern and central mountain states. This region covers approximately 397,832 square miles, with about 297,900 square miles or 74.8% classified as federal land — the highest proportion of federal property among the nine aggregate ecoregions. The terrain of this area is characterized by extensive mountains and plateaus separated by wide valleys and lowlands. Lakes in this region, in particular those within smaller, high-elevation drainages, are very low in nutrients, are very dilute in other water chemistry constituents (*e.g.*, calcium). Therefore biological productivity in these systems is limited in their natural condition. Accordingly, these smaller, high elevation lakes are very sensitive to effects of human disturbances.

Lakes and ponds of the region range from large mainstem impoundments to high-mountain caldera and kettle lakes. Most famous among these mountain caldera lakes are Crater Lake (OR) and Lake Yellowstone (WY). The single deepest measurement of Secchi disk transparency recorded during the NLA – 122 feet (37 meters) – occurred in this ecoregion in Waldo Lake (OR). Based on satellite images in the 1992 National Land Cover Dataset, the distribution of land cover is 59% forest, 32% shrubland and grassland with the remaining 9% of land in other types of cover. A total of 4,122 lakes in the Western Mountains ecoregion are represented in the NLA, 67% of which are of natural origin.

Survey crews travel on horseback to reach remote lakes.
Photo courtesy of Tetra Tech.

Findings

A total of 155 of the selected NLA sites were sampled during the summer of 2007 to characterize the condition of lakes throughout this ecoregion. An overview of the NLA findings for the Western Mountains lakes is shown in Figure 32.

Biological Condition

Fifty-eight percent of lakes are in good biological condition based on planktonic O/E, and when using the diatom IBI, 50% of lakes in the ecoregion are in good biological condition relative to reference condition. Conversely, the percentages of lakes in poor condition are 11% and 3% based on the two analyses, respectively.

Trophic Status

Based on chlorophyll-*a*, 54% of lakes are oligotrophic, 26% are mesotrophic, 16% are eutrophic, and 4% are considered hypereutrophic. The Western Mountains ecoregion has the highest proportion of oligotrophic lakes (very clear with low productivity) of any of the ecoregions across the country.

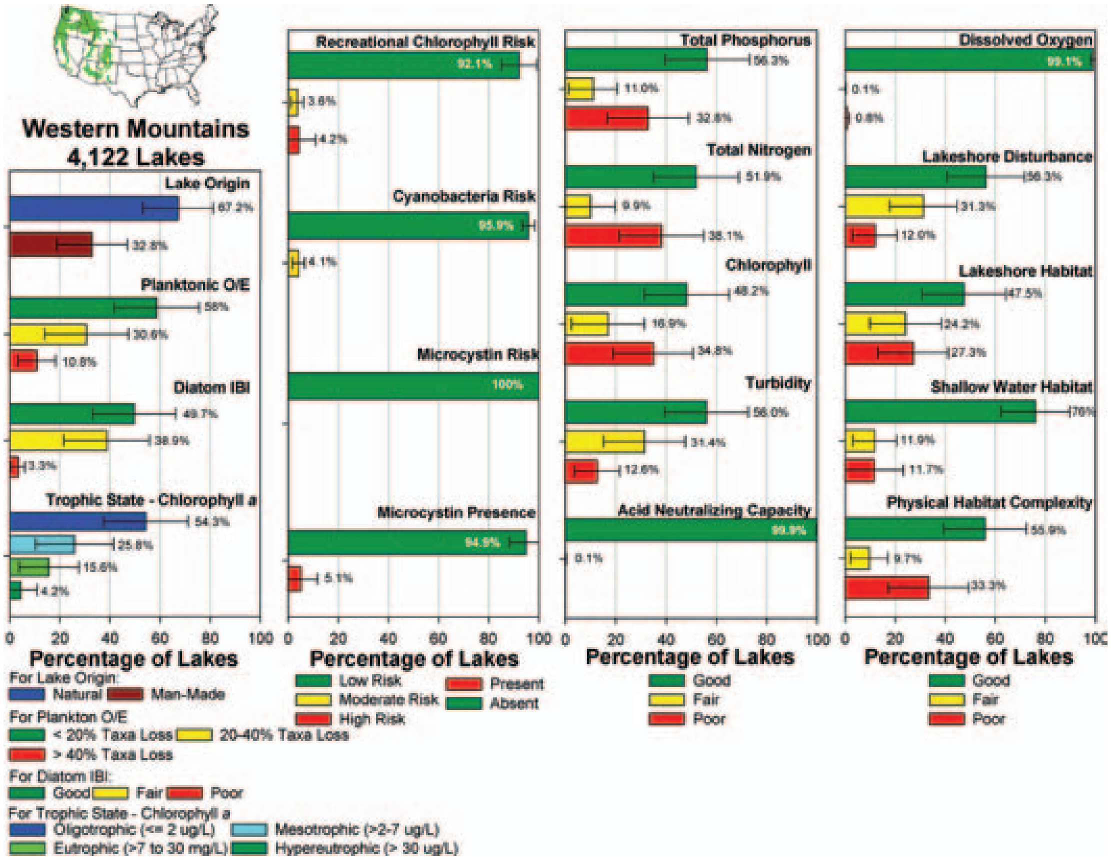


Figure 32. NLA findings for the Western Mountains. Bars show the percentage of lakes within a condition class for a given indicator. For Recreational Chlorophyll risk and Cyanobacteria risk, the percentage numbers indicate the risk of exposure to algal toxins associated with the presence of cholorphyll-*a* and cyanobacteria, not the risk of exposure to chlorophyll-*a* and cyanobacteria *per se*.

Recreational Suitability

Lakes in the Western Mountains exhibit the lowest risk of exposure to cyanobacteria and associated cyanotoxins of all ecoregions. Based on cyanobacterial counts, 96% of lakes exhibit low exposure risk. Microcystin was present in only 5% of lakes.

Physical Habitat Stressors

Lakeshore habitat is considered good in 48% of the lakes in this ecoregion. Similar to the Northern Plains, regionally-specific reference conditions were modified in this ecoregion to account for sparse natural vegetation cover types expected in this mountainous region. With respect to human activity along the lakeshore, this ecoregion has the lowest percentage of lakes with human disturbance of all regions. Forty-three percent of lakes show moderate to high levels of lakeshore human disturbance.

Chemical Stressors

Based on the NLA chemical stressor indicators, water quality in the Western Mountains is consistently in the medium range. Relative to regionally-specific reference expectations, total phosphorus concentrations are considered good in 56% of lakes, fair in 11%, and poor in 33%. Total nitrogen concentrations are considered good in 52% of lakes, fair in 10%, and poor in 38%. Based on chlorophyll-*a,* 48% of lakes are considered in good condition, 17% in fair condition, and 35% in poor condition. Turbidity levels are good in 56% of lakes and fair in 31% of lakes. Lakes are in good condition based on ANC and surface water DO levels when compared to nationally-consistent thresholds.

Xeric
The Landscape

The Xeric ecoregion covers the largest area of all NLA aggregate ecoregions. This ecoregion covers portions of eleven western states and all of Nevada for a total of about 636,583 square miles (21.2% of the United States). Some 453,000 square miles or 71.2% of the land is classified as federal lands, including large tracts such as the Grand Canyon National Park (AZ), Big Bend National Park (TX), and the Hanford Nuclear Reservation (WA). The Xeric ecoregion is comprised of a mix of physiographic features. The region includes the flat to rolling topography of the Columbia/Snake River Plateau; the Great Basin; Death Valley; and the canyons, cliffs, buttes, and mesas of the Colorado Plateau. All of the non-mountainous area of California falls in the Xeric ecoregion.

In southern areas, dry conditions and water withdrawals produce internal drainages that end in saline lakes or desert basins without reaching the ocean. Large lakes in the southwestern canyon regions are the products of large dam construction projects. Water levels in these lakes fluctuate widely due to large-scale water removal for cities and agriculture. Recently, shifts in climate and rainfall patterns have resulted in considerably reduced water levels on several of the major Colorado River impoundments including Lake Mead, Lake Powell, and Lake Havasu. Based on satellite images in the 1992 National Land Cover Dataset, the distribution of land cover is 61% shrubland and 15% grassland, with the remaining 24% of land in other types of cover. A total of 802 lakes in the Xeric ecoregion are represented in the NLA, 91% of which are constructed reservoirs.

Lewis Lake, NM.
Photo courtesy of Tetra Tech.

Findings

A total of 84 of the selected NLA sites were sampled during the summer of 2007 to characterize the condition of lakes throughout the ecoregion. An overview of the NLA results for the Xeric ecoregion is shown in Figure 33.

Biological Condition

Thirty-seven percent of lakes are in good biological condition based on planktonic O/E, and when using the diatom IBI, 70% of lakes in the ecoregion are in good biological condition relative to reference condition. Conversely, the percentages of lakes in poor condition are 49% and 6% based on the two analyses, respectively. The difference between these two biological indices may suggest that the two indicators are responding to different stressors in lakes in this particular ecoregion.

Trophic Status

Based on chlorophyll-*a*, 22% of lakes are oligotrophic, 27% are mesotrophic, 22% are eutrophic, and 28% are considered hypereutrophic.

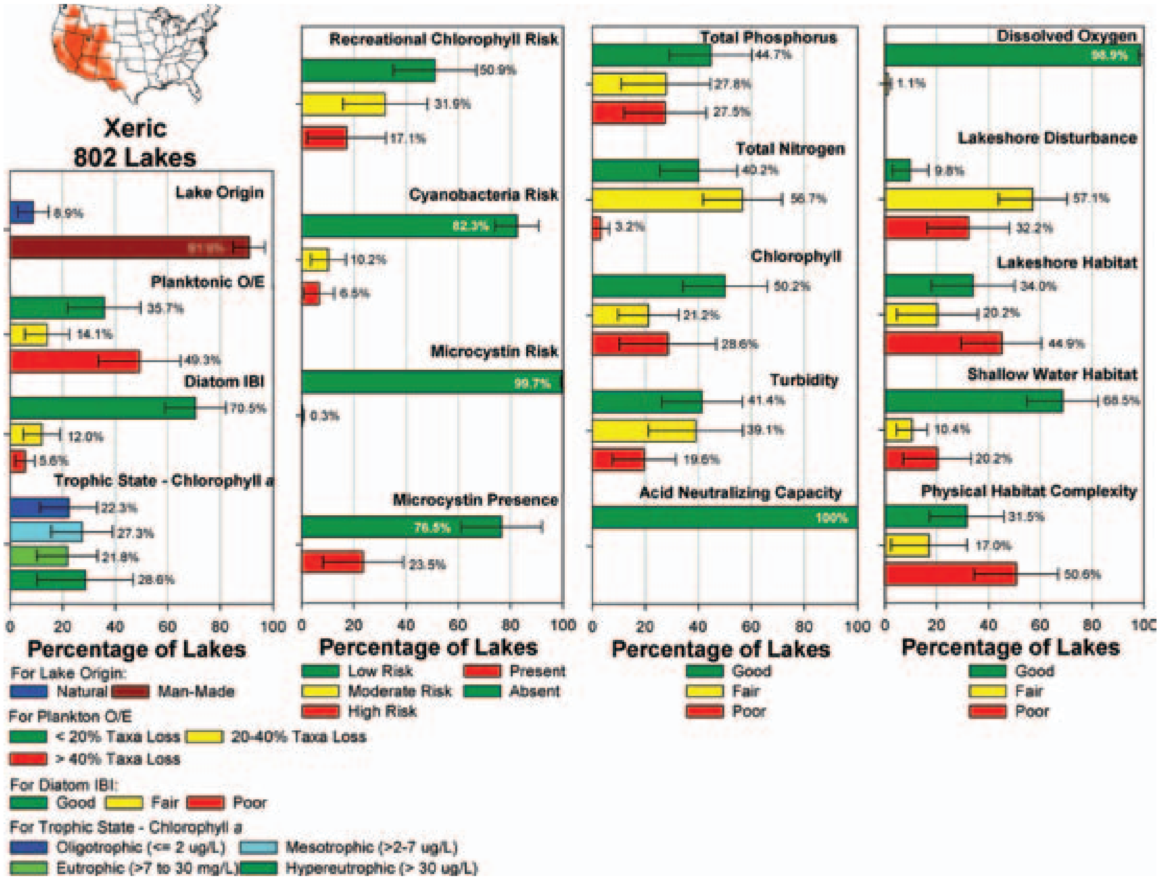


Figure 33. NLA findings for the Xeric. Bars show the percentage of lakes within a condition class for a given indicator. For Recreational Chlorophyll risk and Cyanobacteria risk, the percentage numbers indicate the risk of exposure to algal toxins associated with the presence of cholorphyll-*a* and cyanobacteria, not the risk of exposure to chlorophyll-*a* and cyanobacteria *per se*.

Recreational Suitability

Lakes in the Xeric ecoregion exhibit low to moderate risk of exposure to cyanobacteria and associated cyanotoxins. Based on cyanobacterial counts, 82% of lakes exhibit low exposure risk. Microcystin was present in 23% of lakes.

Physical Habitat Stressors

Lakeshore habitat is considered good in 34% of the lakes in this ecoregion. In the Xeric ecoregion, regionally-specific reference conditions were modified to account for sparse natural vegetation cover types expected in this dry region. Lakes in the Xeric ecoregion exhibit considerably disturbed conditions due to human activities. Over 89% of lakes show moderate to high levels of lakeshore human disturbance.

Chemical Stressors

Like the Western Mountains ecoregion to the north, the water quality in the Xeric ecoregion is in the medium range. Relative to regionally-specific reference expectations, total phosphorus concentrations are considered good in 45% of lakes, fair in 28%, and poor in 28%. Total nitrogen concentrations are considered good in 40% of lakes, fair in 57%, and poor in 3%. Based on chlorophyll-*a,* 50% of lakes are considered in good condition, 21% in fair condition, and 29% in poor condition. Turbidity levels are good in 41% of lakes, and fair in 39%. Lakes are good condition based on ANC and surface water DO levels when compared to nationally-consistent thresholds.

HIGHLIGHT

Partnerships for a Statewide Assessment of Lake Condition

Steve Heiskary
Minnesota Pollution Control Agency

In 2007, the Minnesota Pollution Control Agency (MPCA) along with the Minnesota Department of Natural Resources (MDNR) led the State's participation in USEPA's National Lakes Assessment survey. Various other collaborators were engaged in this study as well, including the U.S. Forest Service (USFS), the Minnesota Department of Agriculture (MDA), and U.S. Geological Survey (USGS). MPCA and MDNR combined on initial planning of the survey and conducted the vast majority of the sampling. USFS staff were instrumental in sampling remote lakes in the northeastern Boundary Waters Canoe Area Wilderness.

Minnesota was assigned 41 lakes as a part of the original draw of lakes for the national survey – the most of any of the lower 48 states. The State then chose to add nine additional lakes (randomly selected) to the survey to yield the 50 lakes needed for statistically-based statewide estimates of lake condition. In addition to the 50 lakes, three reference lakes were later selected and sampled by USEPA as a part of the overall NLA effort.

As part of its statewide assessment, Minnesota opted to add several measurements of unique interest to its overall state program. Examples of these add-ons are: pesticides; water mercury; sediment analysis of metals, trace organics and other indicators; macrophyte species richness; fish-based lake Index of Biotic Integrity (IBIs); and microcystin (at the index site and at a random near-shore site). A few of the findings are highlighted here. All of the reports completed to date can be found at: http://www.mpca.state.mn.us/water/nlap.html.

Pesticides

With the exception of the corn herbicide atrazine, pesticide degradates were more frequently detected than were the parent compounds. Possibly more of these parent compounds may have initially been present in a greater number of lakes, but had degraded prior to sampling. Alternately, parent compounds may have degraded early in the process, with degradates being subsequently transported to the lakes via overland runoff. Since the peak pesticide application period is late spring to early summer, mid-summer (July – August) lake sampling may have allowed ample time for degradation products to reach affected lakes. MDA was a key collaborator in this effort and conducted the pesticide analysis.

Detection of Pesticides and Pesticide Degradates in Minnesota Lakes

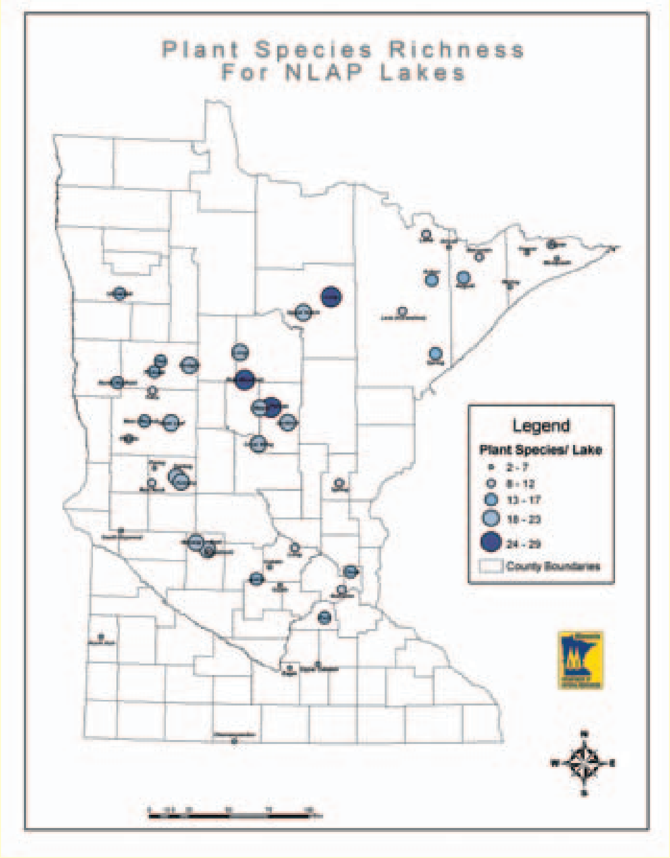
	Atrazine	Deisopropyl-atrazine	Desethy-atrazine	Metolachlor	Metolachlor ESA	Metolachlor OXA
Detection	present	non-detect	present	present	present	present
Detection freq.	87%	2%	64%	4%	27%	7%

Mercury levels

Measurement of total mercury (THg) and methyl mercury (MeHg) concentrations indicate that high levels of THg and MeHg are distributed throughout the state. The northeastern region has higher THg and MeHg concentrations compared to the southwestern region, although the MeHg fraction may actually be somewhat higher in the southwestern region. Otherwise, high THg and MeHg concentrations are distributed throughout the range of NLA lakes. These data can be used as a baseline against which to evaluate the efficacy of mercury emissions controls in MN. The USGS was an important partner in this effort

Aquatic Macrophytes

Plant species richness was assessed at ten random near-shore sites on each lake. Generally, species richness increases from south to north peaking in the north central portion of the State before decreasing in the northeastern arrowhead region. The general trend of increasing species richness from north to south can be explained by water clarity, water chemistry, and human disturbance, and reaffirms previous observations. The decrease in species richness in the northeastern portion of the state can be attributed to tannin stained waters and rocky substrate associated with Canadian Shield lakes located throughout this region.



Continuing Partnerships

Minnesota also is collaborating on a regional assessment of lakes in the Prairie Pothole Region with the states of North Dakota, South Dakota, Montana and Iowa and EPA Regions V and VIII. This collaboration will expand applications of statistically-derived data and serve to enhance state, regional and national lake assessment efforts.

CHAPTER 7.

CHANGES AND TRENDS

Photo courtesy of Great Lakes Environmental Center

IN THIS CHAPTER

- Subpopulation Analysis of Change – National Eutrophication Study
- Subpopulation Analysis – Trends in Acidic Lakes in the Northeast
- Sediment Core Analysis

Chapter 7
Changes and Trends

Among the long term goals of the National Aquatic Resource Surveys is the detection of changes and trends in both the condition of our Nation's aquatic resources and in the stressors impacting them. Trends in particular can be critical for policy makers *i.e.,* whether policy decisions have been effective or whether a different approach is needed to achieve important water quality goals.

This first survey of lakes and reservoirs provides clear information on current status and serves as the baseline for future changes and trends analyses. At this early stage the National Lakes Assessment is, however, able to incorporate three ancillary analyses to provide a cursory look at what changes have occurred. Over time, EPA intends to use further analysis and future surveys to start the trends analyses.

The first indication of change comes from the analysis of a subset of lakes surveyed in the 1970's and again in 2007. Between 1972 and 1976 the Agency and the states implemented the National Eutrophication Survey (NES) – a survey that included more than 800 lakes. The NLA was designed to allow for the comparison of some of the same lakes.

The second example of change is based on data in a regional study of acidic lakes in a subpopulation of lakes, *i.e.,* the northeastern U.S. Finally, a third examination of change involves the evaluation of cores from the lake sediments. By examining different cross sections within the sediment core and the microscopic diatoms present, analysts can infer past conditions in each lake.

Subpopulation Analysis - National Eutrophication Survey

Between 1972 and 1976, EPA conducted the National Eutrophication Survey. This study was designed to assess the trophic condition (defined as nutrient enrichment) of lakes influenced by domestic wastewater treatment plants (WWTP). The purpose of the survey was to measure nutrient inputs from all sources in the watershed relative to those of the WWTP source to determine if WWTP upgrades might be successful in modifying the lake or reservoir trophic state. While national in scope, it was unlike the NLA in that it was not probability-based. Instead it targeted a specific set of 800 wastewater impacted lakes.

For the NLA, a subset of 200 lakes from the 1972-1976 NES survey was randomly selected using the same probability design principles from the broader survey. This allowed the condition of all 800 lakes from the original NES survey to be inferred from

the subsample of 200 lakes sampled in 2007. The phosphorus levels, chlorophyll-*a* concentrations, and trophic condition of the NES population in 2007 could then be compared to what was observed in the 1970s to determine how these metrics have changed over the last thirty-plus years.

When making comparisons between then and now, some design differences between the two studies must be considered. NLA sampling consisted of a single, mid-summer integrated water sample at the deepest spot in the lake and from just below the surface to a depth of up to 2m (a sampling tube). The NES sampling consisted of sampling several sites on the lake as well as the inlets and outlets. NES sampling also included a site at the perceived deepest spot in the lake. Sampling was done with a depth-specific sampler (bottle) at just below the surface and at 1-2m depth intervals. Analysts compared the integrated sample NLA chlorophyll concentrations and NES samples taken at the site nearest the NLA site and from depth(s) that most nearly mimicked the depth of the NLA integrated depth sample. The accuracy and precision of chemical analytical results were considered comparable to each other based on the methods and the quality assurance of both surveys.

The NLA analysts looked at changes in the NES lakes over the past thirty-plus years using two approaches: by comparing concentration levels of key indicators and by examining trophic status. In both cases, researchers were able to estimate the number and percentage of NES lakes that showed a change since the original sampling in the 1970s. It is worth noting that this type of analysis provides an estimate of net change, but little information on change in individual lakes.

Phosphorus levels have decreased in more than 50% of the NES lakes (403) and for 24% (189) no change was detected. An increase in phosphorus levels was seen in 26% of the lakes (207) (Figure 34).

Trophic status based on chlorophyll-*a* also changed (Figure 35). Trophic status improved in 26% (184) of the lakes, and remained

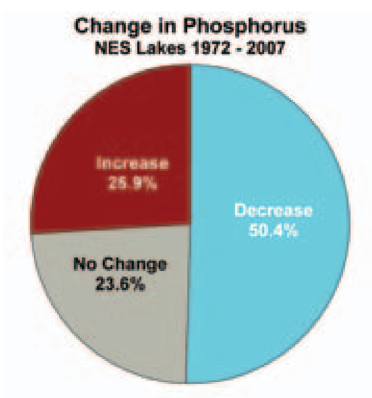


Figure 34. Proportion of NES lakes that exhibited improvement, degradation, or no change in phosphorus concentration based on the comparison of the 1972 National Eutrophication Survey and the 2007 National Lakes Assessment

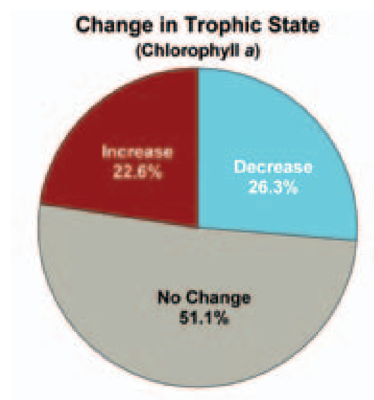


Figure 35. Proportion of NES lakes that exhibited improvement, degradation, or no change in trophic state based on the comparison of the 1972 National Eutrophication Survey and the 2007 National Lakes Assessment.

unchanged in over half (51% or 408 lakes) of the NES lakes. Trophic state degraded in 23% (208) of the NES lakes. Specifically, using chlorophyll-*a* as the indicator of trophic state, 49% of the lakes (394 lakes) in NES were classified as hypereutrophic in 1972. In 2007, that number had fallen to 35% (279) of the lakes. In 1972, just over 5% of the lakes were classified as oligotrophic and by 2007, over 14% of the lakes (117) were classified as oligotrophic (Figure 36).

Subpopulation Analysis - Trends in Acidic Lakes in the Northeast

A similar approach to assessing changes and trends was taken for lakes that are either acidic or sensitive to acidification as part of EPA's EMAP Temporally Integrated Monitoring of Ecosystems/Long Term Monitoring (TIME/LTM) program. During the 1980s, the National Surface Water Survey was conducted on lakes in acid sensitive regions across the country. Again, EPA was able to make some

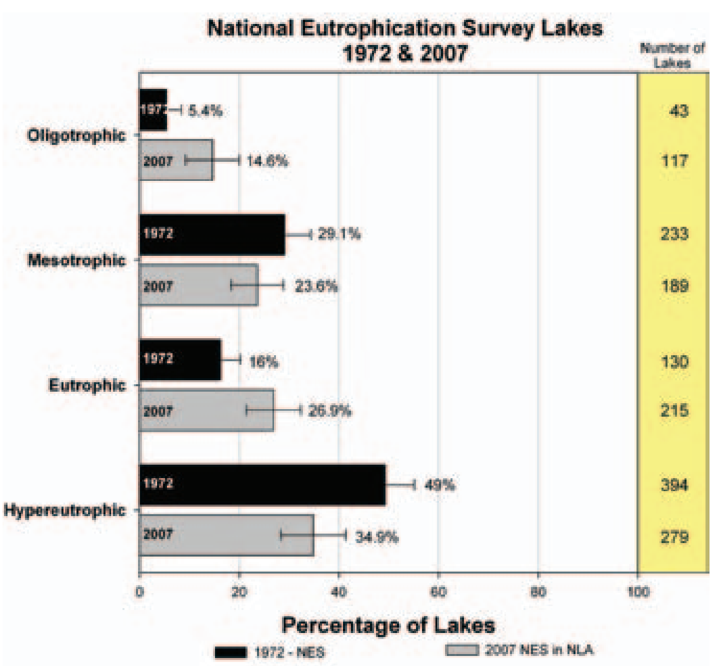


Figure 36. Percentage and number of NES lakes estimated in each of four trophic classes in 1972 and in 2007 based on chlorophyll-*a* concentrations.

comparisons. The NLA results show that acidification of lakes affects a very small number of lakes nationally. However, in certain regions of the country, the problem is of concern, particularly when lakes smaller than 10 acres (4 hectares) are included.

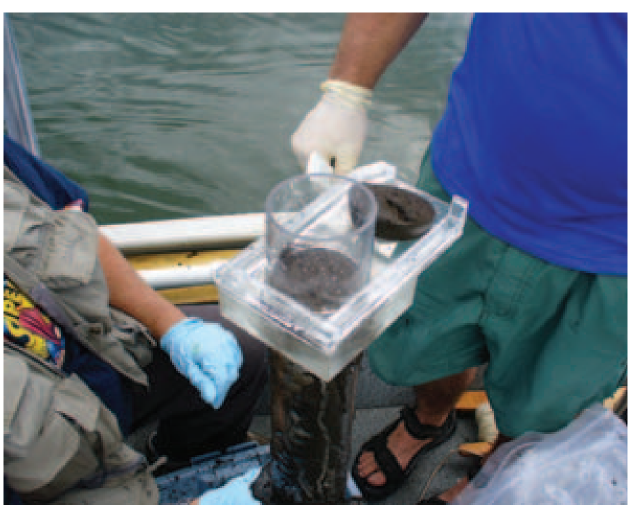
Between the early 1990s and 2005, the acid neutralizing capacity in lakes in the Adirondack Mountains increased to a degree where many water bodies that were considered "chronically acidic" in the early 1990s were no longer classified as such in 2005 (Figure 37). Specifically, between 1991-1994 and 2005, the percent of chronically acidic waterbodies decreased in the Adirondack Mountains from 13.0% to 6.2%. Additionally, acid-sensitive lakes in New England were beginning to show a decrease in acidity. The percent of chronically acidic lakes in this region decreased from 5.6% in 1991-1994 to 4.3% in 2005. This trend suggests that lakes in these two regions are beginning to recover from acidification, though acidic surface waters are still found in these regions.

The trend of increasing ANC in lakes in the Adirondack Mountains and New England between the early 1990s and 2005 corresponds with a decrease in acid deposition in each of these regions and reduced air emissions of the main components to acid deposition, which are sulfur dioxide and nitrogen oxides.

Sediment Core Analysis

In the third examination of change, the NLA incorporated paleolimnological analyses, a technique that uses lake sediment cores to obtain insights about past conditions. NLA analysts looked at thin slices of sediment cores and identified diatom silica casings. The community of diatoms present in each slice gives clues to the chemical and physical conditions in the lake when that layer was deposited. Models have been developed to relate the diatom community to lake chemistry characteristics, such as total phosphorus, and to lake physical characteristics, such as clarity. Using these relationships, the diatoms in deeper layers of the sediment were identified and the chemical conditions present at that point in time were inferred. This technique was used very effectively during studies of acidification in lakes during the 1980s. Individual states and other organizations have also used sediment cores in this manner on more localized/regional scales to improve our understanding of what lakes were like in the past.

EPA piloted this technique for application at a national scale to examine temporal change in a subset of lakes included in the NLA. In the field, the top layer of the sediment core was collected along with a layer deep in the core. Unfortunately, EPA was unable to date the sections of the core to confirm their age. Instead, NLA analysts used independent techniques, their own expertise, and the knowledge of regional experts to determine whether the cores were sufficiently deep for NLA purposes. The Agency acknowledges that this approach is a less reliable means of estimating the age of the cores.



Slicing off the top layer of the sediment core for diatom analysis. Photo courtesy of Frank Borsuk.

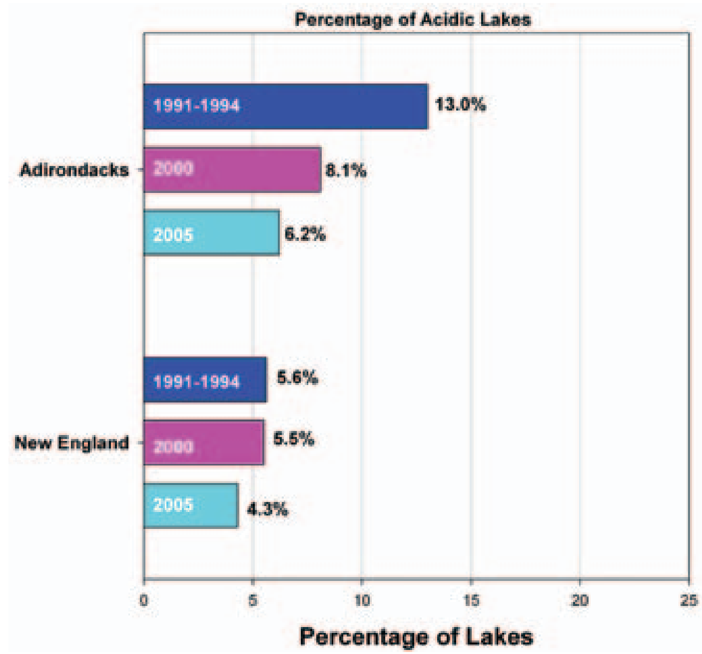


Figure 37. Change in percentage of chronically acidic lakes in the Adirondack Mountains and New England.

For man-made lakes the bottom layer of the sediment cores was not collected because it was presumed sediment cores in these more recent lakes would not represent a pre-industrial condition. Three hundred ninety-two lakes, representing 34% of the target population, were in this category and also were not evaluated. In addition, 334 lakes, representing about 22% of the target population, were not evaluated because the core length was insufficient. In the end, change estimates were possible for 426 lakes, representing 55% of the target population.

Even though the percentage of target population is less than optimum, some information can be gleaned from the data. Results from the cores showed that an estimated 17% of lakes in the lower 48 states exhibited no significant change in inferred total phosphorus between the bottom of the core and the top of the core. A decrease in total phosphorus was estimated to have occurred in 12% of the lakes while almost 7% of lakes were estimated to have experienced an increase in total phosphorus. The pattern in changes for total nitrogen differs somewhat. Nationally, the percentage of lakes showing no change between the top and bottom of the core is less than 5%. Sixteen percent of the lakes showed an increase in total nitrogen while 18% showed a decrease in total nitrogen.

The difference between the top and bottom of the sediment cores suggests that many lakes may have lower total phosphorus and total nitrogen levels now than they once did. Without dating the cores, however, more information and analysis are needed in explaining these results.

While results from this approach are presented below, further analyses will be necessary to determine if sediment core dating should be included in future lake surveys. Issues for consideration include evaluating:

- Whether the approach used is sufficiently robust to identify cores reaching pre-industrial times across the country;
- Whether the assessment of change in a relatively small subset of lakes merits the effort expended in the context of a national survey; and
- Whether alternative coring and/or dating approaches should be considered for future iterations of the NLA.

Photos courtesy of USEPA Region I

Measuring lake depth.

HIGHLIGHT

Climate Impacts on Lakes

Warmer Temperatures and Lake Condition

The preponderance of information indicates that the planet is warming and significant changes in climate are expected around the globe. The International Panel on Climate Change (IPCC) unequivocally attributes the climate change to human activities that have increased greenhouse gases in the atmosphere. The United States alone saw an increase of 1° (F) over the last century. Most of the warming has occurred in the last three decades and the largest observed warming across the country has taken place in the winter months. In southern areas, surface water temperatures are surpassing those of air temperatures, while in the north, there is ample evidence of earlier ice-out dates. For lakes, these changes will impact reservoirs and drinking water sources, hydroelectric power facilities, irrigation regimes, shipping and navigation, and recreational opportunities. From an ecosystem standpoint, warmer lakes will result in changes in water depth, thermal regime, nutrient loading, retention time, mixing and oxygen availability, and suspended sediments – all of which will alter habitat suitability and lake productivity.

Photo courtesy of Great Lakes Environmental Center

Changes in the Upper Midwest — The Great Lakes

While scientists generally agree that the nation will get slightly wetter over the next century, precipitation trends at a regional level are uncertain. In many areas, however, increased rainfall could be offset by increased evaporation, both in terms of soil moisture and surface water. The Great Lakes, which hold 18% of the world's fresh surface water, are being watched carefully. Many agree that warming trends throughout the region will lead to a climate more comparable to the Deep South thus making the lakes themselves smaller and muddier. Since 1988, temperature in Lake Erie has risen 1° (F) and while predictions vary, some researchers forecast that by 2070, lake level will fall about 34 inches and surface area will shrink 15%. This scenario would leave 2,200 square miles of new land exposed. Lower water levels and less ice cover will lead to more sediment delivery, and therefore more algae and potentially more waterborne diseases. Excessive algal blooms can affect aquatic life and harm animals and humans. Climate changes will also affect fish populations and zooplankton communities due to the disruptions in lake dynamics such as the timing and severity of ice-cover, winter-kill and spring/fall turn-over.

Changes in the Southwest – Lake Tahoe and Lake Mead

Persistent drought conditions, increased extreme rainfall events, more wildfires, and heightened flooding, runoff and soil erosion are all expected to afflict the already arid southwest. Since 1988, the average surface water temperature of Lake Tahoe has increased by 1° (F). Other signs of persistent warming are decreased snowfall, later snowfall, and earlier snowmelt. In Tahoe City, California, the percentage of precipitation falling as snow has dropped from 52% in 1910 to 35% in 2007 and since 1961, peak snowmelt throughout the lake region has shifted earlier by two and a half weeks. In *Tahoe: State of the Lake Report 2008*, researchers reported that algal growth, considered an indicator of warming's acceleration, has increased rapidly with concentrations now five times what they were in 1959. Levels of nitrogen and phosphorus deposited from the Angora forest fire (also considered a climate indicator) also were 2-7 times greater than normal.

Photo courtesy of Great Lakes Environmental Center

Fluctuations in precipitation and snowpack have critical impacts on life in the desert. In Nevada, the water level in Lake Mead is steadily dropping and with it the hydroelectric production capacity by Hoover Dam. Studies cited by the National Conference of State Legislatures and Center for Integrative Environmental Research (2008) indicate that there is a 10% chance that Lake Mead could dry up by 2021 and a 50% chance it will be dry by 2050. Lake Mead provides drinking water for over 2 million people and generates electricity for over 1.3 million. Water-based recreation brings in more than $1 billion to the area's economy. Major changes in annual precipitation and snowpack are proving difficult for reservoir managers who must balance winter flooding with maximum capture and storage for summer water needs — all within the context of overall declining water levels.

What the Experts Say

How a changing climate will impact the country's lakes is far from understood and not easy to grasp. The Climate Change Science Program, in its 2008 report, underscores that most observed changes in water quality across the continental U.S. are likely attributable to causes other than climate change and are instead primarily due to changes in pollutant loadings. Nevertheless, there is general agreement with the IPCC (2007) conclusion that higher water temperatures, increased precipitation intensity and longer periods of low levels are likely to exacerbate many forms of water pollution, with impacts on ecosystem integrity, and water system reliability and operating costs. Both groups agree that a mix of mitigation and adaptation will be necessary to address the impacts.

CHAPTER 8. CONCLUSIONS AND IMPLICATIONS FOR LAKE MANAGERS

Photo courtesy of Great Lakes Environmental Center

IN THIS CHAPTER

- ► Overall Findings and Conclusions
- ► Implications for Lake Managers

Photo courtesy of Jim Anderson and Dennis McCauley

Chapter 8

Conclusions and Implications for Lake Managers

Overall Findings and Conclusions

The NLA offers a unique opportunity to frame discussions and planning strategies based on environmental outcomes and across jurisdictional lines. It serves as a first step in the evaluation of the collective successes of management efforts to protect, preserve, or restore water quality. Attributable risk analyses can serve as a useful tool to help prioritize individual stressors. As EPA and its partners repeat the survey, the NLA will be able to track changes in water quality over time for lakes as a whole rather than just for a few individuals. This will help advance the understanding of important regional and national patterns in water quality, and speak to the cumulative effectiveness of the national water program.

Taken together, the results of the NLA provide a broad range of information necessary to understand the condition of our nation's lakes and some of the key stressors likely to be affecting them. The results are especially important because they establish a national baseline for future monitoring efforts which can be used to track statistically-valid trends in lake condition. These stressors in lake systems are now placed in context of their relative importance for restoring and maintaining lake integrity.

Condition of the Nation's Lakes

The results of the survey provide information relating to the fundamental question of "what is the condition of the nation's lakes?" The NLA reports on condition in three important ways. Biological indicators are especially useful in evaluating national condition because they integrate stress of combined problems over time. The NLA shows that 56% of the nation's lakes are in good condition, 21% are in fair condition, and 24% are in poor condition based on a measure of planktonic O/E taxa loss. Recreational suitability is based on the algal toxin, microcystin. Microcystin was found to be present in approximately one-third of lakes and at levels of concern in 1% of lakes. Finally, trophic status results based on chlorophyll-*a* concentrations show that 20% of lakes are hypereutrophic, while 80% are in lower nutrient enrichment categories.

Ecoregional assessments reveal broad-scale patterns in lake condition across state lines and across the country. Again using biological condition as the primary indicator of lake health, the Northern Appalachians, the Upper Midwest and the Western Mountains ecoregions have the greatest proportion of lakes in good condition – over half of the lakes in each of these regions are classified as good.

While it is too early in the survey program to determine if overall lake condition is improving, NLA analysts were able to examine changes in one subset of lakes, first sampled more than thirty years ago. It is encouraging to see that trophic status improved in 26% of the NES lakes and remained unchanged in 51% of the lakes. This means that trophic status in over three-quarters of these lakes remained the same or even improved despite growth of the U.S. population.

Major Physical and Chemical Stressors to Biological Quality

The NLA results show that of the physical indicators measured in the study, degraded lakeshore habitat is the most significant stressor to poor biological integrity. Using this as the primary habitat indicator, just under half of the country's lakes (45%) are in good condition. The NLA results also show that lakes in poor condition for habitat are 3 times more likely to be in poor biological condition. Another physical habitat indicator examined was the presence of human activities. From the standpoint of human disturbances along lakeshores, just one-third (35%) of the country's lakes are in good condition. Conversely, in addition to exhibiting good biological conditions, about half of the lakes in the relatively healthy Northern Appalachians, the Upper Midwest and the Western Mountains ecoregions, are in good habitat condition relative to other ecoregions across the country.

About 40% of the nation's lakes are constructed reservoirs.
Photo courtesy of Eric Vance.

Nutrients in the form of phosphorus and nitrogen are the second most important stressor to lake biological health. Fifty-eight percent of lakes are in good condition relative to total phosphorus levels and 54% are in good condition relative to total nitrogen. Lakes in poor condition for either of these stressors are twice as likely to be in poor biological condition. Yet, unlike habitat condition, nutrient levels vary widely across the country. The Northern Appalachians ecoregion has the greatest percentage of lakes in good condition relative to total phosphorus (TP) and total nitrogen (TN) (79% for TP and 88% for TN) while the Temperate Plains (38% for TP and 27% for TN) and the Northern Plains (22% for TP and 9% for TN) ecoregions have the lowest.

Implications for Lake Managers

While survey results fill key informational gaps in regional and national monitoring programs by generating estimates of the condition of water resources, evaluating the prevalence of key stressors, and documenting trends in the population of waters over time, they do not address all management concerns at all scales. For example, the lakes survey does not address causal factors or sources of stress. For water resource managers and city planners, efforts to reduce stresses and improve water quality entails confronting the source(s) of the stress (such as energy generation, agricultural production, or suburban development) and working toward implementing viable but often difficult solutions.

Address Major Lake Stressors

State lake management programs increasingly report that development pressures on lakes are steadily growing. The NLA findings show that local, state, and national initiatives should center on shoreline habitats, particularly vegetative cover, and nutrient loads to protect the integrity of lakes.

The findings of the four physical habitat indicators show that poor habitat condition imparts a significant stress on lakes and could suggest the need for stronger management of lakeshore development at all jurisdictional levels. Of the four, degradation of lakeshore habitat cover is the most important stressor of lakes. The attributable risk analysis suggests that eliminating this stressor could restore the biological condition in 40% of lakes that are classified as poor, or 8.8% of lakes nationwide. Development and disturbance stressors along lakeshores (such as tree removal, residential construction, and grazing and cropping practices) impact the integrity of lakeshore and shallow water habitats, affecting terrestrial and aquatic biota alike.

These NLA results support the continuing need for national, state, and local efforts to ameliorate the impacts of human activities in and around lakes to protect the lake ecosystem. For example, USDA's Conservation Reserve Enhancement Program supports the planting of buffers to serve as natural boundaries between water bodies and farm land. EPA's Low Impact Development (LID) program helps address lakeshore development pressures (see text box on page 86).

Nutrients have been a longstanding stressor of waterbodies in this country. Nationally, over 40% of the lakes exhibit moderate or high levels of nitrogen or phosphorus concentrations. In addition, regional hotspots are evident - in the Temperate and Northern Plains, nearly all lakes have high levels of nutrients. The NLA findings emphasize the need for continuing implementation of Federal-State partnership programs to control point and non-point sources of nutrient pollution. The NLA data can be used to support and enhance collaboration between jurisdictional authorities and the use of programs such as the Environmental Quality Incentives Program and Conservation Reserve and Enhancement Programs managed by USDA's Natural Resources Conservation Service, and the Section 319 Program and National Pollutant Discharge Elimination System run by EPA.

Track Status and Trends Information

Lake managers should consider the national trend information as well as the ecoregional data in evaluating site specific information in a broader context. Conducted on a five-year basis, subsequent lake surveys will help water resource managers to assess temporal differences in the data and perform trends analyses. Future surveys will also help EPA and its partners evaluate national and ecoregional stressors to these ecosystems, track changes, and explore the relative importance of each in restoring or maintaining waterbody health. Wide-area or regional changes in stressors over time can potentially be linked to human factors such as land use changes (*e.g.*, development) or natural causes (*e.g.*, increased storm surges).

Implement Statewide Statistical Surveys

Statistical survey designs provide water resource managers and the public with consistent, statistically-valid assessments of the broader population of waters in the area of interest (nationally, state-wide, *etc.*) based on data from a relatively small representative sample. Information provided by these surveys can help managers monitor the effectiveness of their lake restoration and pollution control activities as well as target resources and additional monitoring where they are most needed. To date, 40 states are implementing statistical surveys (Figure 38). These states are leveraging their limited monitoring resources to gain state-wide insights into their water resource quality. EPA encourages states to implement state-wide statistical surveys as a component of their CWA monitoring program.

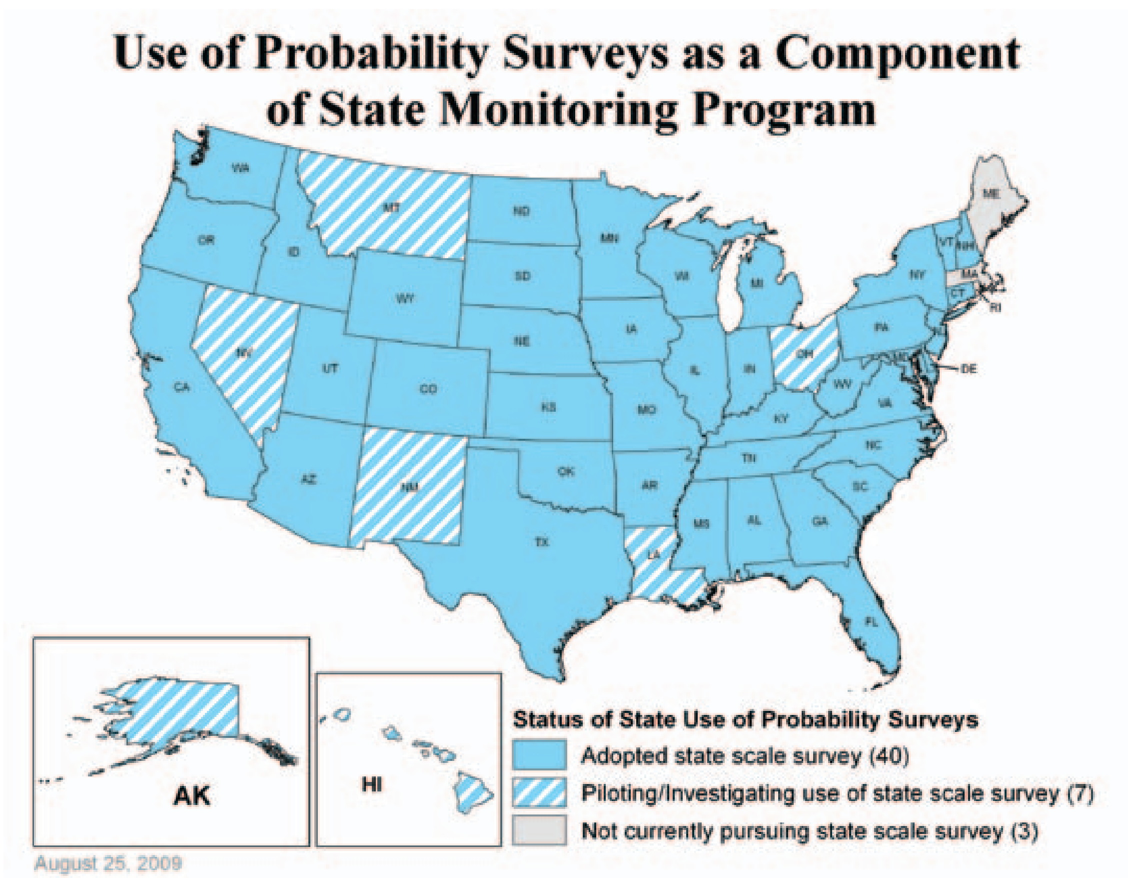


Figure 38. States with state-scale statistical surveys.

Low Impact Development Protects Lake Quality

Low impact development (LID) is a set of approaches and practices that are designed to reduce runoff of water and pollutants from the site at which they are generated. LID techniques manage water and water pollutants at the source through infiltration, evapotranspiration, and reuse of rainwater, preventing many pollutants from ever reaching nearby surface waters. LID practices include rain gardens, porous pavements, green roofs, infiltration planters, trees and tree boxes, and rainwater harvesting for non-potable uses such as toilet flushing and landscape irrigation. The primary goal of LID is to design each development site to protect, or restore, the natural hydrology of the site so that the overall integrity of the watershed is protected.

Development typically causes an imbalance in the natural hydrology of a watershed by replacing pervious surfaces (*e.g.*, fields, forests, wetlands *etc.*) with impervious surfaces (*e.g.,* rooftops, parking lots, roads, *etc.*). This change in ground cover not only increases runoff because of decreased infiltration, it also reduces the potential for the removal of nonpoint source pollutants.

By engineering terrain, vegetation, and soil features, LID practices promote infiltration of runoff close to its source and help prevent sediment, nutrients, and toxic loads from being transported to nearby surface waters. Once runoff is infiltrated into soils, plants and microbes can naturally filter and break down many pollutants and restrict movement of others.

Implementing LID practices in watersheds will contribute to groundwater recharge, improve water quality, reduce flooding, preserve habitat, and protect lake quality. In addition, LID practices increase land value, aesthetics and recreational opportunities, and public/private collaborative partnerships while reducing stormwater management costs. For more information visit: http://www.epa.gov/owow/nps/lid.

States with statistical survey programs are already using the results to develop watershed-scale or site-specific protection or restoration projects. Virginia, for instance, has established an intensive water quality monitoring program incorporating statistical sampling methods. South Carolina's monitoring program includes a statistically-based component to complement its targeted monitoring activities. Each year a new statewide set of statistical random sites is selected for each waterbody type, *i.e.*, streams, lakes/reservoirs, and estuaries.

The State of Florida also implements an annual probabilistic monitoring program. Their program will be an enhancement of its 2000 Status Monitoring Network — a five-year rotating-basin, statistical design sampling of six water resources, including small lakes (1-10 hectares) and large lakes (>10 hectares). Florida is currently in the fifth year of the Network and will report its findings in 2010.

State-wide surveys can be leveraged with the national survey and the information can be used in conjunction with other existing state monitoring programs to get a better understanding of the state's waters. In the same way that a lake association might relate the conditions it measures in a particular lake to other lakes, state/tribal managers can relate the conditions of lakes statewide to relevant ecoregional or national conditions. For example, Vermont compared its lakes' trophic status to the lakes in the Northern Appalachians ecoregion and nationwide

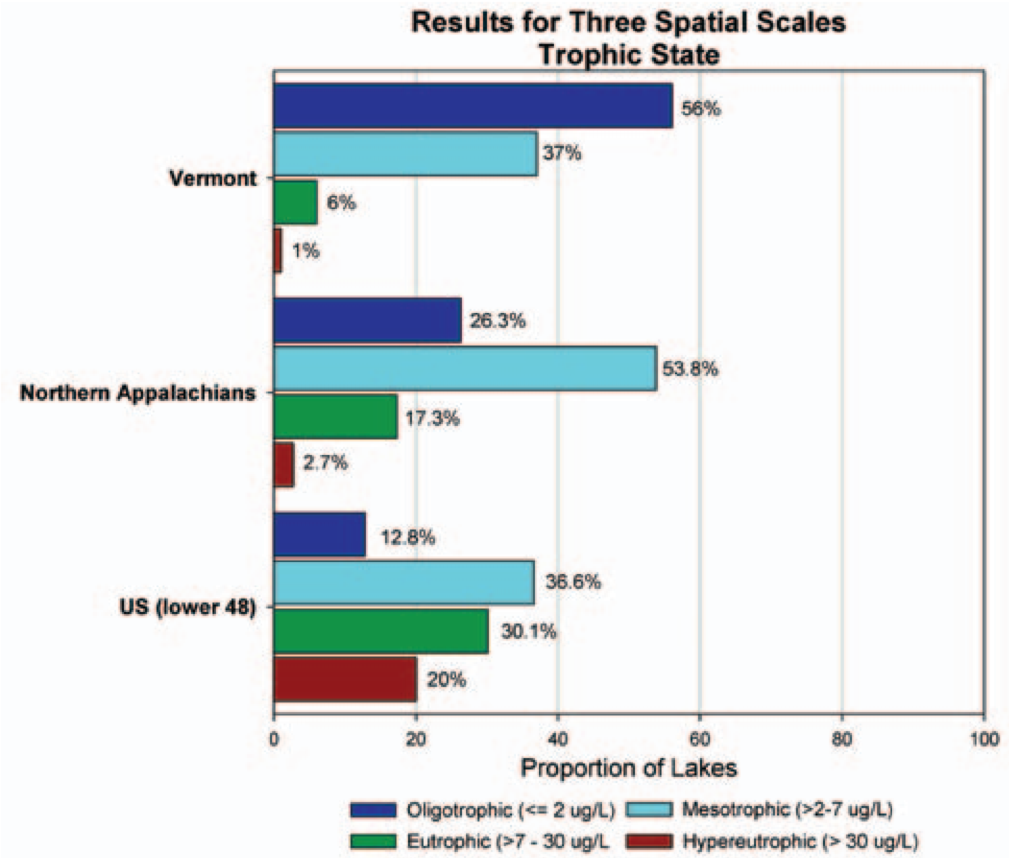


Figure 39. Comparison of lakes by trophic state for Vermont, the Northern Appalachians ecoregion, and the Nation, based on chlorophyll-*a*.

(Figure 39). This assessment shows that lakes in Vermont are more oligotrophic than lakes at the NLA ecoregional or national scale. Lake managers in states with a statistical survey network can use information such as this to target resources and management efforts.

Incorporate New and Innovative Approaches

EPA is encouraging states, tribes, and others to utilize NLA data and methods for their own customized purposes. The NLA provides lake managers with new tools and techniques to adopt into existing programs. Managers are encouraged to consider the host of new assessment indicators and methods that are applicable within assessment programs of any scale. For example, the quantitative assessment of physical habitat at the land-water interface is an area of intensifying focus within the lakes community. The NLA physical habitat assessment method provides a ready approach that has already been implemented by field crews across the lower 48 states and Alaska. The resulting data are readily reduced to four components of habitat integrity that relate directly to ecological integrity in lakes. For lake assessment programs lacking a physical habitat assessment component, the NLA method provides a low-cost and information-rich enhancement.

The incorporation of recreational indicators within lake assessment programs can also yield useful information to lake managers. Public awareness of cyanobacteria and related toxins is increasing, fueled in part by an increasing number of beach closures and related media reports. In the NLA, while only a small proportion of lakes exhibited moderate or high-risk concentrations of microcystin, the proportions of lakes with concentrations of chlorophyll-*a* or cyanobacteria cells associated with the development of elevated microcystin was considerably greater. Routine monitoring of chlorophyll-*a*, cyanobacterial cell counts, and/or microcystin can be implemented using a tiered approach tailored to the likelihood of microcystin occurrence. Many states are now adopting such programs, resulting in greater protection of human health in instances where cyanobacteria blooms may limit or prohibit swimming.

Work Beyond Jurisdictional Boundaries

Survey data on a national scale allows for aggregation of data and comparability of the results across several ecoregional levels. Within each of these ecoregions, states often share common problems and stressors to shared watersheds. The NLA offers a unique opportunity for adjacent states to work together, establish coalitions, and put into place collaborative actions that cross state boundaries. As a starting point, EPA and its state partners are working together to develop approaches to monitoring that will allow comparisons on a state-wide basis and across state boundaries as well. EPA and the states are committed to finding mutually-beneficial and scientifically-sound ways to integrate and exchange data from multiple sources, as well as options to improve both sample collection and analytical methods.

Aquatic weed harvesting is one way to manage plant growth.
Photo courtesy of Frank Borsuk.

Pennsylvania spillway.
Photo courtesy of Frank Borsuk.

HIGHLIGHT

State, Tribal, and Regional Lake Surveys: Examples From Across the Country

State-wide Lake Assessments

Oklahoma: Oklahoma was one of several states that chose to add to the number of nationally-selected lake sites within its boundaries to achieve a state-wide assessment. Oklahoma is looking into using National Lakes Assessment (NLA) survey data for further development of nutrient and biological criteria, incorporating new parameters into its established monitoring program, and nesting a probability-based survey into its fixed station rotation.

Michigan: Twenty-nine Michigan lakes were randomly selected as part of the NLA. To allow for a state-scale assessment, the state added 21 additional randomly-chosen lakes. Michigan's surveyed lakes ranged from an unnamed 10-acre lake in Clare County to 13,000-acre Gogebic Lake in Gogebic County. The state will continue to analyze its lake data set to further evaluate the condition of Michigan's inland lakes based on the national survey assessment tools.

Oregon: Oregon sampled 30 lakes across the state as part of the NLA. In Oregon, the results from the 2007 NLA will help answer two key questions about the quality of lakes, ponds and reservoirs: What percent of Oregon's lakes are in good, fair or poor condition for key indicators of nutrient status, ecological health and recreation? What is the relative importance of key lake "stress factors" such as nutrients and pathogens? The random design took field crews to a wide variety of sites. Elevation at the target lakes ranged from 30 feet to 7,850 feet. Lake depths ranged from 1 meter to 128 meters (Waldo Lake); maximum sampling depth, however, was 50 meters. The most difficult lake to reach was Ice Lake in the Eagle Cap Wilderness, which required the use of an outfitter and horses for the eight-mile and 3,300-foot elevation gain journey.

Ice Lake in the Eagle Cap Wilderness. Photo courtesy of Oregon Department of Environmental Quality.

Enhancing Lake Monitoring for the Lac du Flambeau Tribe, Wisconsin

The Lac du Flambeau Tribe is using the NLA study to enhance its own water program. The ability to develop protective site-specific water quality criteria and assess lake health is limited when available data cover only a small geographic area such as the Lac du Flambeau Reservation. Participation in the NLA enabled the Tribe to compare Reservation lake data to national and regional lake health. The Tribe used the NLA protocols for physical habitat, water chemistry, and vertical water profiles on an additional 11 lakes within the Reservation. These data are being entered into EPA's Water Quality Exchange (WQX) using an Excel template to ensure data uniformity for comparison. The Tribe will develop lake report cards for the general public, managers, and decision makers assessing the health of Reservation lakes as compared to national and regional lake health. The Tribe will also be able to evaluate development of criteria using these data.

Assessing Prairie Potholes: A Collaborative Effort.

The Prairie Pothole Region crosses the north central U.S. and Canada and includes nearly 8,000 prairie pothole lakes. Prairie pothole lakes are intrinsically shallow and defined as natural lakes where 80% or more of the lake is less than 15 feet deep. Prairie Pothole lakes are part of a major waterfowl fly-way and are a valuable regional and national resource. In order to more fully understand this unique ecosystem, North Dakota, Iowa, Minnesota, South Dakota, Montana, USGS, and EPA undertook an assessment of these lakes. Analysts have found that nutrient and chlorophyll-*a* levels in Prairie Pothole lakes are quite high compared to the nation's lakes. A combination of high nutrient levels, elevated algae growth, low transparency, presence of roughfish, and broad, wind-swept basins serve to limit rooted plant growth. Maintaining rooted plant growth is important for Prairie Pothole health. More detailed information on the results of the Prairie Pothole survey will be provided in a NLA supplemental report.

Photo courtesy of Wes Weissenburger

CHAPTER 9.

NEXT STEPS FOR THE NATIONAL SURVEYS

Bayley Lake in Stevens County was one of the lakes the Department of Ecology sampled during the survey.
Photo courtesy of Washington State Department of Ecology.

IN THIS CHAPTER

- Supplemental Reports
- Tools and Other Analytical Support
- Future National Assessments

Photo courtesy of Lauren Wilkinson, Great Lakes Environmental Center.

Chapter 9
Next Steps for the National Surveys

EPA is committed to continually enhance the National Aquatic Resource surveys in order to improve the quality and quantity of information it needs to understand the condition of the aquatic environment and how it is changing over time. As technologies advance, future surveys and collaborations can also lead to new indicators, new monitoring approaches, and new water resource management programs and policies.

With the publication of this report, the lakes survey moves into a design/planning phase in preparation for the next survey in 2012. This phase will incorporate lessons learned from the first lakes survey, other national surveys, and state, tribal and local experiences. Additionally, EPA anticipates that states and other partners will continue to utilize data from the first lakes survey and issue supplemental reports based on their findings.

During 2010, EPA and its state and tribal partners will take stock of the survey and begin planning for 2012. Issues for discussion may include changes to the design, field methods, equipment, laboratory methods, and/or analyses procedures. Other items include improving reference site selection, refining regionally representative reference sites, and adding more reference sites to the survey. Consideration will be given not only

	2006	2007	2008	2009	2010	2011	2012
Lakes	Design	Field	Lab and Data Analysis	Report	Design and Planning		Field

to how alternate approaches will improve future data, but how the Agency can ensure comparability to the initial baseline.

Supplemental Reports

The NLA included data collection for several indicators for which analysis could not be completed in time for this report. These included benthic macroinvertebrates, sediment mercury, and *enterococcus*. Analysts are currently developing macroinvertebrate indicators to add to our understanding of biological integrity of lakes. Sediment mercury samples are still in the data analysis phase, as is the *enterococcus* dataset. EPA plans to produce supplements to this report with the macroinvertebrate, sediment mercury, and *enterococcus* findings. Supplemental information will be posted on http://www.epa.gov/lakessurvey.

In the next few years, EPA plans to continue additional analyses of the survey data to develop tools and strategies that will provide a better understanding of lakes and water resources in general. One important undertaking will be to conduct an in-depth analysis of the relationship between lake condition, stressors, and management actions such as point and nonpoint controls and other restoration activities. EPA plans to publish its progress and findings in interim lake survey reports.

Tools and Other Analytical Support

The next two years will also provide an opportunity for states to tailor their own statewide program to complement the national programs. Extensive discussion during the upcoming research and design phase will focus on ways to leverage and integrate national and state-scale surveys. This approach will improve the efficiency and value investment in monitoring. One EPA near-term project will be to work with the states to develop tools that can be used to re-create the survey for state-wide assessments and for customized purposes. EPA is committed to providing technical support to assist states, tribes and other partners in using these tools. Such an "assessment tool kit" might include IBI or O/E model development, habitat data analysis techniques, decision-support tools, and web-based trainings session.

Future National Assessments

EPA and its state, tribal and federal partners expect to continue to produce national assessments on a yearly cycle. Rivers and stream sampling was completed in 2008 and 2009 and a report will be released in 2011. A national coastal assessment report will be published in 2012 based on field sampling in 2010. Wetlands will be surveyed in 2011, followed by a report in 2013. In 2012, field sampling for lakes will occur again and the assessment report that follows in 2014 will include an evaluation of changes in biological condition and key stressors. Each of the water type surveys will then continue with changes and trends becoming a greater focus for each resource type.

The continued utility of these national surveys and their assessment reports depends on continued consistency in design, as well as in field, lab and assessment methods from assessment to assessment. However, the surveys should also provide the flexibility that allows the science of monitoring to improve over time. Maintaining consistency while allowing flexibility and growth will continue to be one of the challenges of the coming years.

This national lakes survey would not have been possible without the involvement of hundreds of scientists working for state, tribal, and federal agencies and universities across the nation. Future National Aquatic Resource Surveys will continue to rely on this close collaboration, open exchange of information, and the dedication, energy, and hard work of its participants. EPA will continue to work to help its partners translate the expertise they gained through these national surveys to studies of their own waters. It also will work to ensure that this valuable and substantial baseline of information be widely used to evaluate the success of efforts to protect and restore the quality of the Nation's waters.

Acronyms

ANC	Acid Neutralizing Capacity
CPL	Coastal Plains
CWA	Clean Water Act
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
GIS	Geographic Information System
IBI	Index of Biological Integrity
ITIS	Integrated Taxonomic Information System
LDCI	Lake Diatom Condition Index
NAP	Northern Appalachians
NARS	National Aquatic Resource Surveys
NES	National Eutrophication Study
NHD	National Hydrography Dataset
NLA	National Lakes Assessment
NLCD	National Land Cover Dataset
NPL	Northern Plains
O/E	Observed/Expected
ORD	Office of Research and Development, EPA
OW	Office of Water, EPA
PPR	Prairie Pothole Region
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
qPCR	Quantitative Polymerase Chain Reaction
REMAP	Regional Environmental Monitoring and Assessment Program
SAP	Southern Appalachians
SPL	Southern Plains
TIME/LTM	Temporally Integrated Monitoring of Ecosystem/Long Term Monitoring
TMDL	Total Maximum Daily Load
TPL	Temperate Plains
TN	Total Nitrogen
TP	Total Phosphorus
UMW	Upper Midwest
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WMT	Western Mountains
WQX	EPA's Water Quality Exchange
WWTP	Wastewater Treatment Plant
XER	Xeric

Glossary of Terms

Acid Neutralizing Capacity (ANC): A lake's ability to adapt to, *i.e.* neutralize, increases in acidity due to acidic deposition from anthropogenic sources (automobile exhausts, fossil fuels) and natural geologic sources.

Attributable risk: Magnitude or significance of a stressor. Is determined by combining the relative extent of a stressor (prevalence) and the relative risk of the stressor (severity).

Benthic macroinvertebrates: Benthic meaning "bottom-dwelling". Aquatic larval or adult insects, crayfish, worms and mollusks. These small creatures live on the lake bottom attached to rocks, vegetation, logs and sticks, or burrow into the sediment.

Biological assemblage: Key group or community of plant or animal being studied to learn more about the biological condition of water resources.

Biological integrity: State of being capable of supporting and maintaining a balanced community of organisms having a species composition, diversity, and functional organization.

Chlorophyll-a: A type of plant pigment present in all types of algae sometimes in direct proportion to the biomass of algae. A chemical indicator used to assess trophic condition.

Complexity: Used to describe the diversity and intricacy of an ecosystem. A complex habitat is one that has a wide range of different niches for optimum growth and reproduction for both plants and animals.

Condition: State or status of a particular indicator. For example, the biological condition of a lake is the status of a biological assemblage, such as diatoms. Often measured against a reference value or threshold.

Ecoregions: Ecological regions that are similar in climate, vegetation, soil type, and geology; water resources within a particular ecoregion have similar natural characteristics and similar responses to stressors.

Epilimnion: The uppermost, warmest, well-mixed layer of a lake during summertime.

Euphotic zone: The uppermost layer of the lake defined as the depth at which light penetrates.

Eutrophic: See Trophic state.

Eutrophication: The process of increased productivity of a lake or reservoir as it ages. Often this process is greatly accelerated by human influences and is termed cultural eutrophication.

Hypereutrophic: See Trophic state.

Hypolimnion: The lower, cooler layer of lake during the summer.

Lakes Diatom Condition Index (LDCI): The sum of individual measures of a diatom assemblage, such as number and composition of taxa present, diversity, morphology, and other characteristics of the organisms.

Limnological: Of or pertaining to the study of fresh waters.

Littoral zone: The water's edge. The lake bottom extending from the shoreline lakeward to the greatest depth occupied by rooted plants.

Macrophyte: Literally meaning "large plant." An aquatic plant that can grow emergent, submergent or floating.

Mesotrophic: See Trophic state.

National Hydrography Dataset: Comprehensive set of digital spatial data that contains information on surface water features across the U.S.

Nutrients: In the context of the NLA, substances such as nitrogen and phosphorus that are essential to life but in excess can overstimulate the growth of algae and other plants in aquatic environments. Excess nutrient can come from agricultural and urban runoff, leaking septic systems, sewage discharges and similar sources.

O/E (Observed/Expected) Ratio of Taxa Loss: A comparison of the number of taxa that are observed (O) at a site relative to the number of taxa expected (E) to exist for a site of similar nature. The taxa expected at individual sites are based on models developed from data collected at reference sites.

Oligotrophic: See Trophic state.

Pelagic zone: The open area of a lake, from the edge of the littoral zone to the center of the lake.

Primary productivity: The production of organic compounds from atmospheric or aquatic carbon dioxide, principally through the process of photosynthesis. All life on earth is directly or indirectly reliant on primary production. In aquatic ecosystems, the organisms responsible for primary production are the phytoplankton, and form the base of the food chain.

Probability-based design: A type of random sampling technique in which every site in the population has a known probability of being selected for sampling. Results from the sampled sites can be used to represent the population as a whole.

Profundal zone: The deepest part of the lake. The lake bottom located below the depth of light penetration.

Reference condition: The least-disturbed condition available in an ecological region, determined based on specific criteria, and used as the benchmark for comparison with the surveyed sample sites in the region.

Regionally-specific reference: A subset of the reference condition based on reference lake sites of similar type and geography. For ecoregional assessments, the lakes are only compared to the particular reference lakes that are similar for that area.

Relative extent: The relative prevalence of a specified condition (such as poor) for a stressor or biological indicator. A stressor with a high relative extent means that it is relatively widespread when compared to other stressors.

Relative risk: The severity of the stressor. Like attributable risk and relative extent of the risk, this term is used to characterize and quantify the relative importance of the stressor. Stressors with low relative extent and high relative risk are called "hot spots".

Riparian zone: The banks or shoreline of a lake or waterbody.

Riparian or Shoreline disturbance: A measure of the evidence of human activities alongside lakes, such as roadways, dams, docks, marinas, crops, *etc.*

Riparian vegetative cover: Vegetation alongside lakeshore. Intact riparian vegetative cover reduces pollution runoff, prevents streambank erosion, and provide shade, food, and habitat for fish and other aquatic organisms.

Secchi transparency: A measure of the clarity of water obtained by lowering a black and white, or all white, disk (Secchi disk) into the water until it is no longer visible. Measured in feet or meters.

Stressors: Factors that adversely affect, and therefore degrade, aquatic ecosystems. Stressors may be chemical (*e.g.*, excess nutrient, pesticides, metals), physical (*e.g.*, pH, turbidity, habitat), or biological (*e.g.*, invasive species, algal bloom).

Stressor-response: Change in biological condition due to the presence of one or more stressors.

Sublittoral zone: The lake bottom area between the littoral (rooted plants) to the depth at which there is no more light penetration.

Taxa: Taxonomic grouping of living organisms, such as family, genus or species, used for identification and classification purposes. Biologists describe and organize organisms into taxa in order to better identify and understand them.

Threshold: The quantitative limit or boundary. For example, an assessment threshold is the particular percentage of the reference condition or cut-off point at which a condition is considered good, fair or poor.

Trophic state: Meaning "nourishment." Used to describe the level of productivity of a lake.

> *Oligotrophic:* A nutrient poor lake. Describes a lake of low biological productivity and high transparency or clarity.
>
> *Mesotrophic:* A lake that is moderately productive.
>
> *Eutrophic:* A well-nourished lake, very productive and supports a balanced and diverse array of organisms. Usually low transparency due to high algae and chlorophyll-*a* content.
>
> *Hypereutrophic:* Characterized by an excess of nutrients. These lakes usually support algal blooms, vegetative overgrowth, and low biodiversity.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central repository such as a lake, river or the ocean.

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National Lakes Assessment

A Collaborative Survey of the Nation's Lakes

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