Using the 2012 National Lakes Assessment to Describe the Condition of North Dakota's Lakes

Final: January 2018

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Acknowledgements

I would like to thank the many individuals who contributed to this report, with special thanks to Peter Wax, Aaron Larsen, Paul Olson, Preston Blinsky, and Isaac Jensen who sampled lakes for the 2012 National Lakes Assessment. Also, the United States Geological Survey (USGS) sampled some lakes for the assessment. Furthermore, I would like to acknowledge Mike Ell for providing project guidance and oversight and Joe Gross for performing database management and data retrieval assistance. Additionally, I would like to thank Phil Kauffman and Richard Mitchell from the EPA for their advice and materials regarding physical habitat and MMI calculations, respectively. Finally, thanks to Karen Blacksom from the EPA for sending and providing advice on the use of the aquamet package for R, used for calculating metrics for our intensification lakes.

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Introduction

The National Lakes Assessment (NLA) is used by the Environmental Protection Agency (EPA) to evaluate the condition of the Nation's lakes in a comprehensive, statistically-robust study design. The NLA is part of a larger group of surveys referred to as the National Aquatic Resource Surveys (NARS), which also includes the National Wetland Condition Assessment (NWCA), National Rivers and Streams Assessment (NRSA), and the National Coastal Condition Assessment (NCCA). These surveys are done every five years (e.g., NLA was done in 2007 and 2012, and was sampled again in 2017), with multiple partners participating in the sampling of these resources (e.g., state government, private groups, tribes). These surveys provide useful information to the EPA and other interested parties on the health of the Nation's aquatic resources. Further, these surveys provide a statistically-robust survey of local waters where these types of data may not otherwise be available.

In North Dakota, a statistically-valid, random sampling design survey of the State's lakes does not occur outside of the NLA surveys. The State has annual sampling programs on Devils Lake (still in operation) and Lake Sakakawea (in cooperation with the US Army Corps of Engineers and ND Game and Fish), as well as a statewide Lake Water Quality Assessment (LWQA) program focusing on under-sampled lakes throughout the State. These surveys will continue to provide useful information to resource managers as to the health of the State's lakes regarding its physical, biological, and chemical properties.

Methods

For the 2007 NLA, to be included in the selection process, a lake had to be either a natural or man-made lake, pond, or reservoir, at least 3.3 feet (1 meter) deep, have a surface area greater than 10 acres, and a minimum of 0.25 acres had to be considered "open water" (from EPA, 2009). These criteria resulted in a target population of greater than 68,000 lakes and an inference population of greater than 49,000 lakes in the conterminous United States (from EPA, 2009), with over 3,800 of the lakes in North Dakota. In 2012, however, the definition was expanded to include a wider range of lakes. In 2012, lakes had to have a surface area of greater than 2.47 acres (1 hectare) (EPA, *In revision*), less than a quarter of the 2007 size requirement. This new size criterion resulted in a new target population of 159,652 lakes in the conterminous United States, and 4,855 lakes in North Dakota.

In North Dakota, 44 lakes were chosen for sampling in 2012, data from which are then extrapolated to fit the target population. To fit this assumption, individual lakes were given "weights", which were based on lakes within a particular State (e.g., North Dakota), ecoregion (e.g., Temperate Plains), and size class. For example, Devils Lake was given a weight of 9.32, meaning that results from Devils Lake could be used to describe the condition in 9 other Temperate Plains lakes in North Dakota in a similar size class. Further, Buffalo Lodge Lake was given a weight of 196.00, meaning that results from this lake could be extrapolated to 196 other lakes within the Temperate Plains region of North Dakota in a similar size class. In addition to the lakes randomly-selected for 2012 sampling, the North Dakota Department of Health (NDDoH) intensified the sample to a statistically-acceptable sample size of 52 lakes (Figure 1).

Lakes were to be sampled from June through September of 2012, though intensification lakes were sampled during August and September of 2013. Of the 52 total lakes sampled, 38 were sampled by the NDDoH, 12 by the United States Geological Survey (USGS), 1 by the Spirit Lake Nation, and 1 by the Turtle Mountain Band of Chippewa Indians (Table A.1). Though not considered "lakes of the State", tribal lakes were included in the analysis of State data because weighting of these lakes included other State-lakes.

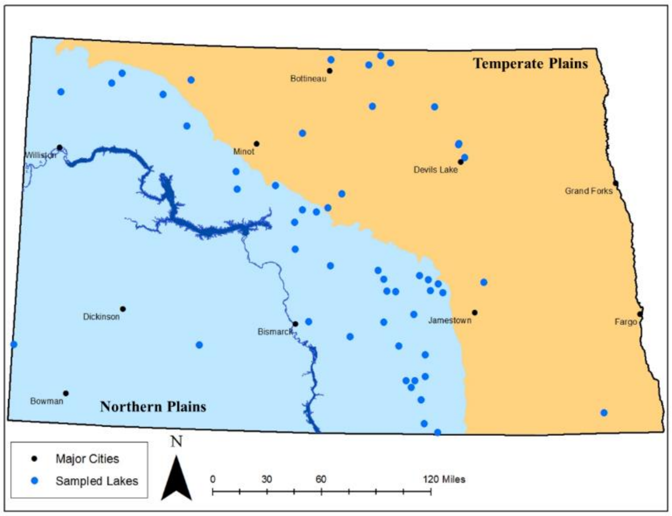

Figure 1: Map showing all lakes sampled as part of the 2012 National Lakes Assessment, as well as the North Dakota State Intensification.

Following random lake-selection by the EPA, North Dakota lakes were field-checked by the NDDoH to ensure lakes were accessible for watercraft and that lakes fit the EPA's definition of a lake for the NLA. Additionally, where there was no public boat ramp, landowner permission was necessary to access the lake. Therefore, when accessibility was not possible due to any of the aforementioned reasons, "over-sample" lakes were selected to replace removed target lakes and then field-checked to ensure suitability for inclusion in the study. North Dakota had an aforementioned 4,855 lakes in its target population for the 2012 assessment. Following field-checking of these lakes, the target population was adjusted to fit the group of target lakes which were to be sampled. For 2012, 860 lakes (17.7% of the initial target population) were dropped from assessment. Reasons for dropping target lakes were: sampleable but were not sampled (0.8%; due to error); sampleable but inaccessible (5.0%; due to barriers or safety concerns); or sampleable but access was denied (11.9%) (Figure 2). Following field-checks, the 52 lakes sampled within North Dakota were used to describe the condition of 3,995 lakes located in the State (see Figure 2).

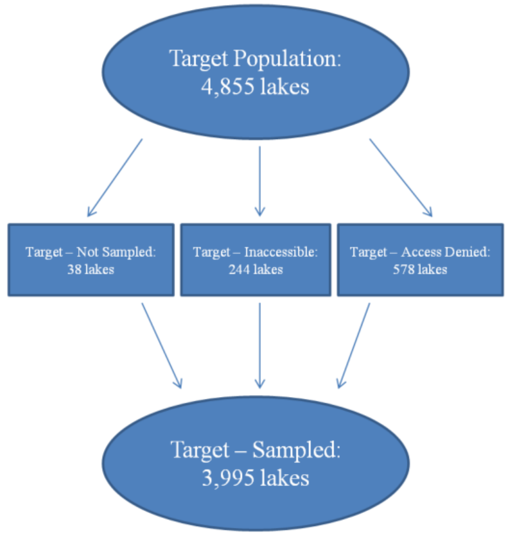

Figure 2: Flow chart showing initial target population of lakes to be assessed in North Dakota (from EPA), with lakes dropped from assessment for reasons such as being sampleable but not sampled (in error), inaccessible (either due to a barrier or safety concern), or where access was denied. Following the removal of those lakes from consideration, the resulting target population of sampled lakes is shown to which the results of this study are to be extrapolated.

A chemical profile, measuring dissolved oxygen (DO), temperature (in ºC), pH, and specific conductance at 0.5- or 1-meter intervals, was taken for every site at the deepest point of the lake, termed the index site. For both surveys (2007 and 2012), water chemistry samples were collected at the index site using a 0-2 meter integrated sampler. Additionally, duplicate samples were collected for chemical analyses for 2012 lakes, with one set going to EPA-contracted labs and the other to the NDDoH Division of Chemistry laboratory. Only samples analyzed for atrazine and turbidity were not sent to NDDoH, and were also not analyzed for the intensification lakes. A full description of field procedures is provided in EPA (2011). In addition to the collection of water samples at the Index site, samples for cyanobacteria and microcystin were collected at a near-shore site, termed the littoral site (see Figure 3).

Benthic macroinvertebrate samples were collected at near-shore sites using a D-frame net within a 1 linear meter section in the dominant substrate type (e.g., macrophytes, cobble). Samples were composited and added to sample bottles (number of bottles varied), then preserved using 95% ethanol. Macroinvertebrates were identified to the lowest possible taxon by EcoAnalysts, Inc. (Moscow, ID) for the 2012 survey.

Zooplankton samples were collected from the index site using both a fine (50 µm; ZOFN) and a coarse net (150 µm; ZOCN). In addition, sites re-visited (n = 13) from the 2007 assessment were also sampled using the same methods from the previous survey, using 80 (ZOFR) and 243 µm mesh (ZOCR). Zooplankton were identified by BSA Environmental Services, Inc. (Beachwood, OH) for the 2012 survey.

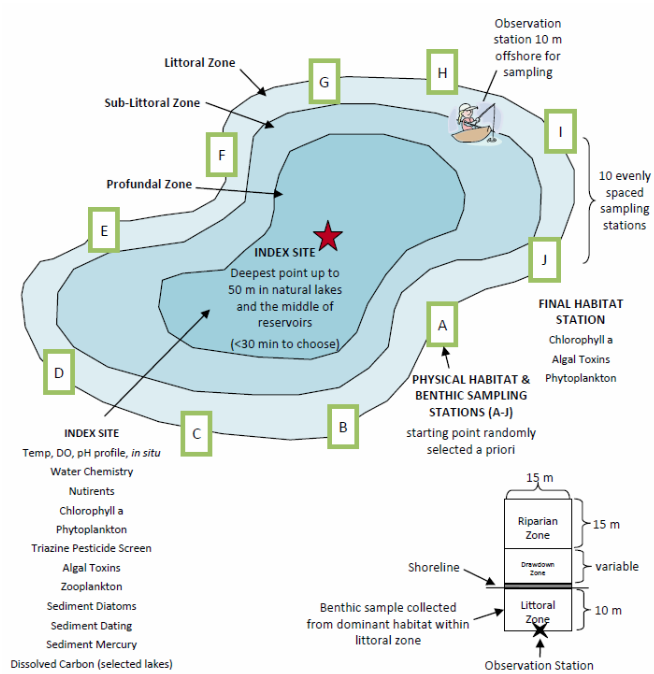

Figure 3: Schematic depicting lake activities for field crews. Activities at littoral sites include physical habitat and macroinvertebrate stations (A through J). Additionally, shown is the index site (determined to be the deepest point near the middle of the lake) where samples for water chemistry, zooplankton, and sediment are collected (Figure 3.2 from EPA, 2011).

Table 1: Parameters measured as part of the 2012 National Lakes Assessment (adapted from USEPA, 2009).

Biological	Recreational	Chemical	Physical
Sediment diatoms	Sediment mercury	Nutrients (N & P)	Lakeshore habitat cover and structure
Zooplankton	Algal toxin (microcystins)	Water column profile	Shallow water habitat cover and structure
Benthic macroinvertebrates	Algal cell counts (cyanobacteria)		Lakeshore human disturbance
Invasive species	Algal density (chlorophyll-α)		
	Pesticides (atrazine)		

Multimetric indices (MMIs) were calculated for both benthic macroinvertebrates and zooplankton. All North Dakota lakes were grouped into the "Plains" region for biological indices, a group that included all lakes from the Northern, Southern, and Temperate Plains ecoregions. Six metric classes were used for each biological index, with one metric represented in each class. Metric classes for the macroinvertebrate MMI were composition, diversity, feeding group, habit, richness, and tolerance which were represented by the following metrics; percent dipteran taxa, Shannon diversity index, predator richness, percent taxa as climbers, richness of EPOT taxa (Ephemeroptera, Plecoptera, Odonata, and Trichoptera), percent individuals with pollutant tolerance values ≥ 2 and < 4 (Table 2).

Metric classes for the zooplankton MMI were abundance/size, cladoceran, copepod, richness/diversity, rotifer, and trophic (feeding group) with specific metrics being percent biomass represented by individuals captured in coarse mesh nets, percent of native individuals as "small" cladocerans, ratio of calanoids to cladocerans plus cyclopoids, family richness in 300-count subsample, number of distinct rotifer taxa, and percent of total density as herbivorous copepods (Table 3).

Extent estimates (i.e., percent and number of lakes in target population) were calculated for the survey (Kincaid and Olsen, 2013), with North Dakota lakes classified as good, fair, or poor for selected biological, chemical, and physical measures. Extent estimates were calculated for the stressor indicators total nitrogen, total phosphorus, sediment mercury (top and bottom), sediment methylmercury, atrazine, riparian disturbance, riparian vegetation, littoral cover, dissolved oxygen; the biological condition indicators planktonic MMI, macroinvertebrate MMI; and the recreation condition indicators chlorophyll-α (littoral and index), microcystin (littoral and index), and cyanobacteria (littoral and index). For comparison, data were parsed for both the Northern Plains (NPL) and Temperate Plains (TPL) ecoregions to examine potential regional differences within the State. Additionally, extent estimates were calculated for the entirety of these aforementioned ecoregions while excluding North Dakota lakes for comparison to the State's condition estimates compared to regionally-similar lakes. Where applicable, comparisons were made between the 2007 and 2012 assessments for lakes considered to be in good, fair, and poor condition for their respective metrics. Although zooplankton condition was compared between the two surveys, different methods were used to determine community health for the 2007 (planktonic observed-to-expected; EPA, 2009) and 2012 assessments (zooplankton MMI; EPA, *In revision*). Pearson correlations were used to determine relatedness of selected dependent variables (e.g., Secchi disk transparency, MMIs) to multiple landscape, riparian, and in-lake physical habitat variables.

Physical habitat variables for the intensification lakes were calculated for physical habitat using the aquamet package in R (Seelinger et al., 2015). These variables were then used to calculate physical habitat condition estimates regarding littoral cover, riparian vegetation, and riparian disturbance. Littoral cover condition in the Plains ecoregion (combination of NPL, TPL, Southern Plains [SPL]) was calculated as:

$$LitCvrQ\_d = \frac{\left[\left(\frac{SomeNatCvr}{1.5}\right)+\left(\frac{fcfcSnag}{0.2875}\right)+\left(\frac{amfcFltEmg}{1.515}\right)\right]}{3}$$ (Eq. 1; from EPA, *In revision*)

where SomeNatCvr describes natural fish cover (excluding snags and aquatic macrophytes), fcfcSnag describes the total areal cover from snags, and amfcFltEmg is the amount of in-lake cover from floating and emergent vegetation. Calculations for littoral cover left out submerged vegetation, as dense stands of this can be an indication of eutrophication or sedimentation.

Riparian vegetation condition estimates were calculated using:

$$RVegQ\_7 = \frac{\left[\left(\frac{rviLowWood}{1.75}\right) + rvfcGndInundated\right]}{2}$$ (Eq. 2; from EPA, *In revision*)

where rviLowWood describes woody vegetation from the ground and understory layers, and rvfcGndInundated describes the amount of inundated terrestrial or wetland vegetation in the ground layer. Calculations of riparian vegetation in North Dakota lakes, specifically, does not account for large, woody vegetation. This exclusion is due to the overall lack of woody vegetation throughout the State, mostly due to plains environments and not due to anthropogenic impacts.

Riparian disturbance was calculated the same for every region and was described as:

$$RDis\_IX = \frac{\left\{1 - \left[\frac{1}{[1 + hiiNonAg + (5 \times hiiAg)]}\right] + hifpAnyCirca\right\}}{2}$$ (Eq. 3; from EPA, *In revision*)

where hiiNonAg describes the index of non-agricultural human impact, hiiAg is the index of agricultural human impact, and hifpAnyCirca describes the fractional presence of any close-to-shore human influence. Further, when calculating expected values for riparian vegetation and littoral cover variables, hiiAg (Index of all human influence as agriculture) was used to describe landscape condition that most affects in-lake condition. Riparian disturbance did not have a regional reference value, but instead was a value applicable to all regions.

Lake shapefiles were re-drawn for the 2012 NLA to imagery available for that year to obtain accurate measurements of area, perimeter, and land cover buffers. Shapefiles were typically drawn using 1:2,500 scale view. Most lakes (37; 71.15% of lakes) were less than 500 acres in area, while a sizable percentage was less than 200 acres (Table 4). To describe land use surrounding North Dakota lakes, buffers of 500 and 1,000 meters were drawn. For land cover percentages, National Agricultural Statistics Service (NASS) data from 2012 were used.

Cumulative distribution functions (CDFs) were used to evaluate percentile levels of specific nutrients and ions (Kincaid and Olsen, 2013) and presented in-combination to compare between assessments. All data analyses were performed using R software (2013) and all maps were created using ArcGIS 10.2.

Table 2: Metrics used as part of the Plains Ecoregion Macroinvertebrate MMI. Metric names and descriptions are from EPA (*In prep*).

METRIC NAME	METRIC DESCRIPTION
DIPTPTAX	Percent Dipteran taxa (Dipertan taxa richness / Total taxa richness * 100)
HPRIME	Shannon Diversity Index
PREDRICH	Predator Taxa Richness
CLMBPTAX	Percent Climber taxa (Climber taxa richness / Total taxa richness * 100)
EPOTRICH	Ephemeroptera + Plecoptera + Odonata + Trichoptera Taxa Richness
TL23PIND	Percent of individuals with pollutant tolerance values ≥ 2.0 and < 4.0

Table 3: Metrics used as part of the Plains Ecoregion Zooplankton MMI. Metric names and descriptions are from EPA (*In prep*).

METRIC NAME	METRIC DESRIPTION
COARSE300_PBIO	Percent of biomass represented by individuals of taxa collected in coarse mesh net (150 µm; NET_SIZECLS_NEW=COARSE) in 300 count subsamples (coarse and fine net samples combined)
SMCLAD_NAT_PIND	Percent of native individuals within the suborder Cladocera that are “small” (CLADOCERA_SIZE=SMALL; coarse and fine net samples combined)
COPE_RATIO_BIO	Ratio of Calanoid to (Cladocera + Cylcopoids) based on biomass (coarse and fine net samples combined). Adapted from Kane et al. (2009) Lake Erie plankton IBI. Calculated as CALANOID_BIO/(CLAD_BIO+CYCLOPOID_BIO)
FAM300_NTAX	Total distinct family richness in 300-count subsamples (coarse and fine net samples combined)
ROT_NTAX	Number of distinct rotifer taxa (coarse and fine net samples combined)
COPE_HERB_PDEN	Percent of total density represented by herbivorous copepods (coarse and fine net samples combined)

Table 4: Count and percentage of lakes sampled by size range in North Dakota for the 2012 NLA.

Size	Percent of Sample Population
< 50 acres	7 lakes (13.5%)
50 - < 100 acres	5 lakes (9.6%)
100 - < 200 acres	16 lakes (30.8%)
200 - < 500 acres	9 lakes (17.3%)
500 - < 1,000 acres	9 lakes (17.3%)
≥ 1,000 acres	6 lakes (11.5%)

Results

Land cover data

In general, land cover surrounding North Dakota lakes is dominated by a combination of herbaceous grassland and agricultural production. With a few exceptions (e.g., Turtle Mountains Level IV Ecoregion), forested cover is rare in the State. Forested land cover had a mean percentage of 4.91% statewide (ranging from 0.00% to 66.21%) and a median cover of 0.14% within the 500-meter buffers (Table 4). Within the 1000-meter buffer of lakes, mean forested land cover was 4.83% (ranging from 0.00% to 70.08%) and a median cover of 0.22% (Table 5). Mean agricultural cover within the 500-meter buffer was 26.53% (ranging from 0.11% to 76.62%) with a median cover of 22.93% (Table 4). Mean agricultural production increased in the 1000-meter buffer to 29.30% (ranging from 0.06% to 77.74%) with a median value of 27.61% (Table 5). Land cover as wetlands within the 500-meter buffer was relatively low, with a mean value of 4.94% (ranging from 0.10% to 16.14%) and a median cover of 3.66% (Table 4). Presence of wetlands within the 1000-meter buffer was relatively low as well, with a mean value of 5.03% (ranging from 0.01% to 15.18%) with a median value of 3.26% (Table 5). Due to widespread flooding throughout North Dakota, particularly in the Prairie Pothole Region (PPR), land cover represented by open water had a wide range of values with a mean of 9.12% (ranging from 0.19% to 34.64%) and a median value of 6.79% within the 500-meter buffer (Table 4). Similarly, mean open water within the 1000-meter buffer was 8.99% (ranging from 0.02% to 35.72%) with a median value of 6.75% (Table 5). Herbaceous grassland is a dominant feature of North Dakota's riparian habitat and a mean value of 49.70% (ranging from 3.58% to 91.13%) within the 500-meter buffer with a median cover of 52.92% (Table 4). Within the 1000-meter buffer, mean grassland cover was 47.71% (ranging from 4.08% to 94.11%) with a median value of 52.64% (Table 5). With development being relatively low throughout most of North Dakota, mean percent of land cover being developed within the riparian area was 4.54% (ranging from 1.46% to 11.91%) with a median value of 3.82% (Table 4). Within 1000-meter the buffer, mean development was 3.97% (ranging from 1.20% to 10.39%) with a median value of 3.59% (Table 5).

Table 5: Land cover for each lake within a 500-meter buffer of land surrounding the lake using the 2012 NASS dataset.

	% Forest	% Agriculture	% Wetlands	% Open Water	% Grassland	% Developed
ND-101	2.85%	**65.40%**	3.98%	**11.34%**	6.04%	6.12%
ND-102	1.43%	**70.63%**	**12.50%**	3.67%	8.10%	3.67%
ND-103	0.01%	**23.00%**	3.71%	6.64%	**62.70%**	3.85%
ND-104	0.59%	**12.32%**	3.91%	5.78%	**74.80%**	2.60%
ND-105	3.33%	**45.86%**	**16.14%**	6.10%	**19.85%**	8.62%
ND-106	0.15%	**10.96%**	**15.35%**	6.78%	**63.20%**	3.57%
ND-107	0.00%	**13.59%**	2.14%	**14.05%**	**67.74%**	2.49%
ND-108	0.00%	8.99%	0.10%	3.27%	**85.47%**	2.17%
ND-109	0.00%	**14.89%**	1.82%	**34.64%**	**42.48%**	6.17%
ND-110	0.43%	**56.86%**	0.87%	1.17%	**28.73%**	**11.91%**
ND-112	0.00%	**30.22%**	3.89%	**12.68%**	**49.77%**	3.45%
ND-113	**66.21%**	0.46%	3.67%	**17.88%**	6.88%	4.91%
ND-114	0.01%	**39.40%**	2.37%	4.28%	**47.48%**	6.46%
ND-115	0.00%	**49.50%**	1.47%	1.10%	**37.09%**	**10.83%**
ND-118	0.03%	**43.58%**	1.17%	6.65%	**46.74%**	1.83%
ND-119	0.00%	**41.73%**	4.95%	**13.96%**	**31.01%**	8.35%
ND-126	0.00%	**58.42%**	3.11%	6.79%	**24.55%**	7.13%
ND-129	0.03%	**17.65%**	**10.03%**	2.96%	**66.67%**	2.55%
ND-131	3.20%	5.65%	2.79%	3.88%	**76.85%**	7.58%
ND-134	0.16%	**31.33%**	0.41%	9.83%	**52.35%**	5.83%
ND-139	1.38%	**11.44%**	**11.01%**	**11.37%**	**59.27%**	5.54%
ND-145	0.00%	3.82%	3.08%	3.63%	**85.35%**	4.12%
ND-146	**40.25%**	**13.20%**	4.07%	**17.00%**	**22.98%**	2.50%
ND-149	0.89%	**22.68%**	6.26%	**13.93%**	**51.71%**	4.51%
ND-151	0.04%	**22.95%**	6.41%	**14.61%**	**52.74%**	3.26%
ND-155	0.00%	**22.82%**	0.56%	1.80%	**70.05%**	4.47%
ND-156	0.85%	**28.25%**	6.56%	7.75%	**53.58%**	3.02%
ND-160	0.00%	**22.90%**	2.27%	5.55%	**65.50%**	3.78%
ND-162	0.00%	**41.01%**	**11.66%**	3.12%	**40.44%**	3.78%
ND-163	0.13%	1.20%	1.27%	0.19%	**91.13%**	1.46%
ND-164	1.02%	9.34%	3.65%	**12.49%**	**71.40%**	2.10%
ND-167	0.37%	**14.65%**	7.69%	5.25%	**66.44%**	5.57%
ND-172	0.66%	**33.04%**	2.93%	8.59%	**52.84%**	1.93%
ND-173	0.15%	**44.29%**	0.63%	2.81%	**49.39%**	2.72%
ND-178	**58.56%**	2.08%	1.65%	**25.66%**	3.58%	8.46%
ND-186	0.00%	4.51%	9.38%	**22.95%**	**57.96%**	4.73%
ND-187	0.48%	**41.09%**	4.84%	8.28%	**39.64%**	5.28%
ND-190	0.00%	0.81%	9.09%	9.58%	**74.30%**	6.22%
ND-193	1.98%	**24.78%**	2.39%	4.56%	**63.97%**	2.33%
ND-194	3.01%	**12.13%**	2.71%	3.36%	**73.64%**	5.15%
ND-196	0.02%	**16.64%**	2.91%	**11.70%**	**66.37%**	2.37%
ND-198	**62.87%**	0.97%	2.76%	**20.36%**	5.24%	7.80%
ND-199	0.00%	**55.73%**	6.41%	**13.69%**	**20.76%**	3.41%
ND-202	1.21%	**28.32%**	3.74%	2.21%	**57.63%**	6.84%
ND-207	1.16%	**36.50%**	**14.32%**	9.26%	**36.85%**	1.89%
ND-210	0.85%	0.11%	2.55%	6.63%	**85.86%**	3.96%
ND-225	0.00%	**76.62%**	**10.06%**	5.64%	5.05%	2.59%
ND-226	0.08%	**19.76%**	0.57%	**18.82%**	**57.81%**	2.81%
ND-232	0.83%	6.10%	6.75%	8.85%	**71.12%**	3.45%
ND-237	0.07%	**69.52%**	**12.19%**	5.17%	**10.72%**	2.33%
ND-242	0.07%	**23.10%**	0.44%	3.89%	**69.63%**	2.62%
ND-266	0.02%	**28.53%**	1.52%	**12.03%**	**52.99%**	4.88%

Table 6: Land cover for each lake within a 1000-meter buffer of land surrounding the lake using the 2012 NASS dataset.

	% Forest	% Agriculture	% Wetlands	% Open Water	% Grassland	% Developed
ND-101	1.42%	**73.69%**	7.99%	6.81%	4.98%	5.08%
ND-102	0.62%	**77.74%**	9.42%	2.97%	4.39%	4.87%
ND-103	0.01%	**31.26%**	2.80%	6.25%	**56.73%**	2.87%
ND-104	0.37%	**27.07%**	4.01%	2.61%	**63.69%**	2.26%
ND-105	2.99%	**50.21%**	**14.40%**	6.68%	**17.94%**	7.71%
ND-106	0.12%	9.86%	**12.04%**	8.56%	**65.69%**	3.72%
ND-107	0.00%	**12.94%**	1.62%	**14.67%**	**64.89%**	2.32%
ND-108	0.00%	**12.28%**	0.01%	5.66%	**79.52%**	2.37%
ND-109	0.00%	**13.25%**	2.56%	**35.72%**	**43.12%**	5.35%
ND-110	0.38%	**57.98%**	1.76%	3.27%	**26.20%**	**10.39%**
ND-112	0.00%	**28.14%**	3.41%	8.35%	**56.87%**	3.21%
ND-113	**69.16%**	0.37%	3.19%	**17.05%**	6.38%	3.85%
ND-114	0.00%	**43.10%**	2.11%	8.55%	**40.34%**	5.90%
ND-115	0.00%	**45.26%**	0.53%	0.31%	**43.90%**	**10.00%**
ND-118	0.03%	**50.45%**	1.32%	5.17%	**40.79%**	2.25%
ND-119	0.00%	**56.25%**	3.99%	6.87%	**26.74%**	6.15%
ND-126	0.01%	**62.50%**	2.67%	4.44%	**26.70%**	3.67%
ND-129	0.04%	**18.78%**	7.37%	2.76%	**68.29%**	2.66%
ND-131	2.37%	**11.88%**	2.02%	2.35%	**75.30%**	6.03%
ND-134	0.15%	**26.48%**	0.32%	7.19%	**60.71%**	5.07%
ND-139	1.91%	**18.77%**	**12.55%**	**10.76%**	**52.71%**	3.31%
ND-145	0.00%	6.06%	5.68%	8.79%	**76.84%**	2.63%
ND-146	**36.20%**	**14.91%**	3.24%	**12.77%**	**28.07%**	4.81%
ND-149	0.57%	**30.08%**	4.32%	**18.19%**	**43.82%**	3.01%
ND-151	0.03%	**21.90%**	5.35%	**15.75%**	**54.60%**	2.37%
ND-155	0.00%	**19.61%**	1.72%	5.64%	**68.95%**	3.96%
ND-156	1.61%	**37.55%**	6.44%	6.38%	**44.96%**	3.06%
ND-160	0.00%	**18.60%**	2.68%	3.99%	**70.88%**	3.85%
ND-162	0.28%	**42.19%**	**10.10%**	6.37%	**37.20%**	3.86%
ND-163	0.41%	0.54%	0.52%	0.02%	**94.11%**	1.20%
ND-164	1.43%	**20.09%**	3.79%	**13.61%**	**58.68%**	2.40%
ND-167	0.30%	**11.28%**	6.81%	6.09%	**69.39%**	6.12%
ND-172	0.38%	**33.15%**	3.87%	**11.85%**	**48.64%**	2.10%
ND-173	0.07%	**37.12%**	1.22%	6.31%	**52.57%**	2.69%
ND-178	**53.36%**	3.32%	2.25%	**29.74%**	5.74%	5.59%
ND-186	0.00%	**13.69%**	**10.41%**	**15.91%**	**55.01%**	3.92%
ND-187	0.40%	**49.59%**	6.69%	5.69%	**33.28%**	4.18%
ND-190	0.05%	6.75%	**15.01%**	6.49%	**66.96%**	4.56%
ND-193	1.57%	**26.61%**	2.27%	5.62%	**62.02%**	1.90%
ND-194	1.64%	**33.16%**	2.49%	1.63%	**56.69%**	4.38%
ND-196	0.01%	**16.93%**	2.26%	**16.66%**	**62.45%**	1.69%
ND-198	**70.08%**	0.31%	1.42%	**18.10%**	4.08%	6.01%
ND-199	0.00%	45.82%	7.86%	8.56%	34.73%	3.03%
ND-202	0.84%	**31.20%**	1.47%	0.77%	**60.93%**	4.79%
ND-207	0.96%	**36.28%**	**14.66%**	**10.00%**	**34.60%**	3.50%
ND-210	0.38%	0.06%	3.28%	4.78%	**88.97%**	2.52%
ND-225	0.00%	**63.21%**	**15.18%**	**11.39%**	6.81%	3.40%
ND-226	0.03%	**29.61%**	0.43%	**21.61%**	**45.38%**	2.88%
ND-232	0.70%	**17.00%**	7.22%	7.23%	**65.31%**	2.54%
ND-237	0.35%	**62.88%**	**14.76%**	5.53%	**12.60%**	3.71%
ND-242	0.01%	**28.57%**	0.37%	6.21%	**61.47%**	3.18%
ND-266	0.01%	**37.04%**	1.48%	8.78%	**49.27%**	3.35%

Nutrient condition

Over the first two NLAs, the majority of North Dakota lakes have been in poor condition with regard to total nitrogen (TN). For the 2012 survey, greater than 45% of North Dakota lakes (1,828 lakes) were in poor condition for TN, which decreased by nearly 25 percentage points compared to the 2007 survey (Figure 4). Further, the decrease in lakes in good and poor condition was accompanied by a large increase in lakes in fair condition (52.89% of ND lakes; 2,113 lakes), an increase of 44.35 percentage points compared to the 2007 survey (Figure 4). Similarly, 50.37% of North Dakota lakes (2,012 lakes) were in poor condition for total phosphorus (TP) in 2012, an increase of 12.68 percentage points compared to the 2007 assessment (Figure 5). Conversely, greater than 40% of the State's lakes (1,622 lakes) were in good condition for TP, an increase of 7.28% when compared to 2007 (Figure 5).

As was observed in 2007, North Dakota had some noticeable differences between ecoregions with regard to nutrients. Greater than 85% of North Dakota NPL lakes were in poor condition for TN in 2012, which was a decrease of 13 percentage points since the last assessment (Table 7). Conversely, a majority of North Dakota TPL lakes were fair for TN (73.25%), which corresponds to a dramatic decrease in the number of lakes in good and poor condition (Table 7). Similar to TN, greater than 87% of North Dakota NPL lakes were poor for TP, compared to only 31% in the TPL (Table 7).

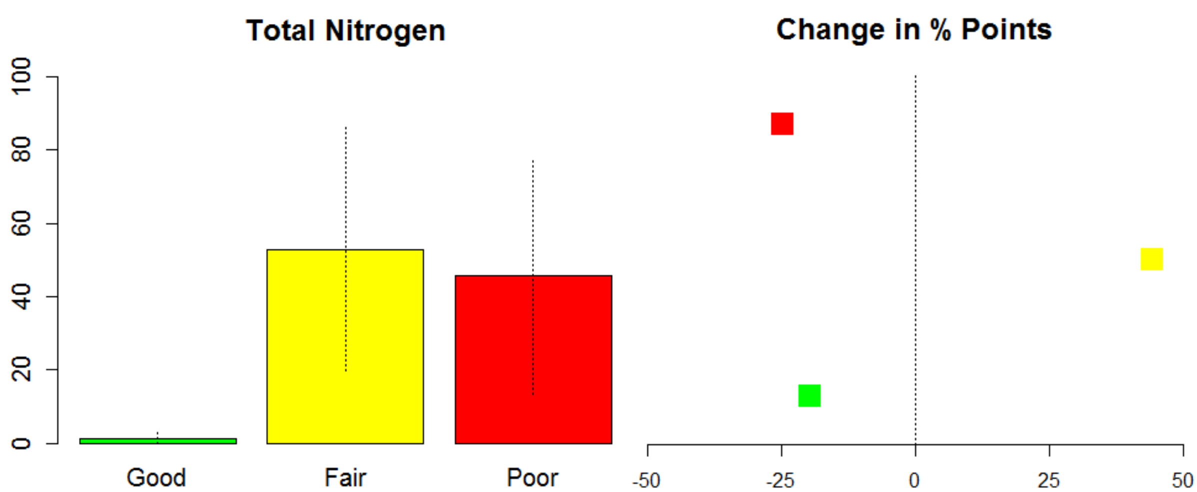

Figure 4: Extent estimates of total nitrogen condition for North Dakota lakes (left) from the 2012 National Lakes Assessment. The graph on the right compares extent estimates from the 2007 and 2012 assessments, where numbers to the left of the dotted line indicate a negative direction (decrease) and numbers to the right of the dotted line indicate a positive direction (increase).

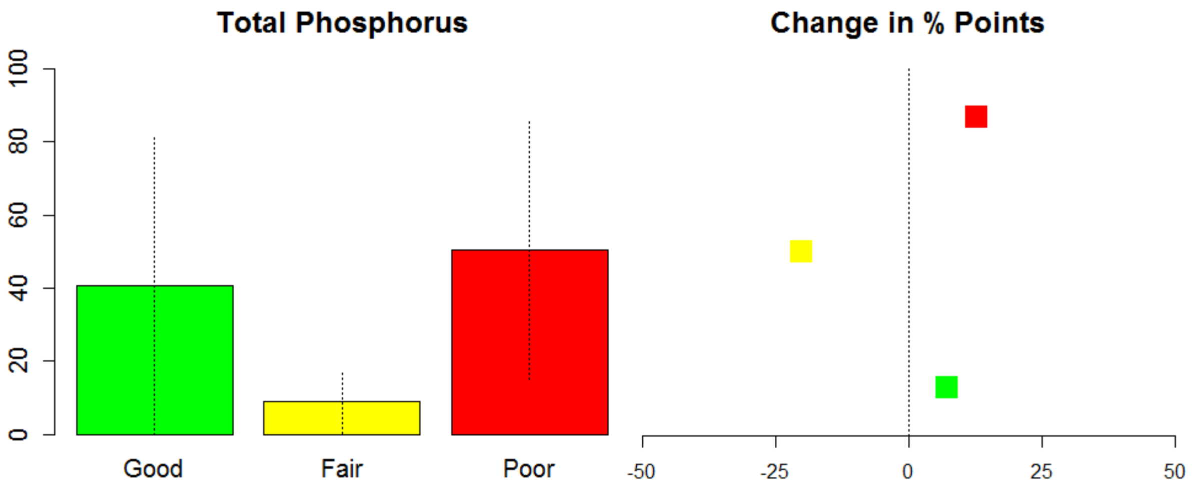

Figure 5: Extent estimates of total phosphorus condition for North Dakota lakes (left) from the 2012 National Lakes Assessment. The graph on the right compares extent estimates from the 2007 and 2012 assessments, where numbers to the left of the dotted line indicate a negative direction (decrease) and numbers to the right of the dotted line indicate a positive direction (increase).

Table 7: Comparison of nutrient condition classes for North Dakota lakes separated by ecoregion, and change in percentage points between 2007 and 2012 assessments.

Condition Class	ND Lakes in NPL	Change in % Points	ND Lakes in TPL	Change in % Points
Total Nitrogen				
Good	0.00%	-1.08%	2.04%	-38.26%
Fair	14.10%	+14.10%	73.25%	+56.43%
Poor	85.90%	-13.02%	24.71%	-18.18%
Total Phosphorus				
Good	6.89%	-11.94%	58.28%	+10.92%
Fair	5.92%	-4.02%	10.67%	-36.80%
Poor	87.20%	+15.98%	31.05%	+25.88%

Physical habitat condition

Physical habitat provides refuge for biological communities (e.g., macroinvertebrates, zooplankton) from predators and direct sunlight. Littoral cover in most North Dakota lakes was in good condition in 2012, with nearly 60% of lakes (2,397 lakes) in good condition (Figure 6). Similarly, riparian vegetation throughout the State was in good condition for the 2012 survey, with greater than 50% of lakes (2,102 lakes) in good condition (Figure 7). Condition of riparian vegetation increased by greater than 25 percentage points since 2007, which was most reflected in a reduction in the number of lakes in poor condition (Figure 7). Nearly 40% of North Dakota lakes were in good condition for riparian disturbance (1,580 lakes), though nearly 40% of lakes were in poor condition (1,548 lakes) (Figure 8). The high number of lakes in good condition for riparian disturbance were highly influenced by a single site (ND-113) which had a high weight, resulting in a large range in the standard error estimate (Figure 8).

North Dakota lakes in the TPL were generally in good condition for littoral cover (76.20%), with a much smaller percentage in the NPL in good condition (29.13%) (Table 8). Similarly, greater than 65% of North Dakota lakes in the TPL were in good condition with regard to riparian vegetation, compared to only 27.20% of NPL lakes (Table 8). Finally, no lakes in the NPL region of North Dakota were in good condition and greater than 60% were in poor condition for riparian disturbance, while greater than 60% of lakes in the TPL were in good condition (Table 8).

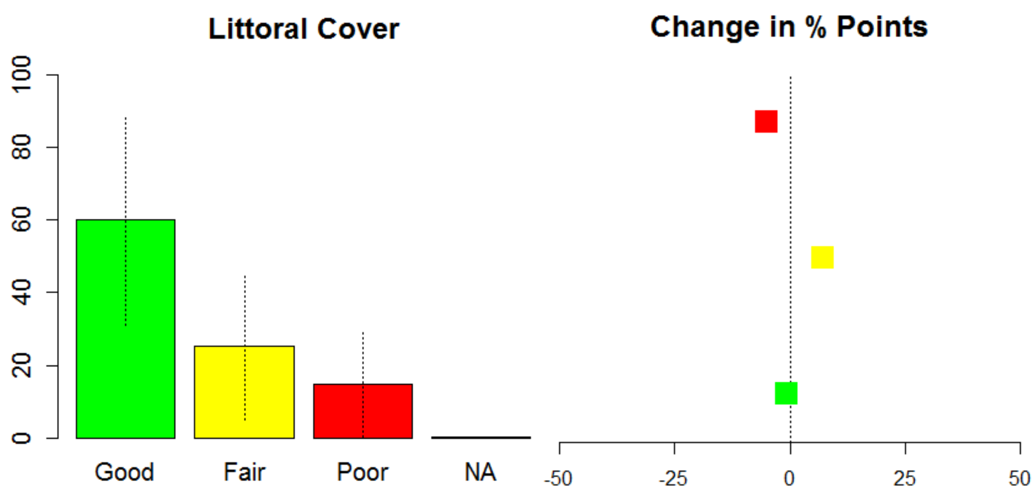

Figure 6: Extent estimates of littoral cover condition for North Dakota lakes (left) from the 2012 National Lakes Assessment. The graph on the right compares extent estimates from the 2007 and 2012 assessments, where numbers to the left of the dotted line indicate a negative direction (decrease) and numbers to the right of the dotted line indicate a positive direction (increase).

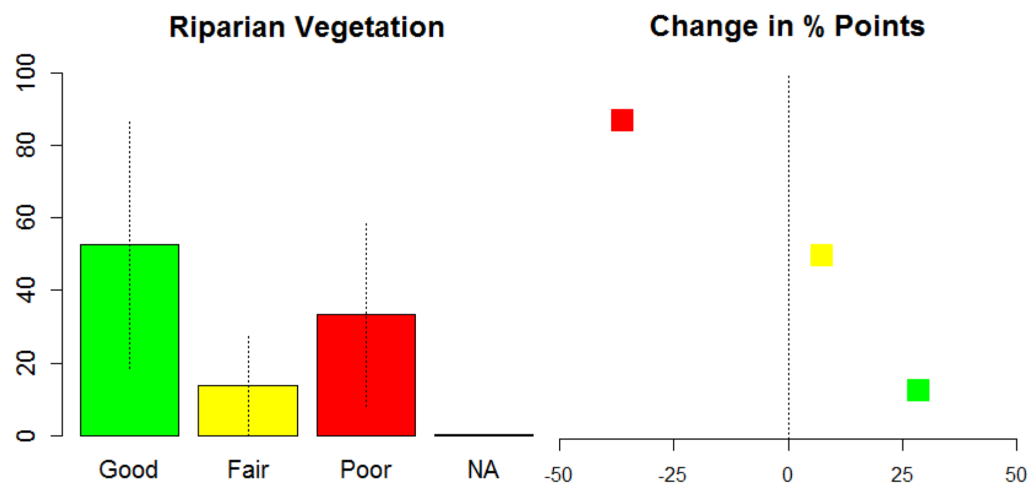

Figure 7: Extent estimates of riparian vegetation condition for North Dakota lakes (left) from the 2012 National Lakes Assessment. The graph on the right compares extent estimates from the 2007 and 2012 assessments, where numbers to the left of the dotted line indicate a negative direction (decrease) and numbers to the right of the dotted line indicate a positive direction (increase).

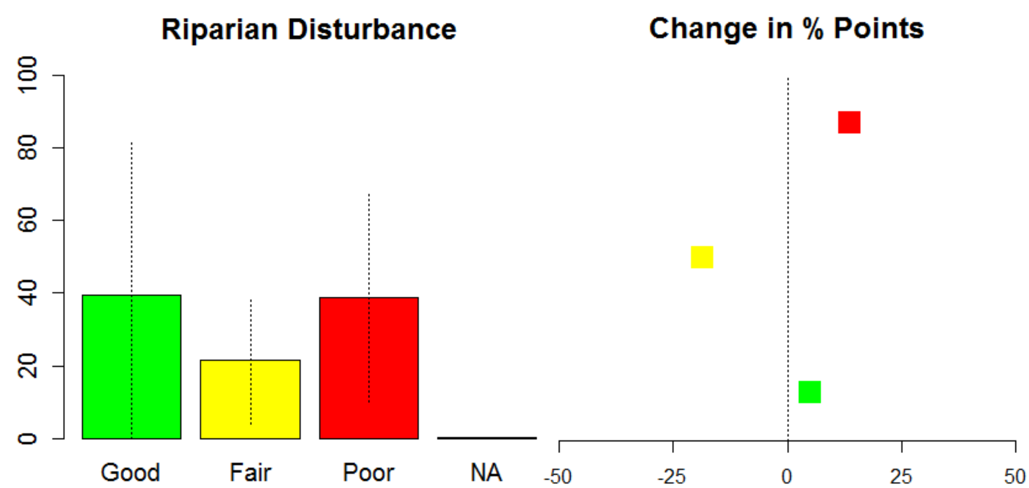

Figure 8: Extent estimates of riparian disturbance condition for North Dakota lakes (left) from the 2012 National Lakes Assessment. The graph on the right compares extent estimates from the 2007 and 2012 assessments, where numbers to the left of the dotted line indicate a negative direction (decrease) and numbers to the right of the dotted line indicate a positive direction (increase).

Table 8: Comparison of physical habitat condition classes for North Dakota lakes separated by ecoregion, and change in percentage points between 2007 and 2012 assessments.

Condition Class	ND Lakes in NPL	Change in % Points	ND Lakes in TPL	Change in % Points
Littoral Cover				
Good	29.13%	-26.30%	76.20%	+10.56%
Fair	36.84%	+17.69%	19.01%	+1.94%
Poor	34.03%	+11.53%	4.43%	-12.64%
Not Assessed	0.00%	-2.55%	0.36%	+0.14%
Riparian Vegetation				
Good	27.20%	+27.20%	65.99%	+18.63%
Fair	23.01%	+10.03%	8.95%	+8.95%
Poor	49.79%	-37.23%	24.71%	-27.72%
Not Assessed	0.00%	0.00%	0.36%	+0.14%
Riparian Disturbance				
Good	0.00%	0.00%	60.32%	-7.90%
Fair	35.97%	-35.49%	13.84%	+4.30%
Poor	64.03%	+35.49%	25.49%	+3.47%
Not Assessed	0.00%	0.00%	0.36%	+0.14%

Biological condition

Greater than 50% of North Dakota lakes (2,151 lakes) were in good condition based on the macroinvertebrate MMI, compared to 17.95% (717 lakes) and 23.87% (954 lakes) in fair and poor condition, respectively (Figure 9). Further, 4.34% of lakes (174 lakes) were not assessed (Figure 9), a designation based on either there being no sample collected or fewer than 100 individuals counted in the sample. With regard to the zooplankton MMI, most lakes in North Dakota were fair (54.95%; 2,195 lakes), driven mostly by lakes in poor condition decreasing by nearly 47 percentage points in the State when compared to the 2007 assessment (Figure 10).

Benthic macroinvertebrate communities were in better condition within North Dakota TPL lakes compared to NPL lakes. Greater than 63% of North Dakota TPL lakes were in good condition for macroinvertebrate MMI, compared to 36.35% of NPL lakes (Table 9). Conversely, a greater percentage of North Dakota NPL lakes were good with regard to the zooplankton MMI (26.61%) compared to 8.39% of TPL lakes (Table 9). There were, however, a greater percentage of North Dakota NPL lakes in poor condition for the zooplankton MMI (41.86%) compared to 24.37% of TPL lakes (Table 9).

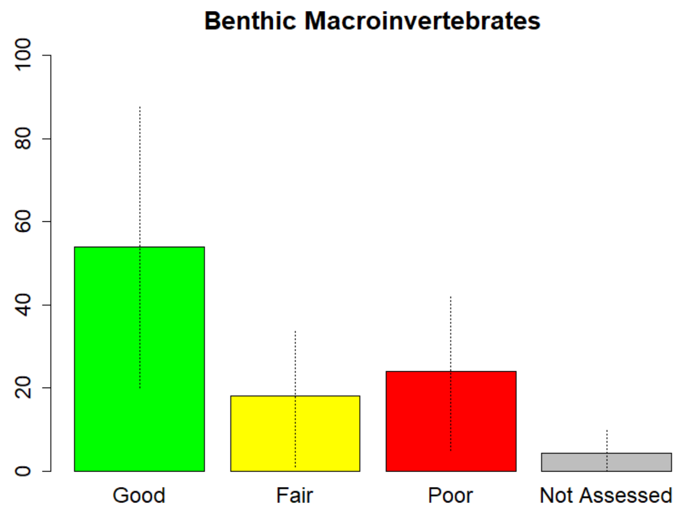

Figure 9: Extent estimate for the State of North Dakota based on benthic macroinvertebrates from the 2012 National Lakes Assessment. Error bars on these graphs display the upper and lower 95% confidence intervals. Lakes designated as Not Assessed (NA) were either not sampled for benthic macroinvertebrates or had fewer than 100 individuals counted.

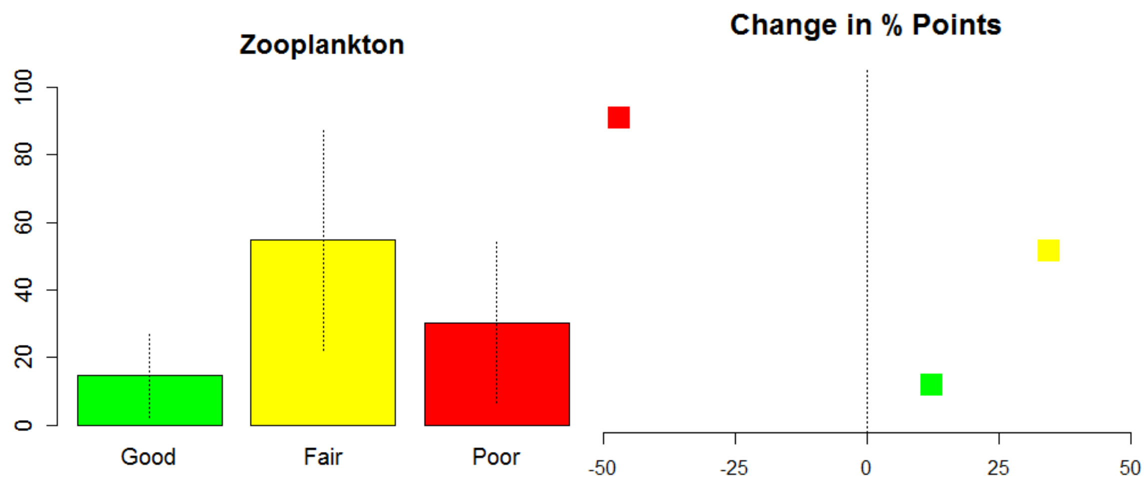

Figure 10: Extent estimates of zooplankton MMI condition for North Dakota lakes (left) from the 2012 National Lakes Assessment. The graph on the right compares extent estimates from the 2007 and 2012 assessments, where numbers to the left of the dotted line indicate a negative direction (decrease) and numbers to the right of the dotted line indicate a positive direction (increase). Condition was determined from a ratio of observed-to-expected taxa for the 2007 assessment, whereas a multimetric index was used to determine condition for the 2012 NLA.

Table 9: Comparison of biological condition classes for North Dakota lakes separated by ecoregion, and change in percentage points between 2007 and 2012 assessments. Benthic macroinvertebrates were not assessed in 2007.

Condition Class	ND Lakes in NPL	Change in % Points	ND Lakes in TPL	Change in % Points
Benthic Macroinvertebrates				
Good	36.35%	n/a	63.02%	n/a
Fair	31.43%	n/a	10.87%	n/a
Poor	25.92%	n/a	25.92%	n/a
Not Assessed	0.00%	n/a	3.32%	n/a
Zooplankton				
Good	26.61%	+26.61%	8.39%	+3.81%
Fair	31.53%	+27.10%	67.23%	+31.52%
Poor	41.86%	-53.71%	24.37%	-35.13%

Recreational condition – Index Site

Algae are the base of aquatic foodwebs, and provide the initial step in making nutrients available throughout the food chain. Excessive algal growth, however, can cause major ecological problems, such as hypoxia in lower depths or release of harmful toxins (e.g., anatoxin, microcystin) to aquatic organisms that rely on water for a part of (or all of) their life. For all classifications presented hereafter in recreational condition, good is analogous to low risk, fair to moderate risk, and poor to high risk. Based on chlorophyll-α, 12.60% of North Dakota lakes (503 lakes) were low risk, a decrease of nearly 75 percentage points compared to 2007 (Figure 11). This decrease in lakes in good condition corresponded to a large increase in lakes in fair condition (73.47%; 2,935 lakes) in 2012 (Figure 11).
Increased cyanobacteria (i.e., blue-green algae) production can lead to an increased level of cyanotoxins in the water column, causing illness and/or death in wildlife, livestock, and humans. Nearly 30% of North Dakota lakes (1,198 lakes) were considered high risk for cyanobacteria densities, while only 17% (693 lakes) were low risk (Figure 12). The largest change from the 2007 survey is an increase of 25 percentage points in high risk lakes, and a corresponding decrease in the number of lakes being low risk (Figure 12).

Though not the only cyanotoxin group identified, microcystin is the most commonly identified cyanotoxin in the United States. Microcystin condition was considered low risk if concentrations were less than 10 µg/L, moderate risk if concentrations were less than or equal to 10 µg/L and greater than 20 µg/L, and high risk if concentration was greater than or equal to 20 µg/L. Nearly 96% of North Dakota lakes (3,832 lakes) were low risk or were non-detect based on microcystin concentration in 2012, a slight improvement over 2007 (Figure 13). Roughly 4% of North Dakota lakes (144 lakes) were high risk for microcystin, which is slightly higher than was measured in 2007 (Figure 13).

There was no clear difference between ecoregions for chlorophyll-α concentration, with 15% and 13% of all North Dakota TPL and NPL lakes, respectively, considered high risk for chlorophyll-α concentration (Table 10). There was, however, a difference among lakes considered low risk for chlorophyll-α concentration, with nearly 25% of all North Dakota NPL lakes and only 6% of TPL lakes considered low risk (Table 10). Conversely, a greater number of North Dakota NPL lakes were high risk for cyanobacteria densities (44%) than lakes in the TPL ecoregion (23%) (Table 10). Further, while there were no lakes in the TPL region of North Dakota that were high risk based on microcystin concentration, compared to greater than 10% of North Dakota NPL lakes were high risk for microcystin (Table 10).

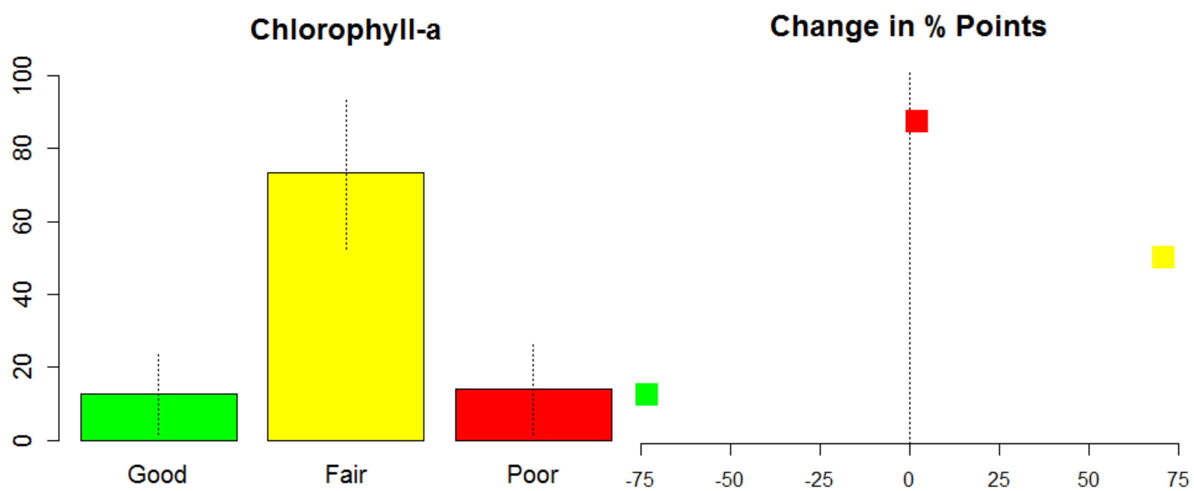

Figure 11: Extent estimates of chlorophyll-α condition for North Dakota lakes (left) from the 2012 National Lakes Assessment. The graph on the right compares extent estimates from the 2007 and 2012 assessments, where numbers to the left of the dotted line indicate a negative direction (decrease) and numbers to the right of the dotted line indicate a positive direction (increase).

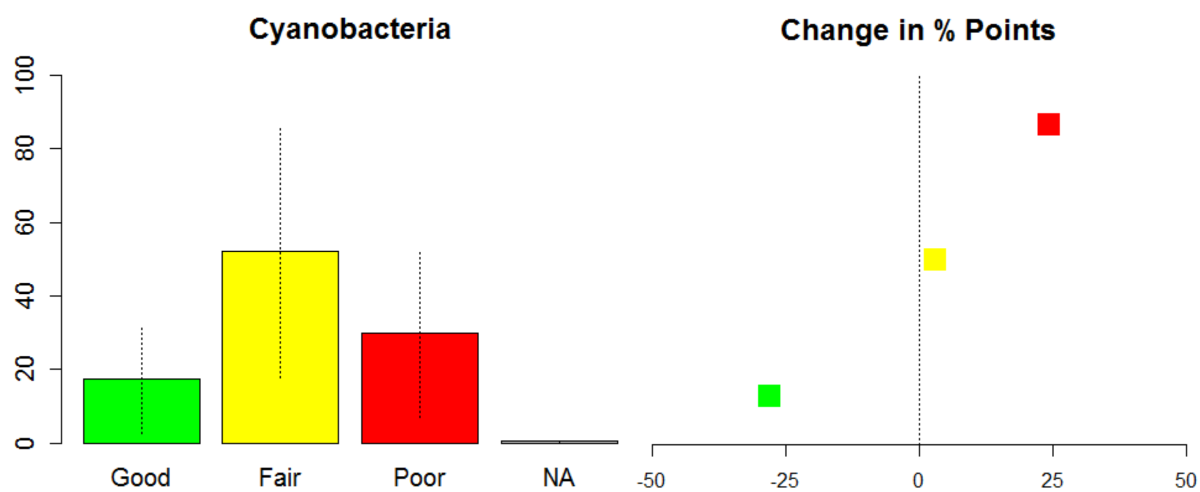

Figure 12: Extent estimates of cyanobacteria density condition for North Dakota lakes (left) from the 2012 National Lakes Assessment. The graph on the right compares extent estimates from the 2007 and 2012 assessments, where numbers to the left of the dotted line indicate a negative direction (decrease) and numbers to the right of the dotted line indicate a positive direction (increase).

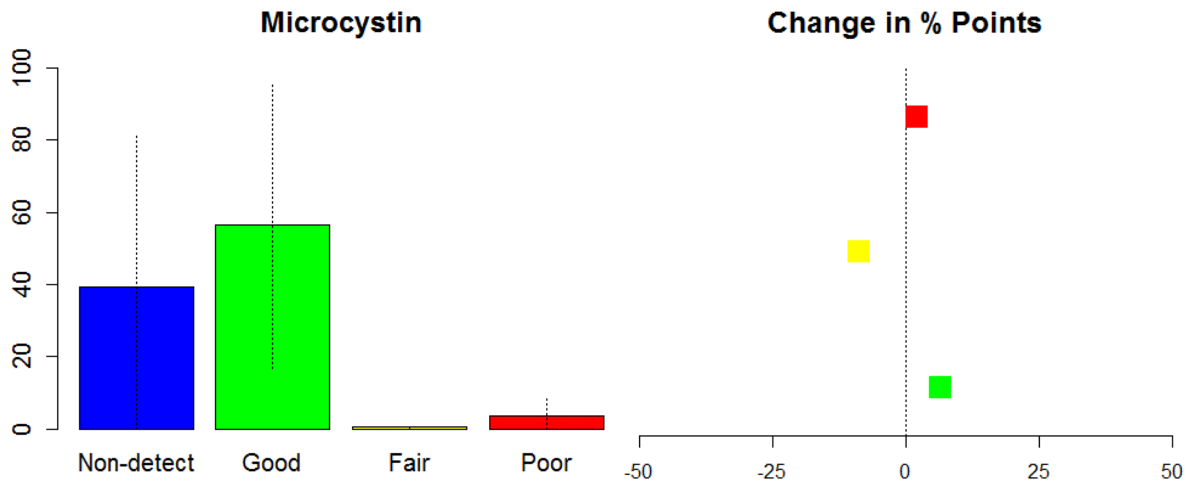

Figure 13: Extent estimates of microcystin (algal toxin) concentration condition for North Dakota lakes (left) from the 2012 National Lakes Assessment. The graph on the right compares extent estimates from the 2007 and 2012 assessments, where numbers to the left of the dotted line indicate a negative direction (decrease) and numbers to the right of the dotted line indicate a positive direction (increase). For the purposes of the change graph, non-detect results were grouped with lakes considered in good condition.

Mercury is a natural element found in many rocks, including coal. When coal is burned, mercury is released into the atmosphere, where it is eventually deposited on to the land and in waters. When ingested by wildlife, mercury exposure has a significant effect. As mercury is ingested by humans, it can have a strong effect as well, with a strong impact on brain development in children. Methylmercury is a converted form of elemental mercury and is the form that bioaccumulates in aquatic ecosystems. The risk of methylmercury exposure in North Dakota lakes was assessed by measuring its concentrations in lake sediments. Based on sediment methylmercury concentrations in sediments, North Dakota lakes are at relatively low risk with nearly 80% (3,112 lakes) in good condition (Figure 14). Similarly, North Dakota lakes were in good condition for total mercury measured from a single sediment core, with 61% (2,442 lakes) and 93% (3,695 lakes) considered in good condition for mercury concentration in the top and bottom of the sediment core, respectively (Figures 15 and 16). This difference between top and bottom likely indicates more impact from mercury deposition in more recent history.

Methylmercury condition was good in both the North Dakota ecoregions, with 75% and 79% in good condition within the NPL and TPL, respectively (Table 10). The greatest difference between top and bottom mercury concentration occurred in the NPL region of North Dakota, with 87% of lakes considered good for bottom mercury concentration, compared to only 45% of lakes for top mercury concentration (Table 10). Further, 95% of North Dakota TPL lakes were in good condition for bottom mercury concentration compared to 69% in good condition for top mercury concentration (Table 10).

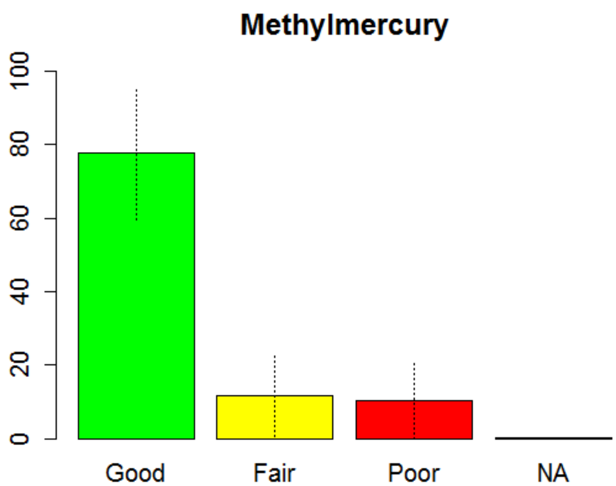

Figure 14: Extent estimates of methylmercury concentration condition in bottom sediments for North Dakota lakes from the 2012 National Lakes Assessment.

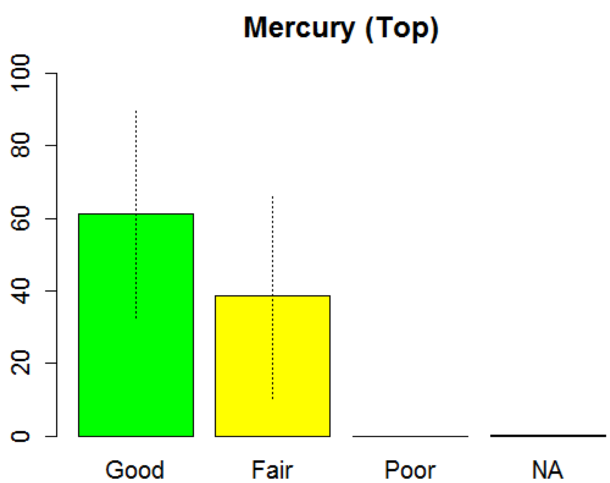

Figure 15: Extent estimates of mercury concentration condition (from the top of the sediment core) in bottom sediments for North Dakota lakes from the 2012 National Lakes Assessment.

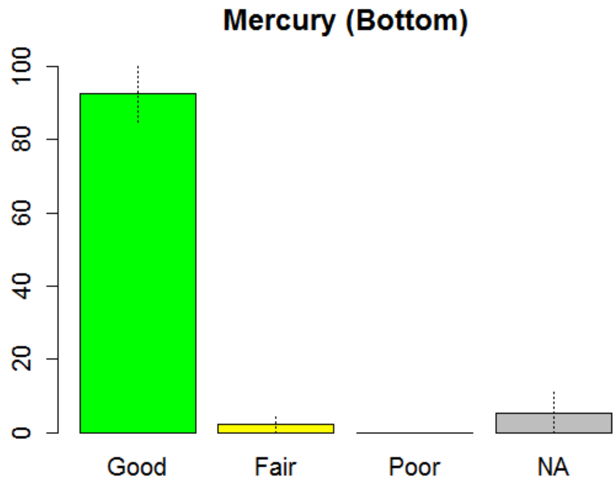

Figure 16: Extent estimates of mercury concentration condition (from the bottom of the sediment core) in bottom sediments for North Dakota lakes from the 2012 National Lakes Assessment.

Dissolved oxygen was relatively high throughout North Dakota lakes with greater than 99% (3,971 lakes) in good condition (Figure 17). The number of lakes in good condition for dissolved oxygen increased by nearly 25 percentage points from the 2007 survey (Figure 17).

Atrazine is a common pesticide used in agricultural production throughout the US, and its presence in freshwater can have significant negative impacts on plants and wildlife. Atrazine was not detected in greater than 80% of North Dakota lakes (3,221 lakes), with 13% of lakes (520 lakes) detected below a concentration of 4 ppb and no lakes detected above 4 ppb (Figure 18). Further, greater than 6% of North Dakota lakes were not assessed for atrazine (Figure 18), as the NDDoH did not collect samples as part of its intensification.

Dissolved oxygen condition was similar between both North Dakota ecoregions, with 98% and 100% of lakes considered in good condition in the NPL and TPL, respectively (Table 10). Though atrazine was in relatively low concentrations throughout North Dakota, a greater percentage of non-detects occurred in the TPL, with 86% of lakes being non-detect compared to 70% in North Dakota NPL lakes (Table 10).

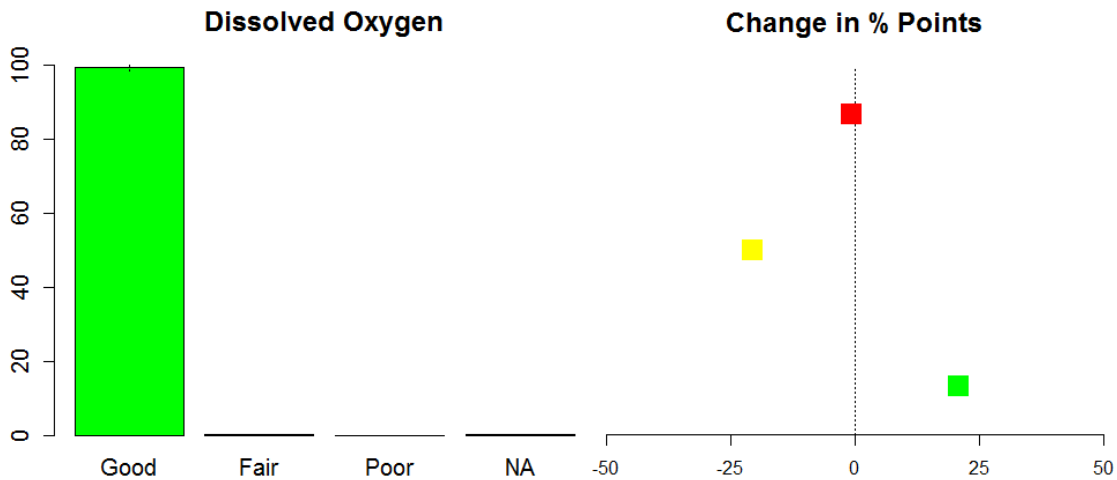

Figure 17: Extent estimates of dissolved oxygen concentration condition for North Dakota lakes (left) from the 2012 National Lakes Assessment. The graph on the right compares extent estimates from the 2007 and 2012 assessments, where numbers to the left of the dotted line indicate a negative direction (decrease) and numbers to the right of the dotted line indicate a positive direction (increase).

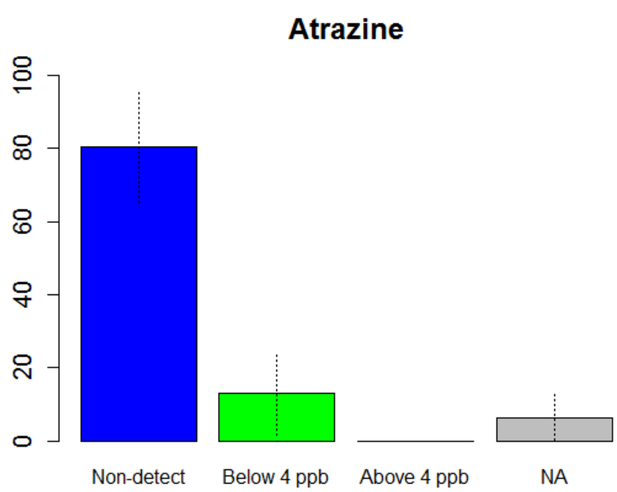

Figure 18: Extent estimates of atrazine concentration condition for North Dakota lakes from the 2012 National Lakes Assessment.

Table 10: Comparison of recreation condition classes for North Dakota lakes (from the index site) separated by ecoregion, and change in percentage points between 2007 and 2012 assessments.

Condition Class	ND Lakes in NPL	Change in % Points	ND Lakes in TPL	Change in % Points
Chlorophyll-α				
Good	24.51%	-55.26%	6.35%	-84.90%
Fair	62.86%	+61.78%	79.03%	+71.87%
Poor	12.63%	-6.51%	14.62%	+10.04%
Cyanobacteria				
Good	22.70%	-5.00%	14.52%	-47.80%
Fair	31.75%	-29.08%	62.95%	+25.27%
Poor	44.21%	+32.74%	22.52%	22.52%
Not Assessed	1.34%	+1.34%	0.00%	0.00%
Microcystin				
Non-detect	3.59%	n/a	58.28%	n/a
Good	84.61%[1]	-7.79%	41.72%[1]	+17.07%
Fair	1.34%	+0.26%	0.00%	-17.07%
Poor	10.46%	+7.53%	0.00%	0.00%
Methylmercury				
Good	75.36%%	n/a	79.25%	n/a
Fair	13.21%	n/a	10.87%	n/a
Poor	11.44%	n/a	9.52%	n/a
Not Assessed	0.00%	n/a	0.36%	n/a
Mercury (Top)				
Good	45.42%	n/a	69.38%	n/a
Fair	54.58%	n/a	30.27%	n/a
Poor	0.00%	n/a	0.00%	n/a
Not Assessed	0.00%	n/a	0.36%	n/a
Mercury (Bottom)				
Good	87.35%	n/a	95.21%	n/a
Fair	0.81%	n/a	2.96%	n/a
Poor	0.00%	n/a	0.00%	n/a
Not Assessed	11.83%	n/a	1.83%	n/a
Dissolved Oxygen				
Good	98.31%	+5.01%	100.00%	+35.71%
Fair	0.88%	-4.74%	0.00%	-35.71%
Poor	0.00%	-1.08%	0.00%	0.00%
Not Assessed	0.81%	+0.81%	0.00%	0.00%
Atrazine				
Non-detect	69.66%	n/a	86.38%	n/a
Below 4 ppb	20.11%	n/a	9.31%	n/a
Above 4 ppb	0.00%	n/a	0.00%	n/a
Not Assessed	10.23%	n/a	4.31%	n/a

[1]Good and non-detect combined for change between 2007 and 2012 surveys

Recreational condition – Littoral Site

Algae are a common component of lake foodwebs and their distribution throughout the lake can be, at times, controlled by abiotic factors (e.g., wind). Therefore, algae can become concentrated in near-shore (i.e., littoral) areas of lakes, with potential consequences including the release of algal toxins in a more confined area. Nearly 60% of North Dakota lakes (2,265 lakes) were in good condition for littoral chlorophyll-α concentrations, compared to only 12% (475 lakes) in poor condition (Figure 19). Classifications for microcystin concentration were the same at the littoral site as those listed at the Index (i.e., deepest) site. Microcystins were not detected in nearly 10% of North Dakota lakes (379 lakes), with an additional 86% (3,453 lakes) low risk (i.e., microcystin concentration less than 10 µg/L) for the toxin (Figure 20).

North Dakota lakes in the NPL region had a greater percentage of lakes in poor condition for littoral chlorophyll-α (20.93%) than did the TPL (7.13%) (Table 11). Similarly, only 19% of North Dakota NPL lakes were considered low risk for nearshore, littoral chlorophyll-α concentration compared to greater than 76% of North Dakota TPL lakes in good condition (Table 11). No lakes in the TPL region of North Dakota were considered high risk based on microcystin concentration, while greater than 10% of lakes in the NPL region were high risk (Table 11).

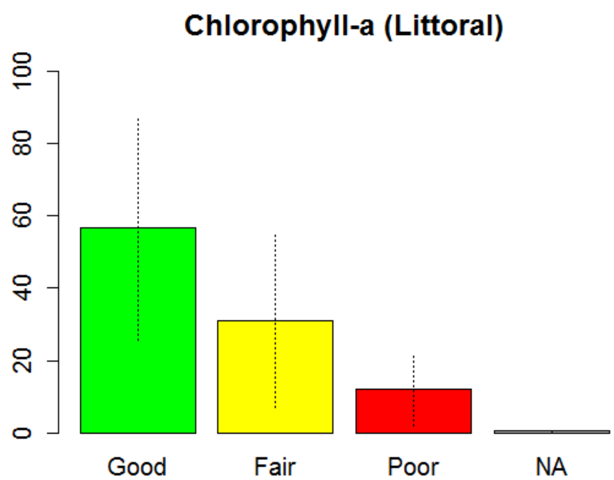

Figure 19: Extent estimates of chlorophyll-α condition for North Dakota lakes collected at the near-shore site from the 2012 National Lakes Assessment.

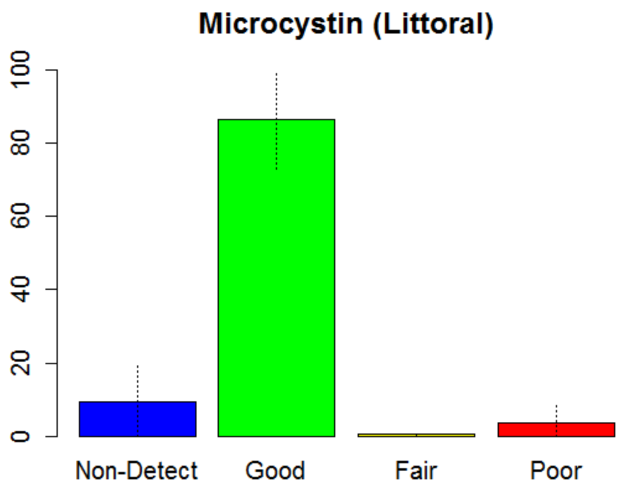

Figure 20: Extent estimates of microcystin concentration condition for North Dakota lakes collected at the near-shore site from the 2012 National Lakes Assessment.

Table 11: Comparison of recreation condition classes for North Dakota lakes (from the littoral site) separated by ecoregion.

Condition Class	ND Lakes in NPL	ND Lakes in TPL
Chlorophyll-α		
Good	18.74%	76.64%
Fair	58.98%	16.23%
Poor	20.93%	7.13%
Not Assessed	1.34%	0.00%
Microcystin		
Non-detect	9.44%	9.52%
Good	78.76%	90.48%
Fair	1.34%	0.00%
Poor	10.46%	0.00%

Correlating environmental variables to biological, chemical, and physical measures

Lake size was a key element to the stratified, random selection of lakes for this survey. Since larger lakes are scarcer, particularly in the PPR, most lakes sampled by the NDDoH were relatively small. Larger lakes were more likely to have littoral and shoreline substrates dominated by sand (R = 0.53 and 0.45, respectively), while having less silt (R = -0.39 and -0.52, respectively) (Table 12). Littoral plant communities were of lesser quality in larger lakes (R = -0.43), while also having less natural fish cover overall (R = -0.44) (Table 12).

When plant growth is relatively scarce and riparian vegetation does not provide the shade that is needed for near-shore biological communities, increased depth, both in the littoral zone and middle of the lake, can provide refuge needed by biological communities from predators and sunlight. In North Dakota, deeper lakes had lower concentrations of carbonate (R = -0.34) and dissolved organic carbon (R = -0.42), while concentrations of barium (R = 0.56) and calcium (R

= 0.36) were much greater in deep lakes (Table 12). Deeper lakes tended to have greater amounts of fish cover from brush (R = 0.38) and drop-offs (R = 0.37) (Table 12). Further, deeper lakes tended to have less emergent vegetation than shallow lakes (R = -0.40), with a greater variety of bottom substrates in the littoral area (R = 0.38) (Table 12). Deeper lakes were more likely to be impacted by docks (R = 0.50) and buildings (R = 0.35), likely due to deeper lakes being more likely to be used for recreation or cabins (e.g., Devils Lake [ND-105], Lake Tschida [ND-131]).

Nutrients (particularly N and P) occur naturally in lakes and rivers, but elevated concentrations of these can often be attributed to anthropogenic impacts (e.g., agriculture, urbanization). These elevated concentrations of nutrients can play a key role in eutrophication and its subsequent negative consequences (e.g., hypoxia at deeper depths). Elevated concentrations of total nitrogen were associated with elevated concentrations of arsenic (R = 0.44), carbonate (R = 0.63), chloride (R = 0.42), dissolved organic carbon (R = 0.64), manganese (R = 0.43), potassium (R = 0.55), silica (R = 0.46), and turbidity (R = 0.62) (Table 13). Similarly, elevated concentrations of total phosphorus were associated with high concentrations of arsenic (R = 0.37), silica (R = 0.43), and turbidity (R = 0.66) (Table 13). Increased emergent plant growth in the littoral zone was associated with lower concentrations of ammonia (R = -0.36), while increased fish cover from all natural sources (e.g., aquatic plants; snags) correlated with lower concentrations of total nitrogen (R = -0.32), total phosphorus (R = -0.32), and ammonia (R = -0.47) (Table 13). Increased canopy cover from big trees was associated with lower concentrations of total nitrogen (R = -0.35) and total phosphorus (R = -0.32) (Table 13); these may be regional differences, however, with Turtle Mountain lakes having lower nutrient concentrations than the rest of the State. Concentrations of total nitrogen were lower in lakes with greater amounts of docks (R = -0.47), lawns (R = -0.37), and parks (R = -0.55) (Table 13); this finding is likely due to people recreating at lakes with lesser eutrophication effects compared to those being a causal relationship.

Biological communities can be a useful surrogate in assessing the health of waterbodies, with much work already having been (or currently) done to understand the relationships between the health of these communities and water quality. The zooplankton MMI was negatively correlated to many water chemistry measures, including calcium (R = -0.58), chloride (R = -0.49), iron (R = -0.37), sodium (R = -0.49), and sulfate (R = -0.51) (Table 14). The macroinvertebrate MMI was negatively related to total nitrogen (R = -0.44) and total phosphorus (R = -0.46) concentrations (Table 14). Macroinvertebrate community health was positively related to increasing littoral macrophytes and riparian vegetation, particularly tall, woody vegetation. Further, the macroinvertebrate MMI decreased with increasing sediment size in North Dakota lakes, a relationship that may be better explained by sampling error and not necessarily a true negative relationship. Chlorophyll-α concentration was positively related to concentrations of total nitrogen (R = 0.47) and total phosphorus (R = 0.46) (Table 14). Finally, chlorophyll-α concentration was strongly related to turbidity (R = 0.62), which suggests most turbidity in North Dakota lakes is represented by algal turbidity.

Table 12: Correlation tables for physical lake characteristics. Bolded values denote a significant relationship, while a single asterisk (*) denotes a correlation coefficient less than 0.01 and two asterisks (**) denote that less than 0.001.

	Lake Area	Max Depth	Littoral Depth
Water Chemistry			
Barium	**0.299**	**0.564****	**0.300**
Boron	0.000	**-0.276**	**-0.294**
Calcium	0.106	**0.363***	-0.032
Carbonate	-0.112	**-0.338**	-0.050
Dissolved Organic Carbon	**-0.429***	**-0.422***	-0.013
Hardness	**-0.278**	0.127	-0.077
Iron	0.067	-0.163	**-0.325**
Magnesium	**-0.291**	0.057	-0.045
Manganese	-0.088	0.040	**-0.341**
Nitrogen (Total)	0.006	**-0.321**	-0.034
Nitrogen (Total, Dissolved)	**-0.307**	-0.236	-0.133
Littoral Vegetation/Substrate and Fish Cover			
Fractional cover of emergent vegetation	**-0.279**	**-0.360**	-0.010
Fractional cover of submerged vegetation	**-0.321**	-0.185	0.006
Fractional presence of all aquatic vegetation	**-0.306**	-0.099	-0.041
Fractional presence of emergent vegetation	**-0.413***	**-0.399***	-0.068
Fractional presence of submerged vegetation	**-0.312**	-0.059	0.169
Index of all aquatic vegetation	**-0.426***	**-0.319**	-0.057
16th-percentile of bottom substrate diameter	**0.293**	0.073	0.132
25th-percentile of bottom substrate diameter	**0.376***	0.121	0.090
50th-percentile of bottom substrate diameter	**0.376***	0.011	-0.018
75th-percentile of bottom substrate diameter	**0.331**	0.111	-0.039
84th-percentile of bottom substrate diameter	**0.270**	0.032	-0.053
Fractional cover of bottom substrate as cobble	0.130	0.037	**0.401***
Fractional cover of bottom substrate as sand	**0.533****	**0.294**	-0.115
Fractional cover of bottom substrate as silt	**-0.386***	-0.191	0.133
Fractional cover of bottom substrate as wood	-0.104	**0.289**	0.183
Fractional presence of bottom substrate as organic	**-0.280**	-0.124	-0.051
Fractional presence of bottom substrate as sand	**0.428***	0.266	0.103
Fractional presence of bottom substrate as silt	-0.257	0.008	**0.375***
Fractional presence of bottom substrate as wood	-0.059	**0.335**	0.200
Number of bottom substrate types at each station	0.102	**0.376***	0.142
Log-transformed mean bottom substrate diameter	**0.356**	0.044	-0.073
Fractional fish cover from aquatic plants	**-0.404***	-0.222	-0.031
Fractional fish cover from overhanging vegetation	-0.043	0.022	**0.335**
Fractional fish cover from snags	0.002	0.235	**0.344**
Fractional presence of all fish cover-types	**-0.328**	-0.117	0.169
Fractional presence of fish cover from aquatic plants	**-0.359**	-0.155	0.028
Fractional presence of fish cover from brush	0.088	**0.384***	0.223
Fractional presence of fish cover from ledges	0.107	**0.372***	**0.314**
Fractional presence of fish cover from overhanging vegetation	0.018	0.046	**0.362***
Fractional presence of fish cover from snags	-0.012	0.233	**0.351**
Index of all fish cover-types	**-0.420***	-0.101	0.056
Index of all fish cover from large structures	0.106	0.257	**0.313**
Index of all natural fish cover-types	**-0.441****	-0.138	0.034

Table 12: (cont.)

	Lake Area	Max Depth	Littoral Depth
Shoreline Substrate			
16th-percentile of shoreline substrate diameter	**0.576****	0.178	0.016
25th-percentile of shoreline substrate diameter	**0.576****	0.141	-0.039
50th-percentile of shoreline substrate diameter	**0.523****	0.163	-0.011
75th-percentile of shoreline substrate diameter	**0.479****	0.161	-0.042
84th-percentile of shoreline substrate diameter	**0.407***	0.159	-0.013
Fractional cover of shoreline substrate as gravel	**0.334**	**0.279**	0.022
Fractional cover of shoreline substrate as vegetation/other	**-0.436****	**-0.322**	0.013
Fractional cover of shoreline substrate as sand	**0.451****	0.254	-0.089
Fractional cover of shoreline substrate as silt	**-0.517****	-0.163	0.090
Fractional cover of shoreline substrate as wood	-0.006	**0.421***	**0.343**
Fractional presence of shoreline substrate as gravel	0.254	**0.285**	0.209
Fractional presence of shoreline substrate as vegetation/other	**-0.308**	-0.256	-0.045
Fractional presence of shoreline substrate as sand	**0.401***	**0.309**	-0.012
Fractional presence of shoreline substrate as silt	**-0.468****	-0.069	**0.297**
Fractional presence of shoreline substrate as wood	0.037	**0.375***	0.224
Number of shoreline substrate types at each station	0.082	**0.285**	**0.291**
Log-transformed mean shoreline substrate diameter	**0.533****	0.181	-0.032
Riparian Vegetation			
Fractional riparian ground cover from bare ground	**0.328**	0.134	-0.078
Fractional riparian understory cover from non-woody vegetation	0.021	-0.020	**0.407***
Fractional riparian understory cover from woody vegetation	-0.063	0.204	**0.340**
Fractional presence of riparian understory cover from non-woody vegetation	0.020	0.150	**0.379***
Fractional presence of riparian understory cover from woody vegetation	-0.019	0.204	**0.290**
Index of tall, woody riparian vegetation	-0.051	0.187	**0.311**
Index of understory riparian vegetation	0.008	0.208	**0.359**
Riparian Disturbance			
Fractional presence of human influence from buildings	**0.298**	**0.325**	0.135
Fractional presence of human influence from docks	0.191	**0.460****	0.203
Fractional presence of human influence from walls	**0.315**	0.158	0.132
Fractional presence of human influence from lawns	0.041	**0.282**	0.111
Fractional presence of human influence from non-agricultural sources	0.004	**-0.284**	0.030
Weighted presence of human influence from buildings	0.271	**0.348**	0.211
Weighted presence of human influence from docks	0.241	**0.503****	**0.297**
Weighted presence of human influence from lawns	0.033	**0.294**	0.125
Weighted presence of human influence from roads	-0.076	**-0.300**	0.132
Index of human influence from non-agricultural sources	0.002	-0.074	**0.276**

Table 13: Correlation tables for nutrient concentrations.

	Total Nitrogen	Total Phosphorus	Ammonia
Water Chemistry			
Arsenic	**0.441****	**0.374***	0.184
Barium	0.110	**0.287**	0.064
Bromide	**0.329**	**0.311**	0.104
Carbonate	**0.628****	**0.334**	-0.030
Chloride	**0.417***	0.131	**0.285**
Dissolved Organic Carbon	**0.639****	0.239	0.063
Manganese	**0.428***	0.218	-0.013
Potassium	**0.547****	0.171	0.261
Silica	**0.461****	**0.429***	0.151
Turbidity	**0.621****	**0.658****	-0.256
Physical Characteristics			
Grassland with 500-meter buffer	**0.345**	0.208	-0.079
Fractional presence of flat banks	**-0.296**	**-0.320**	-0.172
Littoral Vegetation/Substrate and Fish Cover			
Fractional cover from emergent vegetation	-0.129	-0.142	**-0.361**
Fractional cover from submerged vegetation	**-0.289**	-0.231	-0.149
Fractional presence of emergent vegetation	-0.105	-0.182	**-0.337**
Fractional presence of submerged vegetation	-0.234	**-0.287**	-0.206
Index of all aquatic vegetation	-0.226	-0.251	**-0.289**
16^{th}-percentile of bottom substrate diameter	0.127	**0.299**	**0.284**
25^{th}-percentile of bottom substrate diameter	0.106	**0.317**	0.213
50^{th}-percentile of bottom substrate diameter	0.267	**0.429***	**0.337**
75^{th}-percentile of bottom substrate diameter	**0.290**	**0.390***	0.256
84^{th}-percentile of bottom substrate diameter	0.268	**0.338**	0.199
Fractional cover of bottom substrate from gravel	0.145	**0.379***	-0.027
Fractional cover of bottom substrate from sand	-0.000	0.148	**0.292**
Fractional cover of bottom substrate from silt	-0.103	-0.210	**-0.305**
Fractional presence of bottom substrate from gravel	0.281	0.309	**0.304**
Fractional presence of bottom substrate from sand	0.165	**0.286**	0.220
Log-transformed mean bottom substrate diameter	0.274	**0.412***	**0.299**
Fractional fish cover from aquatic plants	-0.220	-0.260	**-0.394**
Fractional fish cover from structures	**-0.292**	0.009	0.100
Fractional presence of fish cover from all sources	-0.158	-0.114	**-0.324**
Fractional presence of fish cover from aquatic plants	-0.104	-0.236	**-0.348**
Fractional presence of fish cover from overhanging vegetation	**-0.312**	-0.045	-0.142
Fractional presence of fish cover from structures	**-0.282**	-0.003	0.118
Index of fish cover from all sources	**-0.363***	**0.360**	**-0.468****
Index of fish cover from all natural sources	**-0.322**	**0.323**	**-0.467****

Table 13: (cont.)

	Total Nitrogen	Total Phosphorus	Ammonia
Shoreline Substrate			
16th-percentile of shoreline substrate diameter	0.199	**0.303**	0.190
25th-percentile of shoreline substrate diameter	0.213	**0.278**	0.187
50th-percentile of shoreline substrate diameter	0.235	**0.292**	0.116
Fractional cover of shoreline substrate from cobble	0.213	**0.285**	0.001
Fractional cover of shoreline substrate from wood	**-0.307**	-0.162	-0.095
Fractional presence of shoreline substrate from cobble	0.257	**0.323**	0.061
Fractional presence of shoreline substrate from vegetation/other	-0.027	-0.224	**-0.280**
Fractional presence of shoreline substrate from sand	0.126	0.155	**0.280**
Riparian Vegetation			
Fractional riparian canopy cover from big trees	**-0.348**	**-0.318**	-0.174
Fractional riparian canopy cover from small trees	**-0.305**	-0.154	-0.157
Fractional riparian understory cover from non-woody vegetation	**-0.324**	-0.150	-0.203
Fractional presence of canopy cover from big trees	**-0.350**	**0.319**	-0.174
Fractional presence of canopy cover from small trees	**-0.329**	-0.154	-0.134
Index of total riparian canopy cover	**-0.310**	-0.162	-0.157
Index of total riparian canopy and understory cover	**-0.297**	-0.120	-0.190
Index of total riparian understory cover	**-0.297**	-0.103	-0.173
Riparian Disturbance			
Fractional presence of nearshore human influence from any sources	0.195	**0.292**	0.156
Fractional presence of human influence from buildings	**-0.295**	-0.076	-0.077
Fractional presence of human influence from parks	**-0.506****	**-0.377**	-0.092
Fractional presence of human influence from docks	**-0.415***	-0.242	-0.082
Fractional presence of human influence from walls	**-0.286**	0.015	-0.067
Fractional presence of human influence from landfills	**-0.300**	-0.171	0.202
Fractional presence of human influence from pasture	**0.277**	**0.336**	0.103
Fractional presence of human influence from lawns	**-0.384**	-0.247	-0.124
Fractional presence of human influence from agriculture	0.254	**0.348**	0.198
Index of human influence from agriculture	0.228	**0.413***	**0.281**
Index of human influence from nearshore agriculture	0.149	0.259	**0.294**
Index of human influence from all nearshore sources	0.149	**0.310**	0.225
Weighted presence of human influence from agriculture	0.224	**0.416***	0.267
Weighted presence of human influence from all sources	-0.012	**0.301**	0.029
Weighted presence of human influence from docks	**-0.468****	-0.236	-0.052
Weighted presence of human influence from landfills	**-0.338**	-0.184	0.198
Weighted presence of human influence from lawns	**-0.368**	-0.235	-0.120
Weighted presence of human influence from parks	**-0.545****	**-0.403***	-0.150

Table 14: Correlation tables for biological metrics.

	Chlorophyll-α	**Macro-invertebrate MMI**	**Zooplankton MMI**
Water Chemistry			
Ammonia	-0.170	-0.281	**-0.329**
Ammonia (Dissolved)	-0.178	**-0.331**	**-0.304**
Anion Sum	0.109	-0.209	**-0.451***
Arsenic	**0.278**	**-0.304**	**0.293**
Bromide	0.095	**-0.330**	**-0.293**
Calcium	0.027	-0.186	**-0.578****
Carbonate	**0.339**	**-0.300**	-0.028
Chloride	0.244	-0.250	**-0.487****
Dissolved Solids (Total)	0.073	-0.252	**-0.430***
Hardness	0.041	-0.098	**-0.369***
Iron	0.138	-0.053	**-0.370***
Magnesium	0.069	-0.112	**-0.298**
Manganese	**0.472****	-0.133	**-0.302**
Nitrogen (Total)	**0.463****	**-0.436***	-0.157
Nitrogen (Total, Dissolved)	0.140	**-0.297**	**-0.280**
Phosphorus (Total)	0.230	**-0.460***	-0.220
Phosphorus (Total, Dissolved)	0.127	**-0.460***	**-0.481****
Potassium	0.113	**-0.425***	**-0.307**
Silica	**0.318**	0.019	-0.026
Sodium	**0.283**	-0.244	**-0.493****
Sulfate	0.084	-0.266	**-0.506****
Turbidity	**0.622****	-0.156	0.062
Littoral Vegetation/Substrate and Fish Cover			
Fractional cover from all littoral vegetation	**-0.317**	0.236	0.071
Fractional cover from floating vegetation	0.227	**0.300**	0.140
Fractional cover from submerged vegetation	**-0.278**	**0.322**	0.034
Fractional presence of all littoral vegetation-types	-0.083	**0.320**	0.121
Fractional presence of emergent vegetation	-0.149	**0.354**	**0.286**
Fractional presence of submerged vegetation	-0.185	**0.348**	0.184
Index of all aquatic vegetation	-0.266	**0.334**	0.148
16th-percentile of bottom substrate diameter	-0.127	**-0.334**	-0.166
50th-percentile of bottom substrate diameter	0.019	**-0.463****	**-0.354**
75th-percentile of bottom substrate diameter	0.098	**-0.370**	**-0.364***
Fractional cover of bottom substrate as cobble	0.090	**-0.312**	**-0.329**
Fractional cover of bottom substrate as organic	0.008	**0.428***	0.082
Fractional cover of bottom substrate as sand	-0.080	-0.280	**-0.311**
Fractional cover of bottom substrate as silt	0.091	**0.311**	**0.337**
Fractional presence of bottom substrate as cobble	0.082	**-0.297**	-0.225
Fractional presence of bottom substrate as gravel	0.052	**-0.456***	**-0.278**
Fractional presence of bottom substrate as sand	0.027	**-0.497****	-0.263
Fractional presence of bottom substrate as silt	-0.147	0.091	**0.332**
Log-transformed mean bottom substrate diameter	-0.004	**-0.397***	**-0.343**
Index of fish cover from all sources	**-0.305**	0.255	0.121

Table 14: (cont.)

	Chlorophyll-α	**Macro-invertebrate MMI**	**Zooplankton MMI**
Physical Characteristics			
Fractional presence of flat banks	-0.242	**0.408***	0.241
Average littoral depth	**0.350**	-0.034	0.109
Shoreline Substrate			
16th percentile of shoreline substrate diameter	0.226	**-0.420***	-0.193
25th percentile of shoreline substrate diameter	0.221	**-0.413***	-0.227
50th percentile of shoreline substrate diameter	0.268	**-0.364**	-0.235
75th percentile of shoreline substrate diameter	0.262	**-0.358**	**-0.289**
Fractional cover of shoreline substrate as cobble	**0.281**	-0.278	-0.276
Fractional cover of shoreline substrate as gravel	0.128	**-0.431***	-0.201
Fractional cover of shoreline substrate as organic	0.052	**0.300**	0.128
Fractional cover of shoreline substrate as vegetation/other	**-0.365***	0.200	0.156
Fractional cover of shoreline substrate as sand	0.040	-0.235	**-0.328**
Fractional presence of shoreline substrate as cobble	0.200	**-0.376**	-0.134
Fractional presence of shoreline substrate as gravel	0.089	**-0.516****	-0.133
Fractional presence of shoreline substrate as organic	0.121	**0.395***	0.160
Fractional presence of shoreline substrate as vegetation/other	-0.075	0.182	**0.319**
Fractional presence of shoreline substrate as sand	0.053	**-0.416***	-0.198
Log-transformed mean shoreline substrate diameter	0.263	**-0.367**	-0.260
Riparian Vegetation			
Fractional riparian canopy cover from big trees	-0.266	**0.291**	0.261
Fractional riparian canopy cover from small trees	**-0.295**	0.151	0.192
Fractional riparian ground cover from bare ground	-0.077	-0.001	**-0.361**
Fractional riparian ground cover from non-woody vegetation	-0.024	**-0.418***	-0.163
Fractional presence of riparian canopy cover from big trees	-0.266	**0.291**	0.259
Fractional presence of riparian canopy cover from small trees	**-0.296**	0.149	0.179
Fractional presence of riparian ground cover from bare ground	-0.056	-0.147	**-0.307**
Fractional presence of riparian ground cover from non-woody vegetation	-0.122	0.117	**0.347**
Index of riparian canopy cover	**-0.292**	0.149	0.191
Index of riparian herbaceous cover	-0.115	**-0.318**	-0.208
Riparian Disturbance			
Fractional presence of human influence from all nearshore sources	0.108	**-0.322**	-0.127
Fractional presence of human influence from pasture	**0.318**	-0.249	-0.022
Weighted presence of human influence from parks	-0.195	**0.293**	0.112

Comparison to 2007 survey

One advantage of these surveys is not only to provide State's with useful information on the present-state of their natural resources, but over time their ability to provide information regarding trends. Though trends cannot (and should not) be assessed between two points, useful information can still be observed between the first two surveys of the NLA. As subsequent surveys are completed, NDDoH will be able to derive trends regarding the health of its lakes that will aid in the management of its waters.

Using data from lakes sampled during both the 2007 and 2012 NLAs (n = 13), simple scatterplots revealed differences between the two surveys. Specific conductance was relatively similar between the two surveys; with the exception of two lakes with elevated concentrations during the 2007 survey having substantially lower measurements for the 2012 survey (Figure 21). Other than in one lake, turbidity was improved in re-visit lakes during the 2012 survey (Figure 21). Total nitrogen was lower in most re-visit lakes in 2012 compared to 2007, while total phosphorus was relatively similar between the two years (Figure 21). Levels of both sodium and sulfate were relatively similar between the two surveys at lower concentrations, but lakes with elevated concentrations during the 2007 survey showed much lower concentrations during the 2012 assessment.

The 2007 and 2012 NLA results were compared using cumulative distribution functions (CDFs) to determine the percent of lakes at or below a certain concentration. Based on chlorophyll-α concentration, no North Dakota lakes were considered oligotrophic in 2007 or 2012. For the 2007 survey, approximately 32% of North Dakota lakes were considered mesotrophic for chlorophyll-α (concentration > 0.9 µg L^{-1} and < 7.3 µg L^{-1}), whereas only about 16% of lakes for the 2012 survey were considered mesotrophic (Figure 22). There were, however, a smaller percentage of lakes considered hypereutrophic (concentration > 55 µg L^{-1}) for the 2012 survey (~ 8% of lakes) compared to the 2007 survey (~ 12%) (Figure 22).

Considered overwhelmingly poor for total nitrogen concentration during the 2007 survey (see NDDoH, 2018), North Dakota lakes had markedly lower TN concentrations during the 2012 survey. For the 2012 survey, the 50th percentile concentration (median) of TN was about 1.69 mg L^{-1}, compared to 2.69 mg L^{-1} for the 2007 survey (Figure 22). Further, the 75th percentile concentration of TN was about 2.48 mg L^{-1} for the 2012 survey, compared to 4.15 mg L^{-1} for the 2007 survey (Figure 22).

Similar to TN, TP concentrations measured during the 2012 NLA were improved over the 2007 survey. Despite these lower concentrations, North Dakota lakes were still relatively high in TP with only one lake considered mesotrophic (and none oligotrophic) for either survey. During the 2007 survey, only 31% of North Dakota lakes were considered mesotrophic or eutrophic based on TP, whereas over 62% of lakes were considered eutrophic during the 2012 survey (Figure 22). Consequently, greater than 69% of North Dakota lakes were considered hypereutrophic for TP in 2007, compared to only about 35% during the 2012 survey (Figure 22).

Though slightly lower than during the 2007 survey, measures of specific conductance in North Dakota lakes in were still relatively high. For example, the median concentration in 2012 was 887 µS cm^{-1}, compared to approximately 1,120 µS cm^{-1} during the 2007 survey (Figure 22). Also, the 75th percentile concentration was 2,190 µS cm^{-1} during the 2012 survey, whereas 75th percentile concentration was about 2,360 µS cm^{-1} during the 2007 survey (Figure 22).

While North Dakota lakes were considered relatively good for turbidity during the 2007 survey (see NDDoH, 2018), concentrations improved for the 2012 survey. For example, the median concentration for turbidity in 2012 was about 2.58 NTUs, compared to greater than 9 NTUs in 2007 (Figure 22). The 75th percentile concentration for turbidity was about 11 NTUs in 2012, compared to nearly 20 NTUs in 2007 (Figure 22).

For the 2007 and 2012 assessments, turbidity and chlorophyll-α were compared to determine which measure more accurately drives light transparency in North Dakota lakes. While regression coefficients were strongly significant when comparing chlorophyll-α to Secchi disk transparency for both 2007 ($R^2 = 0.47$) and 2012 ($R^2 = 0.60$), turbidity was a more accurate predictor of water clarity within North Dakota lakes ($R^2 = 0.76$ [2007]; $R^2 = 0.83$ [2012]). Turbidity was not measured for the eight intensification lakes, and so only the 44 target lakes for the 2012 NLA were analyzed for both turbidity and chlorophyll-α.

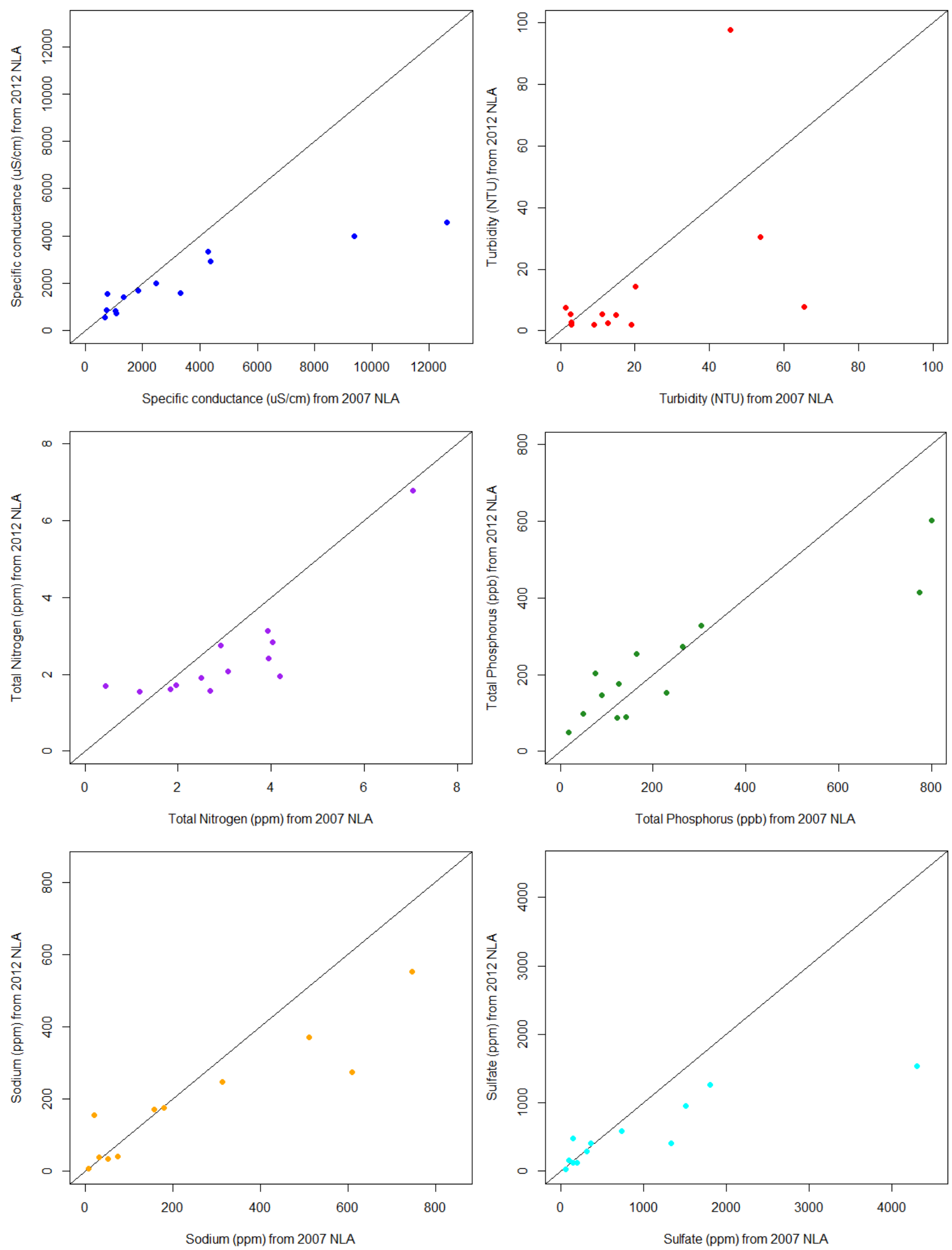

Figure 21: Comparison of 2007 and 2012 data from sites that were repeated during the 2012 assessment.

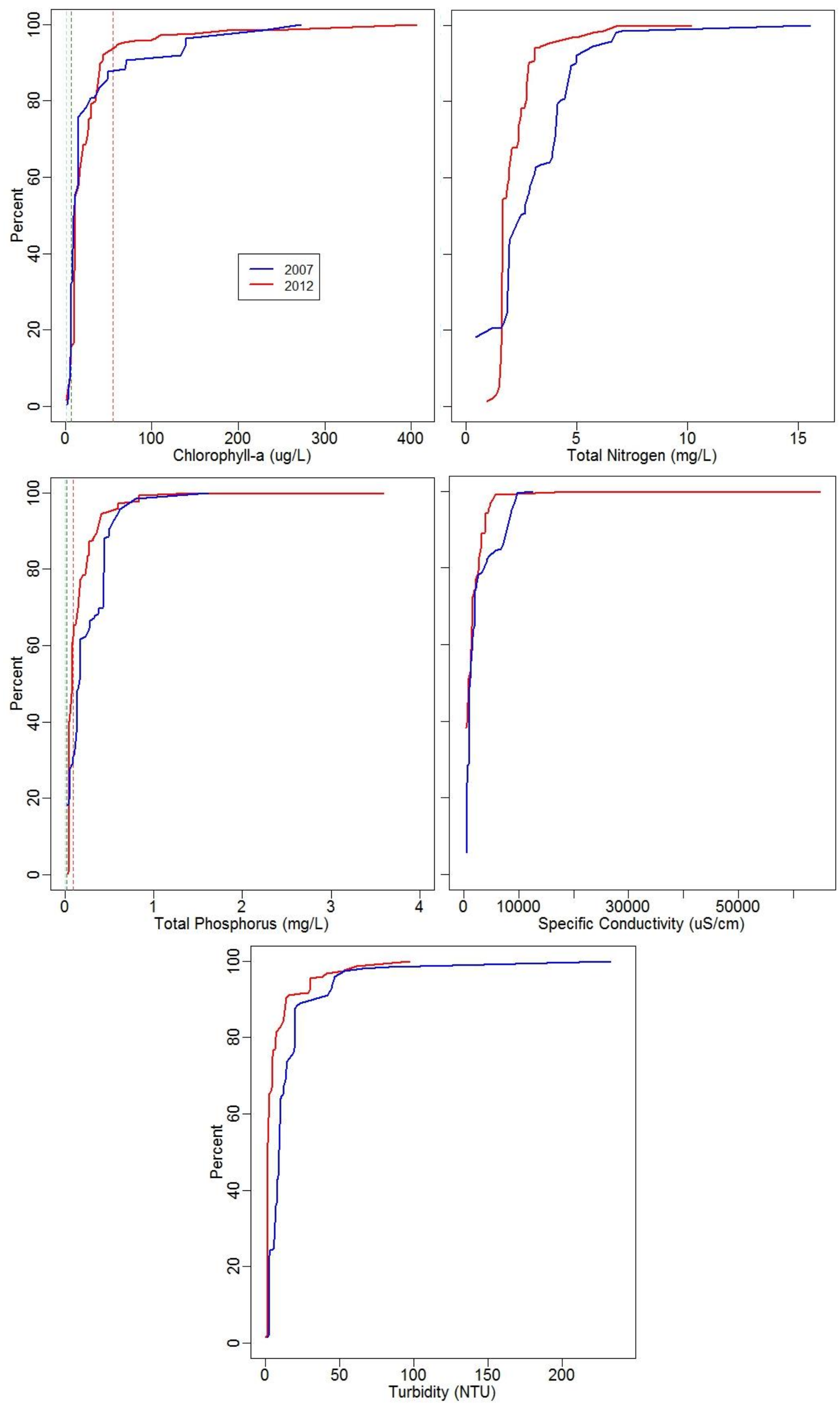

Figure 22: Cumulative distribution plots (CDFs) comparing 2007 and 2012 results using chlorophyll-α, total nitrogen, total phosphorus, specific conductance, and turbidity. Vertical dashed lines, when present, represent boundaries between oligotrophic, mesotrophic, eutrophic, and hypereutrophic classifications (from left to right).

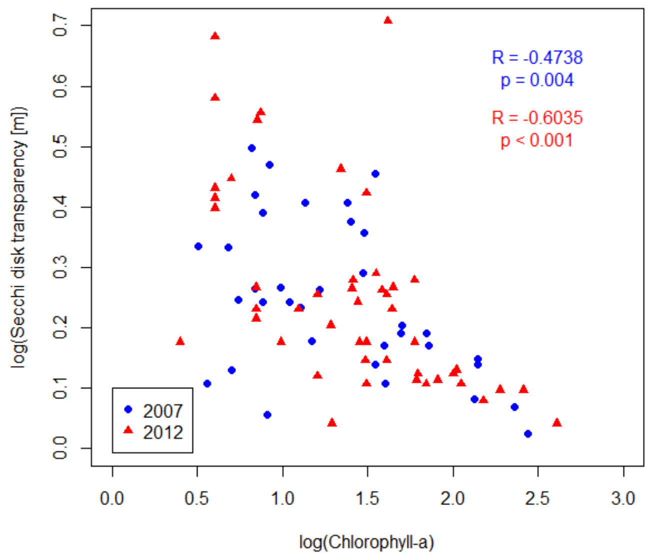

Figure 23: Comparing log-transformed relationship between chlorophyll-α concentration and Secchi disk transparency from the 2007 and 2012 assessments.

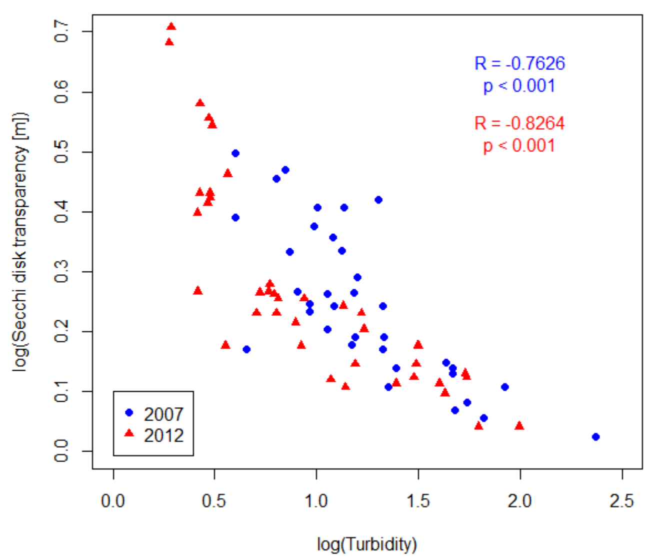

Figure 24: Comparing log-transformed relationship between turbidity concentration and Secchi disk transparency from the 2007 and 2012 assessments.

Summary and Discussion

In general, North Dakota's lakes are in relatively poor condition for nutrients, though the condition appears to be improved compared to the 2007 assessment. This finding is not surprising, however, with NDDoH monitoring indicating elevated nutrients throughout the State, with possible consequences including nuisance algal blooms, nuisance plant growth, and compromised biological communities. Despite increased nutrients noted throughout the State, plant and algal growth were in relatively good to fair condition, though many lakes experience cyanobacteria populations at densities considered to be at high risk. Cyanobacteria can grow quickly and can exhibit major ecological consequences to North Dakota's waters. Biological communities within North Dakota lakes, zooplankton and macroinvertebrates, were in relatively good condition throughout the State, with the former showing marked improvement over the previous survey. Continued participation in these surveys will help North Dakota determine trends in the condition of its lakes, with the goal of providing resource managers and policymakers with useful information regarding its natural resources.

Elevated nutrients in surface water can be directly related to eutrophication. Plants and algae require these nutrients for growth and reproduction, but at high levels these nutrients can cause the growth of these organisms at high densities. Littoral vegetation and algae growth at low and moderate levels can be beneficial to other biological communities (e.g., food, shelter). However, at high concentrations, however, nutrients can cause excessive plant and algal growth, which can lead to oxygen depletion or release of toxins when cyanobacteria (i.e., blue-green algae) are present. Within North Dakota lakes, nutrients (specifically N and P) were relatively high in 2012, particularly in the NPL, similar to findings from the 2007 NLA (NDDoH, 2018). These elevated nutrient levels are not isolated to North Dakota's NPL lakes, but instead are widespread throughout the ecoregion (EPA, 2016). High nutrients are common within the Prairie Pothole Region (PPR) and combined with their shallow average depth, many lakes in North Dakota can be susceptible to eutrophication. Lakes in the State were considered mostly fair for measures of chlorophyll-α and cyanobacteria, though the latter was substantially worse than the previous survey. Increased densities of cyanobacteria can lead to oxygen deprivation at lower depths and are associated with cyanotoxins (e.g., anatoxins, microcystins). Though mostly at low levels, microcystin was detected in approximately 60% of North Dakota lakes, and at higher levels, these toxins can cause significant harm to wildlife, livestock, and humans. These cyanobacteria blooms can be relatively short-lived and cyanotoxins can disappear from the system relatively fast. Therefore, sampling for these toxins at one location on one date does not necessarily give an accurate description of potential or previous blooms on a lake. For example, Upper Des Lacs Lake was found to have low levels of microcystin during the 2012 NLA assessment, but had large cyanobacteria blooms in 2014 and 2015.

Littoral vegetative cover remained in relatively good condition in 2012. Increased in-lake cover was directly correlated with increased zooplankton MMI score. Though increased submergent vegetation can be associated with increased eutrophication (EPA, 2016), a negative impact to lakes for the 2012 survey increased submerged vegetation was associated with improved zooplankton MMI. This relationship is likely due to a lack of tall riparian cover throughout the State, creating a need for in-lake cover to provide refuge for small invertebrates from predators and sunlight. Further, plant cover in shallow, littoral areas can provide refugia for small fish, amphibians, and macroinvertebrates, though data collected in North Dakota did not support the latter. Additionally, submerged vegetation can be an important food source for waterfowl, an important game resource in the State, particularly in the PPR.

Tree growth is rare in the NPL and TPL ecoregions, but when present, can provide significant benefits for near-shore biological communities. With that said, North Dakota lakes were in relatively good condition with regard to riparian vegetation, though this result was strongly driven by a small number of sampled lakes with a high sample weight. Wooded areas are more common in the TPL ecoregion (e.g., Turtle Mountains, Sheyenne National Forest), though there is a high amount of agricultural production within the region as well. North Dakota lakes with increased densities of riparian trees were associated with healthier zooplankton and benthic macroinvertebrate communities. Healthy, treed riparian buffers can provide a “filter” from increased nutrients, sediment, and other non-point source pollutants. The riparian disturbance indicator showed North Dakota lakes to be in relatively good condition, but was strongly driven by a small number of lakes with high sample weights. There were, conversely, a high number of lakes in poor condition for riparian disturbance, though these lakes carried smaller sample weights and, therefore, represented a smaller percentage of lakes throughout the State. With regard to riparian health, North Dakota lakes with increased woody and non-woody vegetation in the riparian zone were related to lower concentrations of carbonate, chloride, potassium, and specific conductance. Increased ions within the water column can have negative effects on biological communities. Similarly, sediment diatoms (collected and identified, but not analyzed for this survey) were strongly related to increased woody vegetation within the riparian zone (NDDoH, 2018), further noting the dependence of biological communities upon riparian health. The protection of lake riparian buffers should be noted for benefits they provide not only to aforementioned abiotic reasons (e.g., shade, nearshore habitat, nutrient and sediment reduction), but additionally for the subsequent benefit provided to near-shore (littoral) biological communities.

North Dakota lakes had a relatively high amount of cropland surrounding them, which can have adverse effects on water quality and in-lake biological communities. Increased agricultural production in the PPR is associated with a subsequent loss of wetlands (likely due to drainage) (Johnson, 2013), which can be attributed to elevated nutrient concentrations in the region. These lands are being converted to farmland (despite in some cases poor soils) driven by increased commodity prices, farm subsidies, the production of genetically-modified organisms (GMOs) (e.g., crops), and increased ethanol production in the State (Johnson et al., 2008). Also, this survey found an increasing amount of nutrients in lakes with greater amounts of farmland within the riparian buffers, a finding consistent with findings elsewhere throughout the country. Thus, wetland loss and continual conversion of land to cropland can lead to increased nutrients being deposited in these lakes, with the potential consequence of increased eutrophication. Riparian areas of North Dakota lakes were co-dominated by grasslands, which are commonly used as nesting grounds for upland birds and waterfowl, as well as habitat for hundreds of game and non-game species.

North Dakota lakes are an important resource to the State. In addition to providing recreation (e.g., fishing, boating, swimming), lakes provide refuge and breeding habitat for fish, waterfowl, amphibians, and semi-aquatic mammals. Protection of these waterbodies, especially those not designated as "fisheries", is an important step to providing key habitat for the production of multiple game and non-game species. Surveys such as these will continue to bridge data gaps in North Dakota, and continue to provide useful, unbiased scientific information to scientists, policymakers, and citizens on the condition of our waters.

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APPENDIX A

SAMPLED LAKE INFORMATION

Table A.1: List of lakes sampled in North Dakota as part of the National Lakes Assessment in 2012 (Intensification sites in 2013).

Code	Lake Name[1]	County	Eco	Category	Latitude	Longitude	Sampled by
NLA12_ND-101	Grass Lake[2]	Richland	TPL	NLA07RVT[3]	46.09723	-97.2372	NDDoH
NLA12_ND-102	Cavanaugh Lake	Ramsey	TPL	NLA07RVT	48.24815	-98.8982	NDDoH
NLA12_ND-103		Kidder	NPL	NLA07RVT	47.07428	-99.6307	USGS
NLA12_ND-104	Cottonwood Lake	McLean	NPL	NLA07RVT	47.61489	-100.827	NDDoH
NLA12_ND-105	Devils Lake	Ramsey	TPL	NLA07RVT	48.25678	-98.8915	SLTN
NLA12_ND-106	Buffalo Lodge Lake	McHenry	TPL	NLA07RVT	48.32705	-100.757	NDDoH
NLA12_ND-107	Camp Lake	McIntosh	NPL	NLA07RVT	45.95348	-99.1358	NDDoH
NLA12_ND-108	Doyles Lake	Logan	NPL	NLA07RVT	46.3667	-99.5035	NDDoH
NLA12_ND-109	Reule Lake	Stutsman	NPL	NLA07RVT	46.89273	-99.4165	USGS
NLA12_ND-110	Douglas Lake	Ward	NPL	NLA07RVT	47.86474	-101.513	NDDoH
NLA12_ND-112	Alkaline Lake	Kidder	NPL	NLA07RVT	46.64003	-99.5872	NDDoH
NLA12_ND-113		Rolette	NPL	NLA07RVT	48.89570	-99.7128	TMBCI
NLA12_ND-114	Lake Etta	Kidder	NPL	NLA07RVT	46.83158	-99.7647	USGS
NLA12_ND-115	McDowell Dam[2]	Burleigh	NPL	NLA12NEW[4]	46.82604	-100.634	NDDoH
NLA12_ND-118		Logan	NPL	NLA12NEW	46.36786	-99.3985	NDDoH
NLA12_ND-119		Sheridan	TPL	NLA12NEW	47.73684	-100.439	NDDoH
NLA12_ND-126		Divide	NPL	NLA12NEW	48.74898	-102.943	NDDoH
NLA12_ND-129	Long Lake	Burleigh	NPL	NLA12NEW	46.71384	-100.153	USGS
NLA12_ND-131	Lake Tschida	Grant	NPL	NLA12NEW	46.61482	-101.895	NDDoH
NLA12_ND-134	Walz WPA Lake	McIntosh	NPL	NLA12NEW	46.02279	-99.292	NDDoH
NLA12_ND-139		Ward	NPL	NLA12NEW	47.9042	-101.06	NDDoH
NLA12_ND-145		Kidder	NPL	NLA12NEW	47.08001	-99.7306	USGS
NLA12_ND-146		Bottineau	TPL	NLA12NEW	48.91493	-100.433	NDDoH
NLA12_ND-149		Stutsman	NPL	NLA12NEW	47.06803	-99.0799	USGS
NLA12_ND-151		Burleigh	NPL	NLA12NEW	47.27492	-100.398	NDDoH
NLA12_ND-155		Mountrail	NPL	NLA12NEW	48.35144	-102.141	NDDoH
NLA12_ND-156		Stutsman	NPL	NLA12NEW	47.17037	-99.248	NDDoH
NLA12_ND-160	Neustel Lake	Kidder	NPL	NLA12NEW	47.17341	-99.7711	USGS
NLA12_ND-162	Wright Lake	Rolette	TPL	NLA12NEW	48.55086	-99.9253	NDDoH
NLA12_ND-163		Golden Valley	NPL	NLA12NEW	46.54392	-104.028	NDDoH
NLA12_ND-164		Stutsman	NPL	NLA12NEW	47.1384	-99.1325	USGS
NLA12_ND-167	Fisher Lake	McLean	NPL	NLA12NEW	47.39867	-100.811	NDDoH
NLA12_ND-172	Meander Lake	Stutsman	NPL	NLA12NEW	47.20189	-99.3524	NDDoH
NLA12_ND-173	Dewald Lake	Logan	NPL	NLA12NEW	46.40003	-99.2822	NDDoH
NLA12_ND-178	Gravel Lake	Rolette	TPL	NLA12NEW	48.95477	-99.8332	NDDoH
NLA12_ND-186	Shirley Lake	Williams	NPL	NLA12NEW	48.57418	-103.665	NDDoH
NLA12_ND-187	Rice Lake	Ward	NPL	NLA12NEW	48.00697	-101.532	NDDoH
NLA12_ND-190		Towner	TPL	NLA12NEW	48.54729	-99.1852	USGS
NLA12_ND-193	Fischer Lake	Stutsman	NPL	NLA12NEW	47.08352	-99.2273	USGS
NLA12_ND-194	Upper Des Lacs Lake	Ward	TPL	NLA12NEW	48.7202	-102.115	NDDoH
NLA12_ND-196	Long Alkaline Lake	Kidder	NPL	NLA12NEW	47.24137	-99.8373	NDDoH
NLA12_ND-198		Rolette	TPL	NLA12NEW	48.87734	-99.9795	USGS
NLA12_ND-199		McHenry	TPL	NLA12NEW	47.8483	-100.278	NDDoH
NLA12_ND-202	Jensen Lake	Divide	NPL	NLA12NEW	48.66521	-103.063	USGS
NLA12_ND-207		McLean	NPL	ND12INT[5]	47.71308	-100.7378	NDDoH
NLA12_ND-210	School Section Lake	Burke	NPL	ND12INT	48.59744	-102.4409	NDDoH
NLA12_ND-225	Werner’s Lake	Stutsman	TPL	ND12INT	47.14906	-98.6058	NDDoH
NLA12_ND-226	George WPA Lake	McIntosh	NPL	ND12INT	46.2130	-99.3303	NDDoH
NLA12_ND-232	Siebold Lake	Sheridan	NPL	ND12INT	47.70004	-100.5707	NDDoH
NLA12_ND-237		Ramsey	TPL	ND12INT	48.14360	-98.8204	NDDoH
NLA12_ND-242		Logan	NPL	ND12INT	46.31079	-99.4444	NDDoH
NLA12_ND-266		Logan	NPL	ND12INT	46.57259	-99.2846	NDDoH

[1]Not all lakes have names. If no name exists, field left blank.
[2]Sites were visited twice during 2012 sampling
[3]Revisit site from the 2007 assessment
[4]New site for the 2012 assessment
[5]Sampled as part of North Dakota’s intensification