The Condition of North Dakota's Lakes: An Evaluation Using Data from the 2007 National Lakes Assessment

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, Tanner O'Clair, and Kenny McDonnell who sampled lakes for the 2007 National Lakes Assessment. Also, thanks to Aaron Larsen who gave valuable feedback on previous versions of this manuscript. 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.

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1.0 Introduction

The National Lakes Assessment (NLA) is used by the Environmental Protection Agency (EPA) to evaluate the condition of the Nation's lakes through a comprehensive, statistically-robust sample design. This survey is a collaborative effort with the EPA, state governments, tribes, and other private partners. The NLA is part of the National Aquatic Resource Surveys (NARS), which are used to evaluate the health of the Nation's waters through a series of unbiased, comprehensive sampling designs. Other surveys involved in NARS are the National Rivers and Streams Assessment, National Wetlands Condition Assessment, and National Coastal Condition Assessment. These surveys are conducted in five-year intervals, with the first NLA conducted in 2007 (described here) followed by subsequent NLAs in 2012 and 2017. In North Dakota, primary sampling for these surveys is performed by the North Dakota Department of Health (NDDoH). Data from these NARS surveys then provide useful and unbiased information to scientists, policymakers, and citizens on the condition of waters in their region and State.

For the 2007 NLA, lakes were sampled from June through September 2007. To be included in the selection process, a site 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 USEPA, 2009). The EPA used the National Hydrography Dataset (NHD) as a basis for lake identification and site selection. 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 USEPA, 2009), with over 3,800 lakes in North Dakota.

Prior to 2007, a statistically-valid, random sampling design survey of the State's lakes has never been conducted in North Dakota. The State has annual sampling programs on Devils Lake (still in operation) and Lake Sakakawea (in cooperation with the US Corps of Engineers and the North Dakota Game and Fish), as well as a statewide Lake Water Quality Assessment (LWQA) program focusing on under-sampled lakes. This NLA survey provides useful information as to the physical, biological, and chemical properties of the State's lakes.

2.0 Methods

Thirty-eight (38) lakes were selected for sampling during the 2007 NLA. These lakes were assessed for biological, chemical, physical, and recreational condition in accordance with EPA procedures (from USEPA, 2007). These lakes represented 3,749 lakes in North Dakota, with 1,845 lakes in the Northern Plains Ecoregion (NPL) and 1,904 lakes in the Temperate Plains (TPL). Portions of the NPL and TPL encompass an area known as the "Prairie Pothole Region" (PPR), an area known for relatively shallow, productive water-filled depressions referred to as potholes. Most lakes sampled were between 10 and 100 hectares in size (68.42% of lakes) (Table 2), with the majority of lakes sampled having a maximum depth less than or equal to 3 meters (about 10 feet) (60.53%).

Following lake-selection, North Dakota lakes were field-checked to ensure accessibility for watercraft and that the lakes met EPA's criteria. Confirmation of lake location was made using latitude and longitude, and was visually assessed using satellite imagery. 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 and field-checked to ensure suitability for inclusion in the study. Of the final 38 lakes, 27 were in the NPL, with the remaining 11 in the TPL (Figure 1).

All lakes were sampled one time during the sampling period (June through September), with the exception of unnamed lakes in Kidder, McHenry, Sheridan, and Stutsman Counties (one each) and Doyles Lake (Logan County) and Camp Lake (McIntosh County), which were re-visited for QA/QC purposes. Resample data, however, are not presented in this report. A chemical profile, measuring dissolved oxygen (DO), temperature (in ºC), pH, and specific conductance at 1- or 0.5-meter intervals (depending on depth), was taken for every site at the deepest point (termed the Index site) of the lake using a YSI multi-probe sonde. Water chemistry was collected at the Index site using a 0-2 meter integrated tube sampler. The water chemistry sample was transferred to a 1-gallon cubitainer, stored on ice, then shipped that evening to the EPA-contract laboratory. A sediment core was taken for sediment diatom identification and enumeration and mercury concentration. For sediment diatom analyses, top and bottom sections were taken from each core to compare past and present condition. Zooplankton tows were performed at the Index site (typically the deepest point), with total tow-length needing to equal at least 3 meters with tows beginning at 0.5 meters above sediment surface. In lakes less than 3 meters deep, multiple tows were used to achieve a 3 meter tow. Two zooplankton nets were used, one fine-mesh (80 µm) and one coarse (243 µm). At ten pre-selected stations around the lake, physical habitat assessments were taken by visually analyzing canopy, understory, and ground cover. Additionally, macrophyte sampling occurred at a minimum of half (n = 5) of the perimeter stations to determine overall littoral cover. Macrophyte density and type were assessed using a modified rake to drag along the substrate, collecting any plant material. Plants were sampled near-shore at 0.5 and 1 meter of depth, and then continued toward the middle of the lake until no aquatic plants were detected. A full description of field procedures is provided in USEPA (2007).

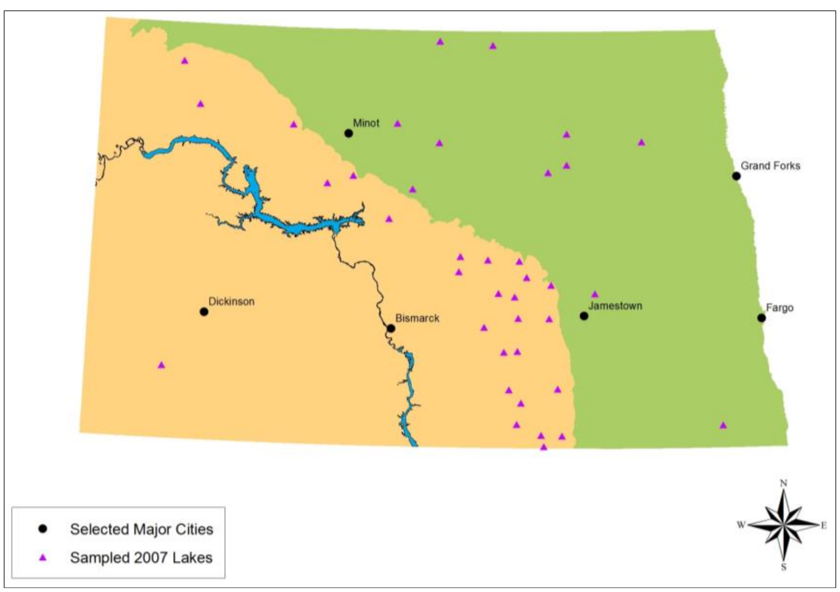

Figure 1: Map showing the location of lakes sampled throughout North Dakota for the 2007 National Lakes Assessment.

Table 1: Overview of parameters measured for the 2007 NLA (adapted from USEPA, 2009).

Biological	Recreational	Chemical	Physical
Sediment diatoms	Algal toxin (microcystins)	Nutrients (N & P)	Lakeshore habitat cover and structure
Phytoplankton	Algal cell counts (cyanobacteria)	Water column profile	Shallow water habitat cover and structure
Macrophytes	Algal density (chlorophyll-α)	Sediment mercury	Lakeshore human disturbance

Zooplankton were identified by EcoAnalysts for the survey (www.ecoanalysts.com). Observed-to-expected (O/E) values were calculated for each lake, and classified as either “good” (>25th percentile), “fair” (5th-25th percentile), or “poor” (< 5th percentile). Expected values were calculated from reference lakes located throughout the United States, with different groups created based on taxa similarity (not by region) for comparison with observed taxa (USEPA, 2010). For information on the analysis of zooplankton data for the National survey and the O/E metric, see USEPA (2010).

Sediment diatoms were identified by Michigan State University, Philadelphia Academy of Sciences, and Colorado State University for the 2007 survey. Top and bottom sections of sediment cores were used to determine an Index of Biotic Integrity (IBI) for sediment diatoms. Bottom sections were used to assess pre-settlement conditions and were used as an undisturbed control which was compared to the top section. Fossilized diatoms from bottom sections were used to “reconstruct” pre-settlement water quality in lakes. Final structural and tolerance metrics used in the IBI were: proportion impacted species, proportion reference species, Shannon diversity (H’), richness, proportion colonial indivuals, proportion of low total phosphorus taxa, proportion of high total phosphorus taxa, proportion of low total nitrogen taxa, proportion of high total nitrogen taxa (from USEPA, 2010). Genus/growth form metrics used in the IBI were: proportion *Achnanthidium* individuals, proportion *Cocconeis* individuals, proportion *Cyclotella* and *Stephanodiscus* individuals, and proportion of epiphytic taxa (from USEPA, 2010). Further information on the sediment diatom IBI and its application are available in USEPA (2010).

Using data from the NLA, the EPA developed thresholds for lakes to be considered in good, fair, and poor condition based on multiple metrics. Weights were applied to each lake sampled to describe how many other, non-sampled lakes were similar (based on location and size) and for which these data could be extrapolated. With the EPA-determined weights and thresholds, extent estimates could then be determined state-by-state, if desirable. Extent estimates were calculated for this report using methods developed by 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 stressor indicators, including total nitrogen (TN), total phosphorus (TP), salinity, turbidity, riparian disturbance, riparian vegetation, littoral cover, dissolved oxygen (DO); and biological indicators, including planktonic O/E, sediment diatom index of biotic integrity (IBI), chlorophyll-α; and recreational indicators including microcystin and cyanobacteria. For comparison, data were parsed for both the NPL and TPL 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 of the State’s lake-health to regionally-similar lakes (Figure 2). All data analyses were performed using R software (2013) and all maps were created using ArcGIS 10.2.

Table 2: Percent and count of lakes sampled by size class in North Dakota.

Size Class	Percent of Sample Population
1: < 10 hectares	5.26% (2 lakes)
2: > 10-50 hectares	44.74% (17)
3: > 50-100 hectares	23.68% (9)
4: > 100-500 hectares	18.42% (7)
5: > 500-5000 hectares	5.26% (2)
6: > 5000 hectares	2.63% (1)

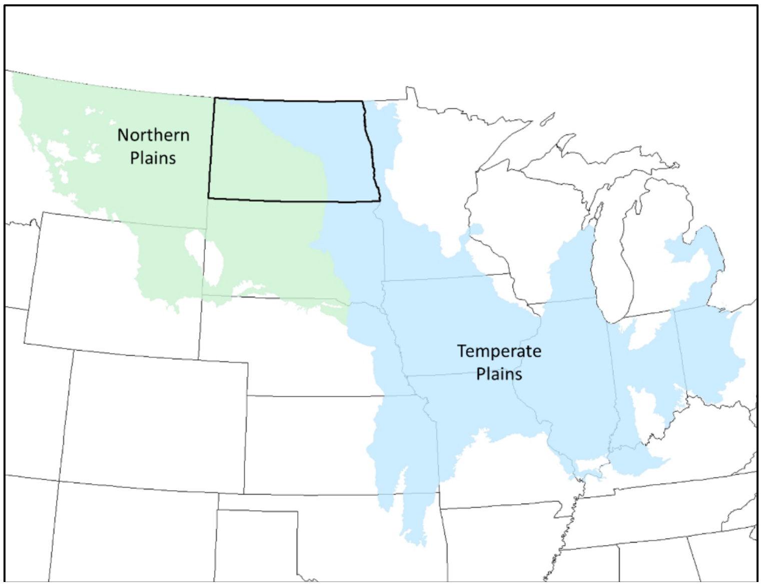

Figure 2: Ecoregion map showing extent of Temperate Plains and Northern Plains throughout the Upper Midwest.

3.0 Results

Nutrients, Turbidity, and Salinity

The majority of North Dakota lakes were fair or poor based on concentrations of TN and TP. Greater than 70% of lakes were poor for TN (2,642 lakes) (Figure 3), with the majority of these in the NPL (> 98% of NPL lakes [1,825 lakes]) (Figure 4). Lakes in the TPL were in better condition, with 43% of lakes assessed as poor (816 lakes) (Figure 4). Thirty-seven percent (37%) of North Dakota lakes (1,413 lakes) were poor for TP, with 33% (1,249 lakes) and 29% (1,087 lakes) as good and fair, respectively (Figure 3). High concentrations of TP were found in the NPL with greater than 70% of lakes considered poor (1,314 lakes) (Figure 4).

Greater than 80% of North Dakota lakes were in good condition for turbidity (3,011 lakes), and only 9% (321 lakes) and 11% (417 lakes) considered fair and poor, respectively (Figure 3). Lakes in the TPL were better for turbidity with 100% of lakes considered good (1,903 lakes), compared to 60% in the NPL (1,107 lakes) (Figure 4).

North Dakota lakes were mostly in fair or poor condition based on salinity with over 70% of lakes in those classes (2,397 lakes) (Figure 3). Fifty-six percent (56%) of lakes in the TPL were in good condition for salinity (1,076 lakes), while no lakes were in good condition in the NPL (Figure 4). Most NPL lakes were fair based on salinity (64%; 1,179 lakes) (Figure 4).

When compared to lakes throughout the entire NPL, excluding North Dakota, North Dakota NPL lakes were more impaired based on chemical conditions than lakes from elsewhere throughout the ecoregion. Nearly 99% of lakes in North Dakota's NPL were poor based on TN, while 76% of all other lakes in the NPL were in poor condition (Table 3). TP condition was similar between North Dakota's NPL lakes and the rest of the Ecoregion, with 71% and 73% classified as poor, respectively (Table 3). Approximately 60% of North Dakota lakes in the NPL were in good condition for turbidity, while 84% of lakes throughout the rest of the ecoregion were classified as good (Table 3). No lakes in North Dakota's NPL were classified as good for salinity, compared to 45% throughout the rest of the NPL (Table 3).

While North Dakota lakes in the TPL were relatively healthy based on chemical condition compared to the rest of the region, the sample size for these lakes is relatively low (n = 11) and conclusions based on these data should be used cautiously. Based on TN, North Dakota lakes were better than the rest of the Ecoregion with 40% of lakes in good condition compared to 21% for the rest of the ecoregion (Table 3). North Dakota lakes were relatively healthy based on measures of TP with 47% of lakes classified as good and only 5% as poor, compared to 34% and 41%, respectively, for the rest of the ecoregion (Table 3). Likely a result of low sample size, 100% of lakes are in good condition for turbidity in North Dakota's portion of the TPL, compared to 78% throughout the rest of the ecoregion (Table 3). For salinity, however, over 34% of North Dakota lakes were in poor condition compared to only 3% for the rest of the TPL.

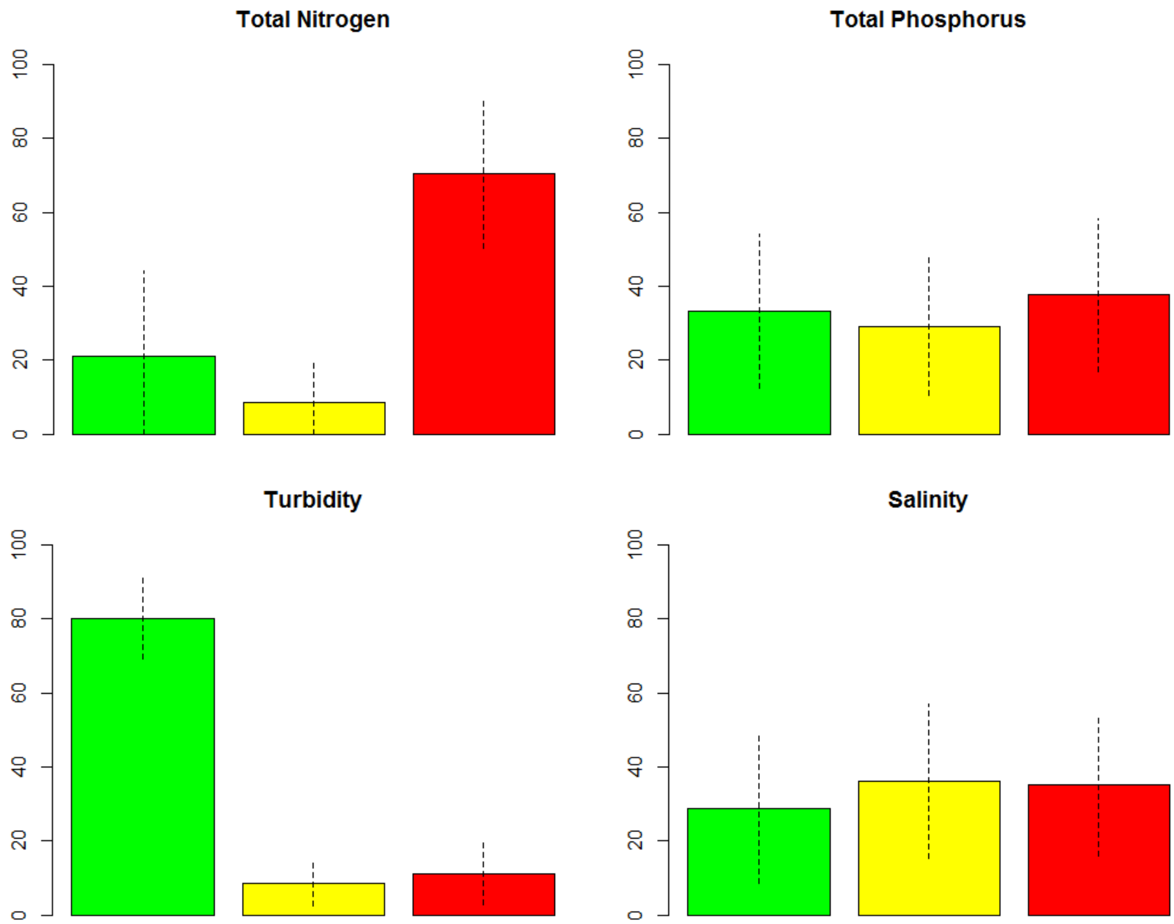

Figure 3: Chemical extent estimates for the State of North Dakota from the 2007 National Lakes Assessment (Green = "Good"; Yellow = "Fair"; Red = "Poor"). Error bars on these graphs display the upper and lower 95% confidence intervals.

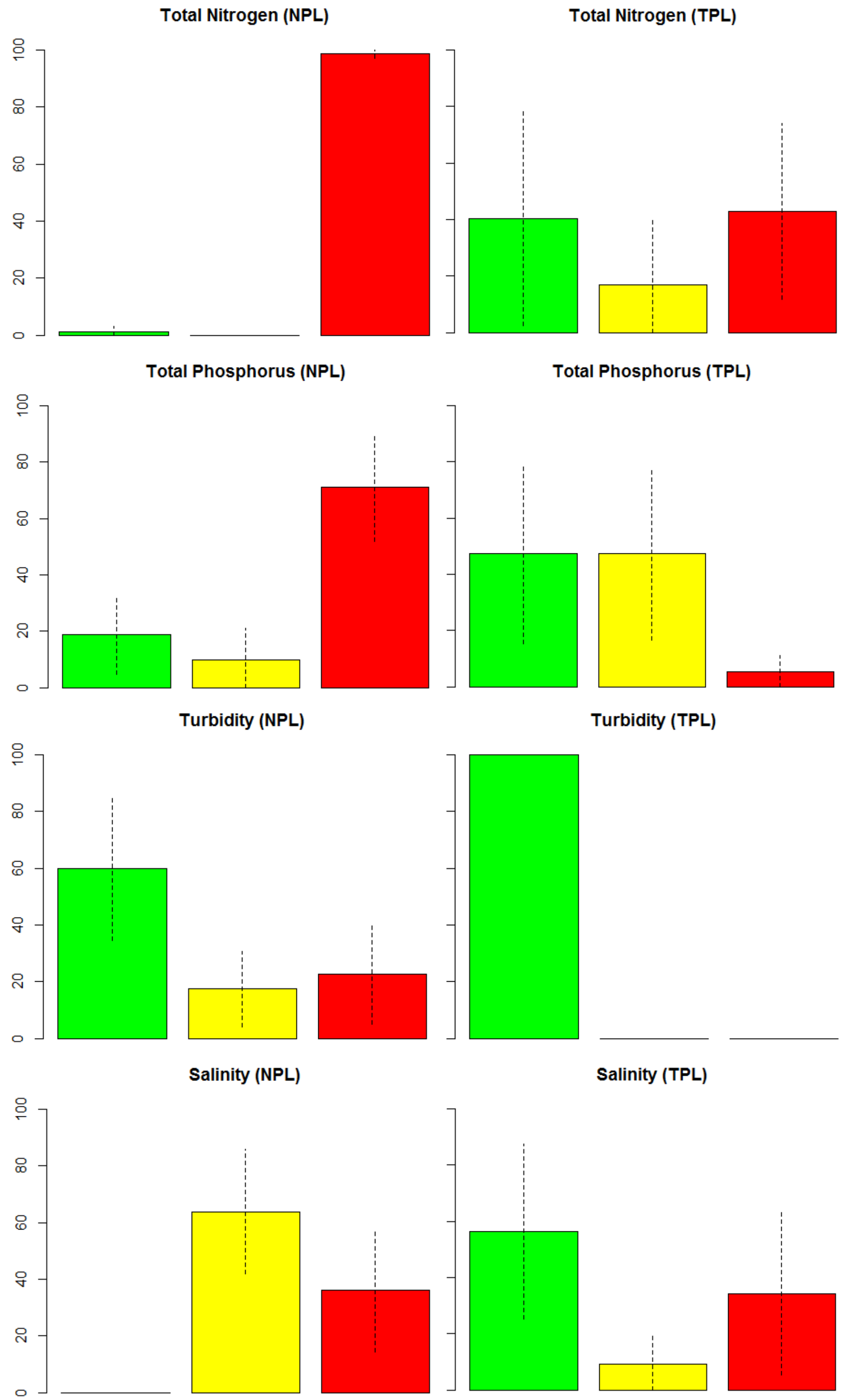

Figure 4: Comparison of chemical condition for the NPL (n = 27) and TPL (n = 11). Error bars on these graphs display the upper and lower 95% confidence intervals.

Table 3: Comparison of chemical condition classes for North Dakota lakes to all other lakes in represented ecoregions (i.e., Northern and Temperate Plains). Percentages may not add-up to 100% due to the exclusion of sites that either had "No data" or "Not assessed" designations for this table.

Condition Class	ND Lakes in NPL	All Other Lakes in NPL	ND Lakes in TPL	All Other Lakes in TPL
Total Nitrogen				
Good	1.08%	23.93%	40.30%	20.88%
Fair	0.00%	0.00%	16.82%	40.78%
Poor	98.92%	76.07%	42.89%	38.34%
Total Phosphorus				
Good	18.83%	26.64%	47.36%	34.01%
Fair	9.94%	0.00%	47.47%	25.09%
Poor	71.22%	73.36%	5.17%	40.90%
Turbidity				
Good	59.98%	83.53%	100.00%	77.51%
Fair	17.41%	7.45%	0.00%	14.57%
Poor	22.61%	9.01%	0.00%	7.93%
Salinity				
Good	0.00%	44.63%	56.52%	74.47%
Fair	63.87%	24.45%	9.12%	22.23%
Poor	36.13%	30.92%	34.36%	3.30%

Physical Habitat Condition

Lake physical habitat based on the riparian disturbance indicator in North Dakota is in poor condition, with 40% (1,501 lakes) and 25% (946 lakes) of lakes classified as fair and poor, respectively (Figure 5). This is driven by impacts in the NPL portion of North Dakota with 100% (1,846 lakes) of lakes in fair or poor condition (Figure 6). Riparian vegetation condition follows a similar pattern with over 69% of North Dakota lakes in poor condition (2,604 lakes) (Figure 5), influenced by scores from the NPL (87% of lakes as poor [1,606 lakes]) (Figure 6). Conversely, 61% of lakes (2,273 lakes) are in good condition for littoral cover (Figure 5), with 55% (1,023 lakes) and 66% (1,249 lakes) considered good for the NPL and TPL, respectively (Figure 6).

In general, riparian disturbance is high throughout the NPL, a pattern mirrored by North Dakota lakes. All North Dakota lakes in the NPL were classified as fair or poor based on riparian disturbance, compared to 99% of lakes throughout the rest of the ecoregion (Table 4). Riparian vegetation was in poor condition with no lakes in North Dakota classified in good condition, compared to 21% of lakes throughout the rest of the NPL which were classified as good (Table 4). Despite low scores based on riparian vegetation, North Dakota's NPL lakes scored well for littoral cover. Greater than 55% of North Dakota NPL lakes were in good condition for littoral cover, while only 27% of lakes throughout the rest of the ecoregion were in good condition (Table 4).

When compared to other lakes in the TPL, North Dakota lakes were generally similar or slightly better with regard to physical habitat. Greater than 68% of lakes in North Dakota's TPL were in good condition for riparian disturbance, compared to only 26% throughout the rest of the ecoregion (Table 4). Conversely, 47% of North Dakota's TPL lakes were in good condition for riparian vegetation compared to 60% throughout the rest of the ecoregion (Table 4). Sixy-six percent (66%) North Dakota's TPL lakes were in good condition with regard to littoral cover, compared to 60% throughout the rest of the ecoregion (Table 4).

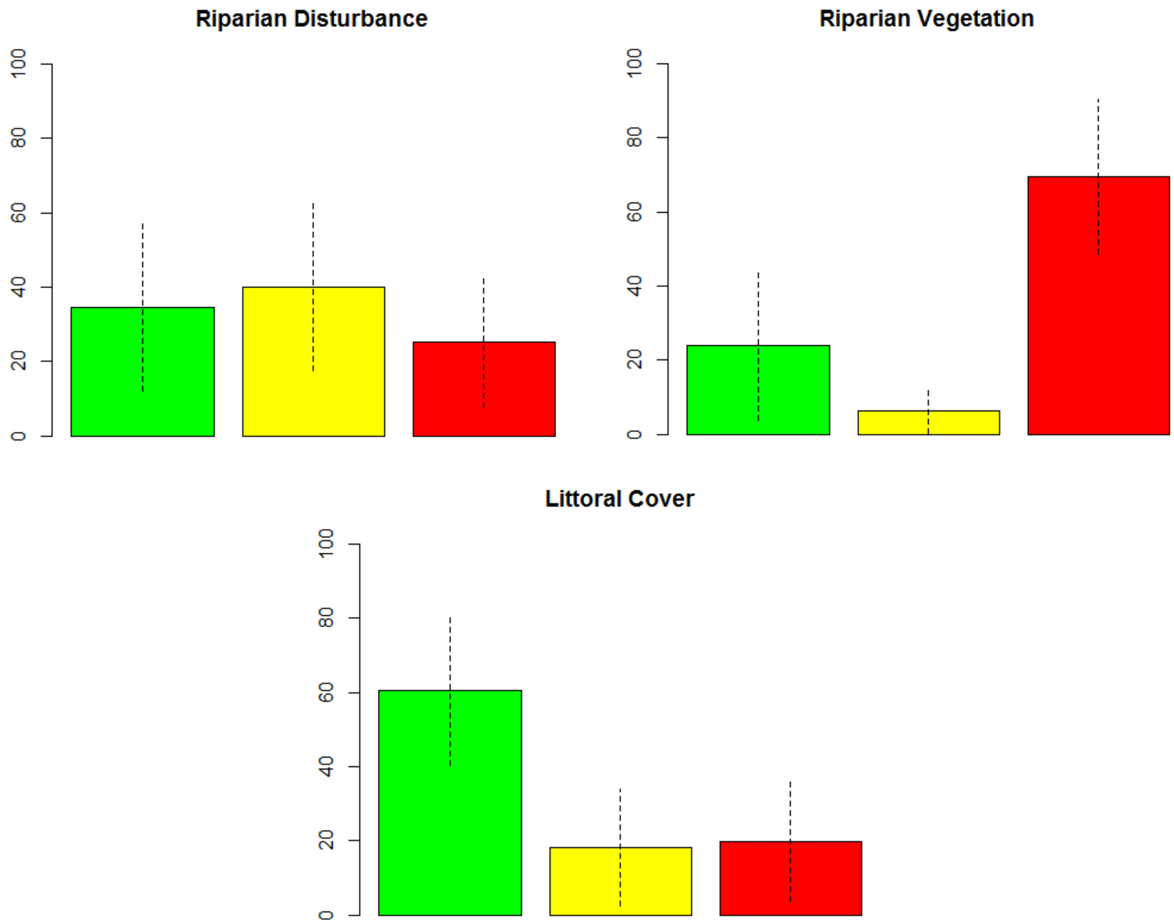

Figure 5: Physical habitat condition estimates for the State of North Dakota from the 2007 National Lakes Assessment. Error bars on these graphs display the upper and lower 95% confidence intervals.

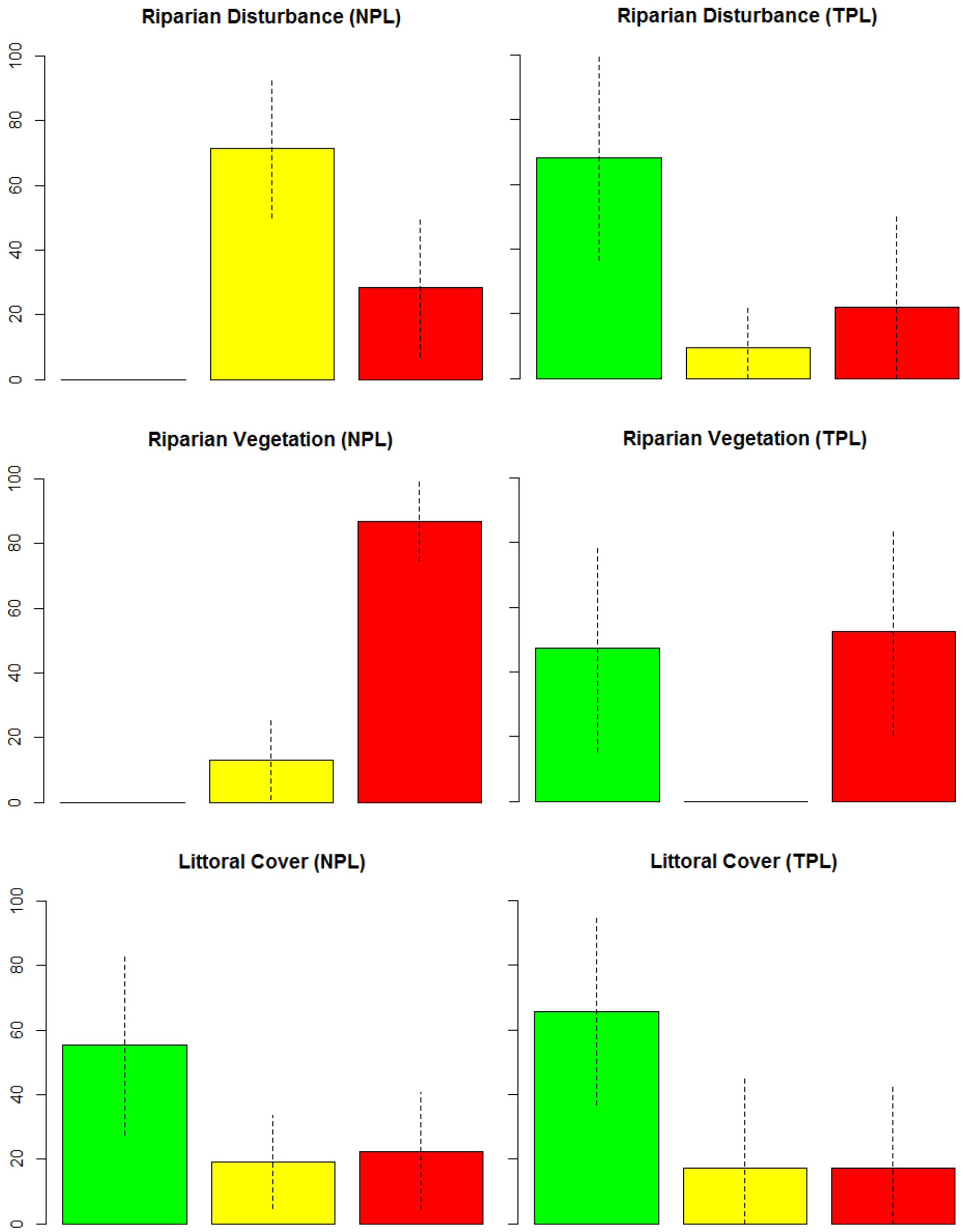

Figure 6: Comparison of riparian and littoral cover extent estimates for the NPL (*n* = 27) and TPL (*n* = 11). Error bars on these graphs display the upper and lower 95% confidence intervals.

Table 4: Comparison of physical habitat condition classes for North Dakota lakes to all other lakes in represented ecoregions (i.e., NPL and TPL). Percentages may not add-up to 100% due to the exclusion of sites that either had "No data" or "Not assessed" designations for this table.

Condition Class	**ND Lakes in NPL**	**All Other Lakes in NPL**	**ND Lakes in TPL**	**All Other Lakes in TPL**
Riparian Disturbance				
Good	0.00%	0.81%	68.22%	25.97%
Fair	71.46%	52.75%	9.54%	55.75%
Poor	28.54%	45.76%	22.02%	16.52%
Riparian Vegetation				
Good	0.00%	21.25%	47.36%	59.79%
Fair	12.98%	2.45%	0.00%	3.84%
Poor	87.02%	74.43%	52.43%	34.60%
Littoral Cover				
Good	55.43%	26.72%	65.64%	60.26%
Fair	19.15%	20.46%	17.07%	15.52%
Poor	22.50%	50.37%	17.07%	22.45%

Dissolved Oxygen Condition

The EPA classified lakes as either good (> 3 mg/L), fair (1-3 mg/L), or poor (< 1 mg/L) for dissolved oxygen (DO) levels in the top two meters of depth. In general, assessed North Dakota lakes were well-oxygenated in 2007, with less than 1% of lakes in poor condition (20 lakes) and only 21% of lakes as fair (784 lakes) (Figure 7). DO levels in the TPL were in worse condition than those in the NPL, with 64% (1,224 lakes) and 93% (1,722 lakes) in good condition, respectively (Figure 8).

North Dakota lakes in the NPL had similar DO conditions to the rest of the region with 93% and 96% of lakes considered good, respectively (Table 5). In the TPL, however, North Dakota lakes were much lower than the rest of the Ecoregion with 64% and 95%, respectively, in good condition for DO (Table 5).

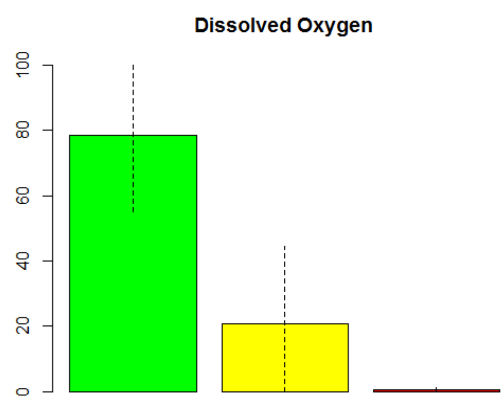

Figure 7: Condition estimate for dissolved oxygen throughout the State for the 2007 NLA. Error bars on this graph display the upper and lower 95% confidence intervals.

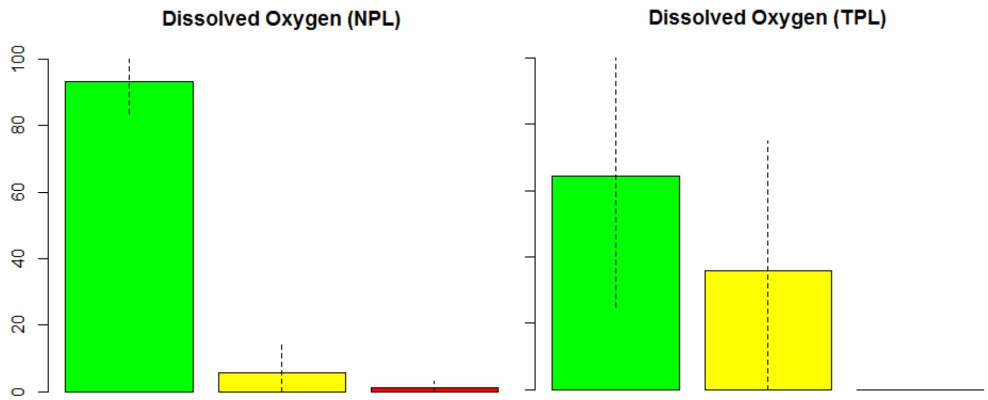

Figure 8: Comparison of DO extent estimates for the NPL (*n* = 27) and TPL (*n* = 11). Error bars on these graphs display the upper and lower 95% confidence intervals.

Table 5: Comparison of dissolved oxygen condition classes for North Dakota lakes to all other lakes in represented ecoregions (i.e., NPL and TPL). Percentages may not add-up to 100% due to the exclusion of sites that either had "No data" or "Not assessed" designations for this table.

Condition Class	ND Lakes in NPL	All Other Lakes in NPL	ND Lakes in TPL	All Other Lakes in TPL
Dissolved Oxygen				
Good	93.30%	95.86%	64.29%	95.43%
Fair	5.62%	4.14%	35.71%	2.03%
Poor	1.08%	0.00%	0.00%	1.20%

Biological Condition

In general, North Dakota lakes were in poor condition based on biological condition indicators. Greater than 77% of North Dakota lakes (2,896 lakes) were in poor condition based on planktonic O/E. Further, about 2% of lakes (87 lakes) were in good condition (Figure 9), with these in the TPL and no lakes in the NPL (Figure 10). In the NPL, greater 95% of lakes (1,764 lakes) were in poor condition based on planktonic O/E (Figure 10). Similarly, greater than 75% of North Dakota lakes (2,813 lakes) were poor based on the sediment diatom IBI (Figure 9), with nearly 98% of lakes (1,803 lakes) in the NPL in poor condition (Figure 10; Table 6). Although greater than 50% of lakes (1,009 lakes) in the TPL were in poor condition based on sediment diatom IBI, greater than 35% of lakes (680 lakes) were in good condition (Figure 10; Table 6). Conversely, greater than 85% of North Dakota lakes (3,209 lakes) were in good condition based on chlorophyll-α (Figure 9), accentuated by greater than 91% of lakes in the TPL considered good (1,737 lakes) (Figure 10; Table 6).

Biological condition, in general, is poor throughout the NPL, with greater than 95% of North Dakota's NPL lakes in poor condition based on the planktonic O/E indicator compared to 93% throughout the rest of the NPL (Table 6). North Dakota's NPL lakes were worse based on sediment diatom IBI compared to the rest of the ecoregion with 98% of lakes in North Dakota considered poor compared to 69% of lakes in the ecoregion considered poor (Table 6). Conversely, a greater proportion of the State's lakes were in better condition with regard to chlorophyll-α, with nearly 80% of lakes in good condition compared to 68% throughout the rest of the ecoregion (Table 6).

Lakes in the TPL portion of North Dakota were, in general, in better condition than those in the NPL, and were similar to those throughout the rest of the TPL. Fifty-nine percent (59%) of North Dakota TPL lakes were in poor condition for planktonic O/E compared to 60% throughout the rest of the ecoregion (Table 6). Based on the sediment diatom IBI, 53% of North Dakota's TPL lakes were in poor condition compared to nearly 49% throughout the rest of the TPL. For chlorophyll-α, however, North Dakota lakes were in much better condition, with greater than 91% of lakes in good condition compared to only 41% throughout the rest of the TPL.

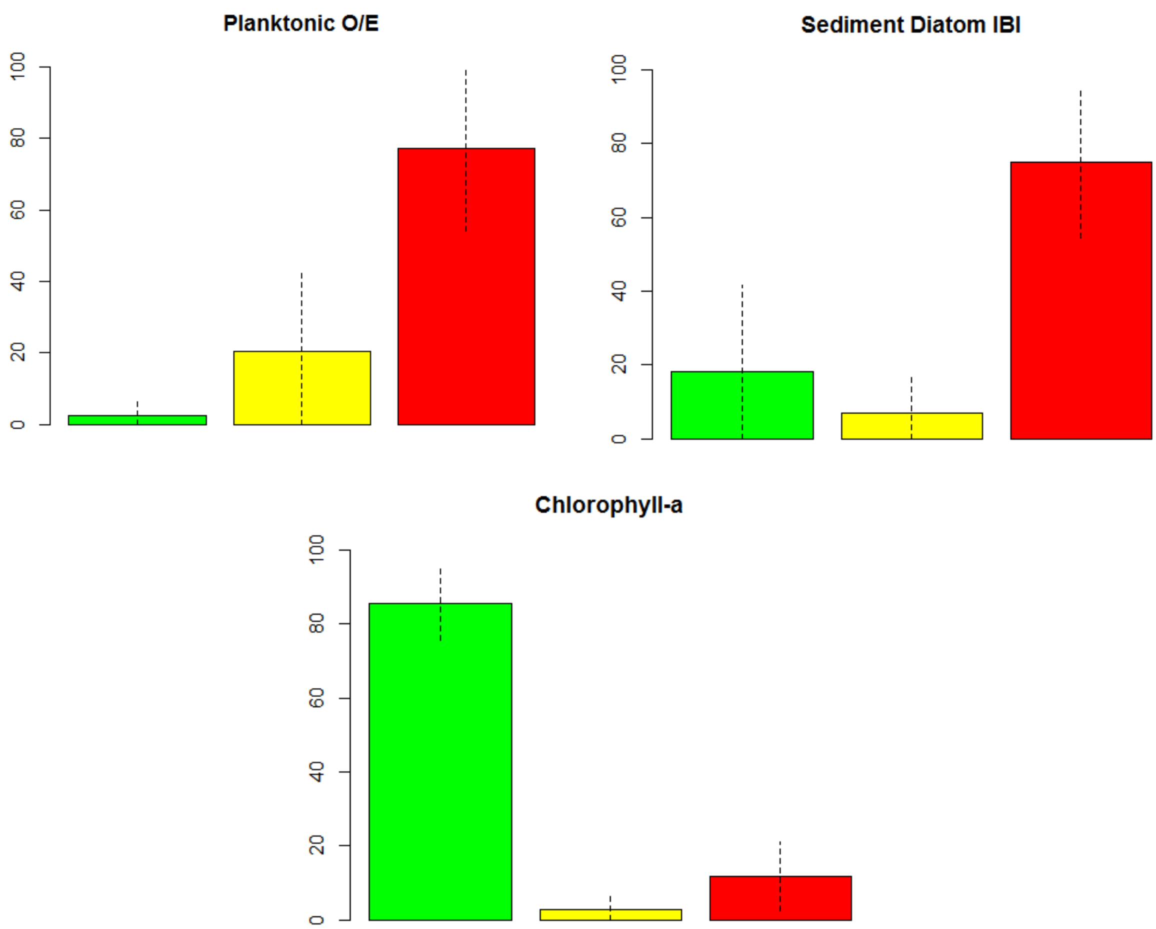

Figure 9: Condition estimate for biological indicators for the State of North Dakota from the 2007 National Lakes Assessment. Error bars on these graphs display the upper and lower 95% confidence intervals.

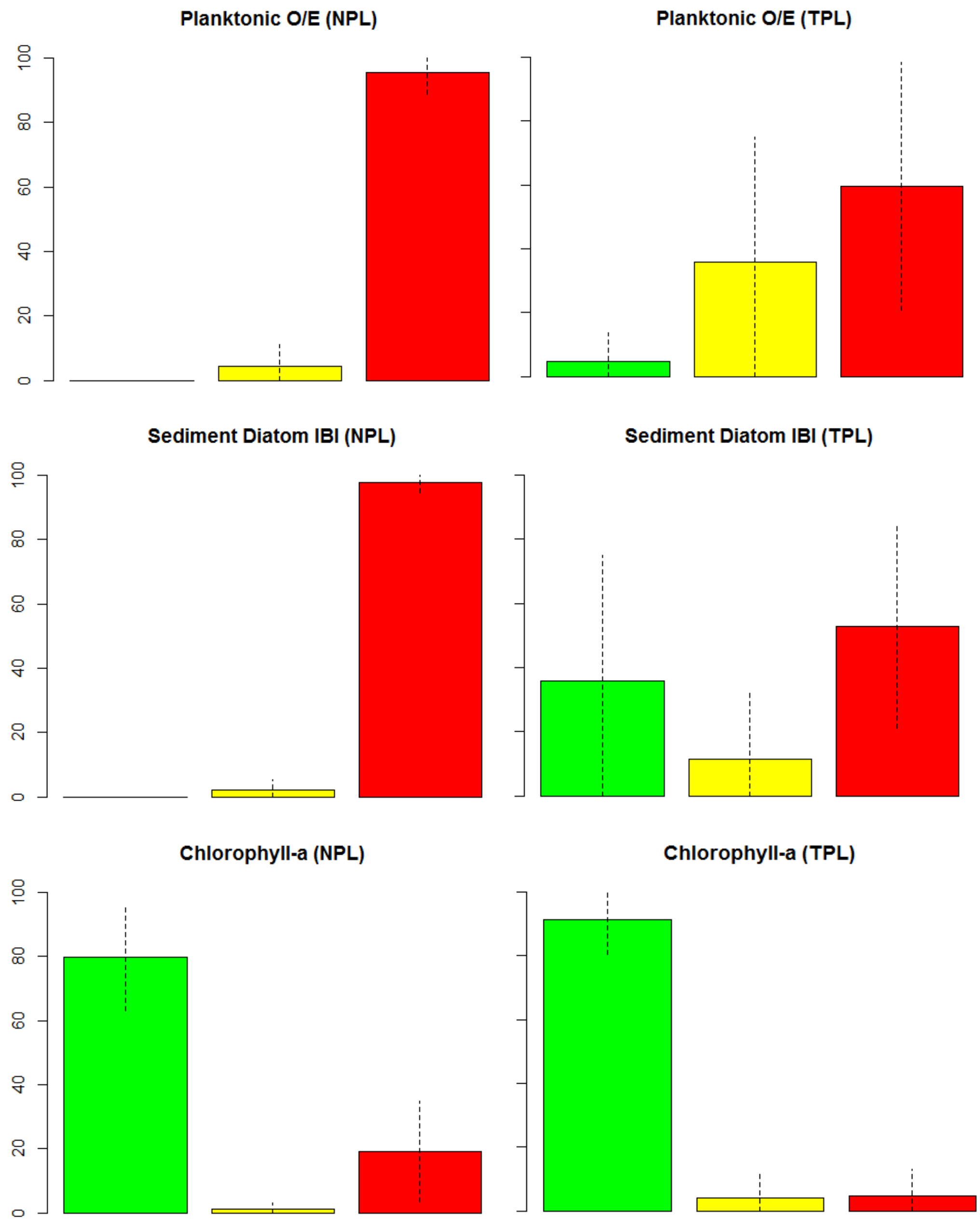

Figure 10: Comparison of biological extent estimates for the NPL (n = 27) and TPL (n = 11). Error bars on these graphs display the upper and lower 95% confidence intervals.

Table 6: Comparison of biological condition classes for North Dakota lakes to all other lakes in represented ecoregions (i.e., NPL and TPL). Percentages may not add-up to 100% due to the exclusion of sites that either had “No data” or “Not assessed” designations for this table.

Condition Class	**ND Lakes in NPL**	**All Other Lakes in NPL**	**ND Lakes in TPL**	**All Other Lakes in TPL**
Planktonic O/E				
Good	0.00%	0.86%	4.58%	16.95%
Fair	4.43%	4.79%	35.71%	21.06%
Poor	95.57%	93.41%	59.49%	59.93%
Sediment Diatom IBI				
Good	0.00%	23.15%	35.71%	18.94%
Fair	2.27%	7.87%	11.27%	26.09%
Poor	97.73%	68.69%	53.01%	48.88%
Chlorophyll-α				
Good	79.77%	68.27%	91.25%	41.41%
Fair	1.08%	20.88%	4.16%	18.45%
Poor	19.15%	10.85%	4.58%	39.97%

Recreational Condition

Two indicators were used to assess recreational condition; one is the presence of the cyanotoxin, microcystin, and the other is the abundance of cyanobacteria (i.e., blue-green algae). The importance of these human- and animal-health indicators cannot be under-rated; therefore, extent estimates based on these variables are concerning, even if poor classifications are at low percentages. Nearly 90% of North Dakota lakes (3,350 lakes) were low risk (i.e., less than 10 µg L^{-1} microcystin) for microcystin in 2007 (Figure 11), with 83% of lakes in the TPL (1,578 lakes) considered low risk (Figure 12). Cyanobacteria risk was high (i.e., greater than 100,000 cells L^{-1}) in North Dakota with only 45% of lakes low risk, and only 27% of lakes (511 lakes) in the NPL as low risk (Figure 12; Table 7).

Less than 1% of lakes throughout the NPL were high risk for microcystin compared to about 3% of North Dakota NPL lakes (Table 7). Only 28% of lakes in North Dakota’s NPL were classified as low risk for cyanobacteria, compared to 70% throughout the rest of the ecoregion (Table 7).

Eighty-three (83%) of lakes in the TPL portion of North Dakota were low risk for microcystin compared to greater than 99% of lakes throughout the rest of the ecoregion (Table 7). Conversely, no lakes in North Dakota’s TPL were considered high risk for cyanobacteria compared to nearly 30% of lakes throughout the rest of the ecoregion (Table 7).

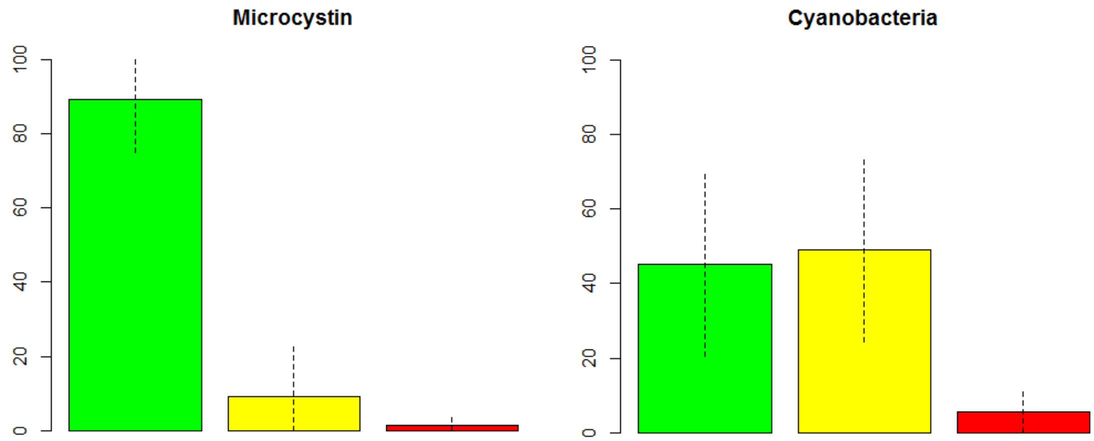

Figure 11: Condition estimates for recreational indicators, microcystin and cyanobacteria, for the State of North Dakota from the 2007 National Lakes Assessment. Error bars on these graphs display the upper and lower 95% confidence intervals.

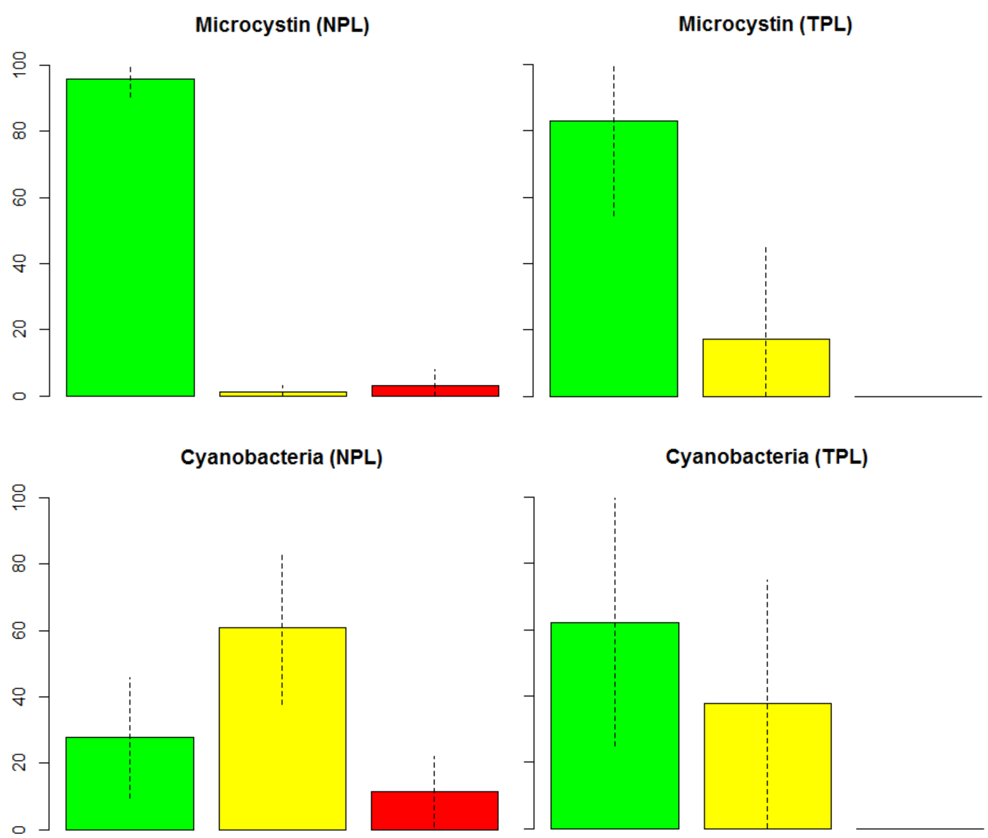

Figure 12: Comparison of microcystin and cyanobacteria extent estimates for the NPL (*n* = 27) and TPL (*n* = 11). Error bars on these graphs display the upper and lower 95% confidence intervals.

Table 7: Comparison of recreational condition classes for North Dakota lakes to all other lakes in represented ecoregions (i.e., NPL and TPL). Percentages may not add-up to 100% due to the exclusion of sites that either had "No data" or "Not assessed" designations for this table.

Condition Class	ND Lakes in NPL	All Other Lakes in NPL	ND Lakes in TPL	All Other Lakes in TPL
Microcystin				
Low Risk	95.99%	99.44%	82.93%	99.22%
Moderate Risk	1.08%	0.00%	17.07%	0.49%
High Risk	2.93%	0.56%	0.00%	0.29%
Cyanobacteria				
Low Risk	27.70%	70.23%	62.32%	41.91%
Moderate Risk	60.83%	24.42%	37.68%	28.20%
High Risk	11.47%	5.36%	0.00%	29.58%

Correlating Land Use and Physical Habitat Variables to Biological Condition Indicators and Secchi Disk Transparency

The biological condition indicator, chlorophyll-α concentration, was positively correlated to the amount of cropland in the basin (R = 0.381) and in the 200-meter buffer area (R = 0.330) (Table 8). Secchi disk transparency was most related to measures of in-lake cover, likely due to a lack of algal growth when littoral plant growth was high, but no relationships with land cover. The amount of continuous plant cover throughout the lake was most strongly related to transparency depth (R = 0.572), as well as indices of total littoral fish cover (R = 0.542) and cover from natural structures (R = 0.538) (Table 8). The amount of woody vegetation in the understory and canopy layers of the riparian area were positively correlated to increased transparency depth (R = 0.342) (Table 8). Additionally, variety of substrate types throughout the lake related positively to transparency (R = 0.433) (Table 8). Surprisingly, non-agricultural human influences close to shore was positively correlated to increased transparency (R = 0.485) (Table 8).

Zooplankton community health, as measured by the planktonic O/E indicator, was in poor condition throughout the State, as evidenced by nearly 80% of lakes in poor condition. Measures of physical habitat, both in-lake and riparian, were most strongly related to zooplankton community health. Increased variability in the amount of littoral cover was negatively related to zooplankton community, but planktonic O/E was positively related to natural fish cover (Table 8). Further, the amount of woody vegetation in the riparian area was positively related to zooplankton community health, as was the amount of organic shoreline substrate (Table 8).

Similar to planktonic O/E, the sediment diatom IBI was poor throughout North Dakota, with only 18% of lakes in good condition. Sediment diatoms were strongly related to the amount of forest in the basin (R = 0.651) and in the 200-meter buffer (R = 0.658) (Table 8). Measures of riparian condition were strongly related to sediment diatom IBI, including understory woody vegetation (R = 0.538), ground woody vegetation (R = 0.561), shoreline organic substrate (R = 0.495), and shoreline woody substrate (R = 0.399) (Table 8). Further, measures of riparian disturbance had strong, negative effects on the sediment diatom community. Presence of all human influence types was related to decreases in IBI scores (R = -0.416), most influenced by pasture (R = -0.356) and all agricultural types (R = -0.371) (Table 8).

Table 8: Pearson correlations between dependent variables and environmental variables for all North Dakota lakes sampled for the 2007 National Lakes Assessment.

	Chlorophyll-α	**Secchi Disk**	**Planktonic O/E**	**Sediment Diatom IBI**
Land cover – Basin				
% Open water	-0.12871	-0.09773	-0.10369	-0.02348
% Developed	-0.05638	0.20748	-0.14443	-0.30296
% Forest	-0.07824	0.14051	0.29848	**0.65138****
% Grassland	-0.26991	-0.09744	-0.26114	-0.12121
% Pasture	-0.05136	0.17841	0.04300	-0.02000
% Cropland	**0.38056**	-0.00710	0.15522	-0.17624
% Wetland	0.20112	-0.02763	-0.00489	-0.10626
Land cover – Within buffer				
% Open water	-0.04238	0.17482	-0.07547	-0.22938
% Developed	-0.14902	0.05134	-0.11106	-0.08246
% Forest	-0.12316	0.14080	0.29564	**0.65817****
% Shrubland	0.00059	-0.10447	0.26635	-0.00633
% Grassland	-0.15741	-0.16330	-0.23724	-0.14075
% Pasture	-0.19016	0.03295	-0.08511	0.09681
% Cropland	**0.32967**	-0.19888	-0.00055	-0.11139
% Wetland	0.15138	-0.15196	0.19627	0.00366
In-lake cover				
Fractional areal cover of submergent macrophytes	-0.24940	**0.51456***	-0.07757	-0.09509
Fractional areal cover of all aquatic macrophytes	-0.17863	**0.49457***	-0.03524	0.02651
Standard Deviation areal cover of emergent macrophytes	0.32175	-0.33037	-0.26197	0.04277
Standard Deviation areal cover of submergent macrophytes	-0.00034	-0.03127	**-0.35010**	-0.03647
Interdecimile range of cover from all macrophytes	-0.00310	-0.06329	**-0.34032**	-0.17662
Fractional cover of littoral fish cover from vegetation	-0.17763	**0.45945***	-0.01399	-0.03650
Index of total littoral fish cover	-0.07435	**0.54239***	0.22785	0.08597
Index of littoral fish cover from natural structures	-0.07565	**0.53784***	0.22652	0.09744
Fractional presence of natural littoral fish cover types	0.03830	**0.36097**	**0.34797**	0.18543
Fractional presence of continuous fish macrohabitat cover	-0.12797	**0.57169****	0.23716	0.02833
Riparian cover				
Fraction of plots having no canopy woody vegetation	0.03559	-0.27735	-0.31618	**-0.50378***
Fraction of plots having understory woody vegetation	0.13552	-0.00718	0.15283	**0.45732***
Fraction of plots having bare ground	-0.06082	0.14802	-0.06165	**-0.36831**
Fraction of plots having ground cover as woody vegetation	0.01916	-0.00527	0.22082	**0.43062***
Fraction of areal cover composed of understory woody vegetation	-0.08131	0.24835	**0.33862**	**0.53784****
Fraction of areal cover composed of ground woody vegetation	-0.10383	0.20969	**0.33170**	**0.56054****
Standard Deviation areal understory cover as woody vegetation	-0.00920	0.13052	0.24188	0.38177
Standard Deviation areal ground cover as woody vegetation	-0.12009	0.07268	0.20466	**0.55065****
Index of areal cover from woody vegetation	-0.07757	0.32335	0.31850	**0.41240**
Index of cover from canopy and understory woody vegetation	-0.06714	**0.34214**	**0.32973**	**0.42367***
Fraction presence of organic shoreline substrate	-0.17909	0.26068	**0.34307**	**0.34995**
Fraction presence of woody shoreline substrate	0.07775	0.17741	0.31454	**0.42516***
Fraction of areal cover from organic shoreline substrate	-0.18087	0.28454	0.25917	**0.49454***
Fraction of areal cover from woody shoreline substrate	0.00978	0.11858	0.15582	**0.39897**
Average count of substrate classes per station	-0.27355	**0.43294**	0.05199	-0.08639
Fraction of stations with flat banks	**0.42707***	-0.06550	0.31146	0.01283
Mean horizontal distance to high-water mark	0.29632	-0.12806	-0.19205	**-0.33033**

Table 8: (cont.)

	Chlorophyll-α	Secchi disk	Planktonic O/E	Sed. dia. IBI
Riparian disturbance				
Weighted presence of human influence from pasture	-0.15170	0.02879	-0.15339	**-0.35617**
Weighted presence of all agricultural human influence	-0.11328	0.08813	-0.07401	**-0.37076**
Weighted presence of all human influence types	-0.16471	0.27825	-0.07348	**-0.41608**
Index of all human influence types	-0.15997	0.27810	-0.07418	**-0.41918***
Index of human influence from agriculture	-0.11811	0.09205	-0.06581	**-0.37246**
Index of all human influences occurring close to shore	-0.31725	**0.35421**	0.00245	-0.25950
Index of non-agricultural influences close to shore	-0.20070	**0.48548***	0.10551	-0.11471
Frac. presence of any human influence	-0.02424	0.03293	-0.14535	**-0.44189***
Frac. presence of any human influence close to shore	**-0.32143**	0.28343	-0.07713	-0.26232
Riparian disturbance intensity index	-0.07512	0.16289	-0.12926	**-0.47768***
Riparian agricultural disturbance intensity index	-0.05869	0.05790	-0.07960	**-0.43297***
Riparian disturbance intensity and extent index 1	-0.04343	0.08085	-0.14466	**-0.47035***
Riparian disturbance intensity and extent index 2	-0.05491	0.10256	-0.14075	**-0.47681***

4.0 Summary and Discussion

In general, North Dakota lakes were assessed as fair to poor for the majority of indicators for chemical and physical stressors and biological condition. Physical habitat in the State was considered poor, a finding reflected throughout the Midwest and accentuated in the NPL. It should be noted, however, that these criteria are weighted heavily on the amount of woody vegetation (Kaufmann et al., 2014). North Dakota lakes were in good condition for measures of turbidity, littoral vegetation, and chlorophyll-α. Lakes in the PPR generally have high concentrations of phosphorus and nitrogen, as well as extensive areas of grassland/pasture and a lack of woody vegetation. These extensive areas of grassland/pasture associate to a “lesser” quality of riparian vegetation, but these habitats are not necessarily disturbed. North Dakota lakes were also assessed as having a higher risk for recreational condition indicators (i.e., microcystin, cyanobacteria) when compared to the NPL and TPL outside of North Dakota.

Nutrient levels in North Dakota lakes were relatively high, which was not surprising given the number of PPR lakes in the sample population. PPR lakes are generally high in nutrients, shallow, and productive; therefore, higher concentrations of nitrogen and phosphorus were expected in this region. Nearly all lakes represented in the NPL in North Dakota were in poor condition for TN and TP, a finding that was reflected throughout the rest of the NPL. This ecoregion is defined by relatively little to no large, woody vegetation and an abundance of grassland/prairie, the latter of which is commonly used for livestock grazing. High amounts of grazing and row crop production in this ecoregion can be partially attributed to elevated nutrient levels, as suggested from other studies (e.g., Freeland et al. 1999).

Levels of specific conductance within North Dakota are relatively high, with further evidence provided by this study where lakes were mostly fair or poor based on salinity. These elevated conductivity readings could have adverse effects for fish (Koel and Peterka, 1995), amphibian (Karraker et al., 2008), and waterfowl production (Swanson et al. 1984) throughout the State. Due to the dynamic water-level fluctuations and potential DO issues during the winter months in PPR lakes, some of these may also be fishless.

Physical habitat indicators assessed in North Dakota lakes were generally in poor condition, though in-lake cover was in good condition for the 2007 survey. Riparian disturbance being moderate to high is likely a result of an abundance of row crop and livestock production near the lake-edge, with relatively little (or no) protection within the riparian zone. These disturbance factors can greatly increase the frequency of ecologically detrimental events (e.g., erosion, eutrophication), which can then correlate to a cascading, negative effect on biological communities. Being a prairie state, North Dakota's lakes being poor for riparian vegetation is likely a result of the natural lack of tree abundance in the State, as these metrics generally rely on a good mix of herbaceous and woody vegetation (e.g., Kaufmann et al., 2014). Increased trees in the riparian zone can offer a refuge from higher water temperatures in lakes (i.e., shading), an important factor in the production of nearshore biological communities. Further, increased disturbance in the riparian area can have detrimental effects on nesting success of waterfowl, most affected by increases in the amount of cropland (Greenwood et al., 1995).

With regard to nutrients, natural, vegetated buffers between crop-production areas and wetlands/lakes can effectively reduce nutrient runoff to lakes (Janssen et al., 2000), which can have a positive influence on zooplankton communities in areas with higher proportions of agricultural activity (Dodson et al., 2005). Conversely, littoral cover throughout the State was generally in good health, likely a byproduct of these PPR lakes being relatively shallow and high in nutrients. Water-level fluctuations in the PPR influences the density of aquatic vegetation in lakes and wetlands; for example, when water-levels rise, the amount of littoral vegetation tends to decrease, and vice versa (van der Valk, 2005). In-lake plant cover provides an important refuge for zooplankton, macroinvertebrates, and small-bodied fishes. Further, many fish species (e.g., centrarchids) utilize dense stands of aquatic macrophytes for many portions of their life cycle. However, Rose and Crumpton (1996) found that PPR lakes and wetlands that had dense in-lake cover tended to have more anoxic conditions, and therefore may be detrimental to biological communities, especially fish. Further, lakes in the PPR tend to have relatively low dissolved oxygen concentrations during ice-cover (Barica and Mathias, 1979), suggesting that fish communities in many of these lakes may be sparse. When present, however, fish (particularly fathead minnows) can drive changes in biotic and abiotic factors within PPR lakes and wetlands (Zimmer et al., 2002).

Biological condition in North Dakota lakes was in poor condition, with greater than 95% of lakes being in poor condition for the sediment diatom IBI and planktonic O/E indicators. These biological measures were strongly correlated to physical habitat variables. Zooplankton communities rely on in-lake and riparian cover, both for protection from predators and refuge from increased temperature (reviewed in Burks et al., 2002), the latter of which may be of concern in these relatively shallow, unprotected PPR lakes. Being near the bottom of the food-chain, health of the zooplankton community is paramount to overall health of a lake ecosystem. Despite the relatively low scores for planktonic O/E in North Dakota, it should also be noted that no reference lakes for which "expected" values were determined were located within the State (from USEPA, 2010); therefore, extent of poor condition for planktonic O/E may be exaggerated due to a lack of local data. Additionally, the sediment diatom community was highly correlated to the amount of woody vegetation in the riparian area. Further, increased levels of disturbance in the riparian area also had adverse effects on the sediment diatom community. USEPA (2010) used Canonical Correspondence Analysis (CCA) to correlate the sediment diatom community to physical and chemical factors, with factors total nitrogen, total phosphorus, Secchi disk transparency, and specific conductance explaining the most variance for the national survey. These factors being in relatively poor condition throughout the State may also be strong drivers of the relatively poor condition of North Dakota's sediment diatom community. Development of this type of IBI (i.e., using sediment diatoms) is unprecedented (from USEPA, 2010), and further research and development will help strengthen its precision and accuracy to assess biological condition. Therefore, concern over relatively poor scores throughout North Dakota should be approached with caution, with this analysis being in its beginning stages. Similar to zooplankton, these diatoms represent the base of the food-chain and are essential for ecosystem functioning in North Dakota's lakes. These two measures will be re-assessed for the 2012 NLA, and it will be interesting to see how data from these two surveys will compare. Though not assessed for this survey, macroinvertebrate, amphibian, and fish community assessments would provide further information as to the health of North Dakota's lakes and reservoirs.

Despite relatively high nutrient concentrations in North Dakota lakes, the chlorophyll-α concentration indicator was assessed in relatively good condition. Increased disturbance in the riparian zone and watershed, particularly from cropland, had strong influences on algal growth in lakes in the State. Availability of nutrients typically increases in areas of increased agricultural production; these higher concentrations of nutrients can drive algal growth (particularly cyanobacteria). Conversely, lakes with relatively high conductivity have been found to have lower chlorophyll-α concentrations (Evans and Prepas, 1996), possibly a reflection of relatively high salinity in North Dakota lakes. Microcystin and cyanobacteria were generally found in low concentrations throughout the State, and only a small percentage of lakes were considered high risk. These recreational indicators, however, can have tremendous effects on human and animal health, and even small percentages of lakes where these indicators occur should be viewed with concern. In addition to aforementioned factors, many algal species (particularly cyanobacteria) can have short-term blooms and can be temperature-dependent, therefore, the timing of sample collection could also play a role.

In recent history, the climate in the PPR has been warming and getting wetter, with a decrease in the range of diurnal temperature (Millett et al., 2009), the combination of which will likely have huge impacts on the functioning of lakes in the PPR. Drought and deluge are common physical changes occurring within the PPR (Winter and Rosenberry, 1998), with many wetlands flooding to become productive lakes, followed by the subsequent fall of water-levels and associated desiccation of some wetlands. With the majority of lakes in the PPR being relatively small, they are more affected by the amount of snowmelt and runoff they received year to year, while larger lakes within the region are impacted more by longer-term climatic cycles (e.g., drought) (Zhang et al., 2009). Wetland loss from agricultural practices in the PPR was estimated by Johnson (2013) at approximately 6,200 hectares per year since 2001 using National Land Cover Dataset (NLCD) data, a loss that likely attributes to increased nutrient concentrations within the region. Johnson (2013) did report, however, that less wetland loss occurred in the Missouri Coteau portion of the PPR due to less desirable land for cultivation, which is where the majority of the sampled lakes are located. Despite these lands being "less desirable", farm subsidies, genetically-modified organisms (GMOs), and increased ethanol production has spurred increases in row crop production in this region, with increases in the occurrence of riparian disturbance and tiling (Johnson et al., 2008). Further protection and restoration of the PPR is essential to protecting ecosystem services in the region by reducing sedimentation and nutrient loading and increasing water storage (Gleason et al., 2011).

Previous to this, no statistically-valid, probability-based survey was used to assess the health of North Dakota's lakes. Further research with these NARS surveys will provide scientists, managers, and decision-makers with useful information on the status of the State's lakes. Data collected from future surveys may also be used to not only assess current status of North Dakota's lakes, but also offer insight into possible trends occurring throughout the State. The health and life-histories of many of North Dakota's fish, waterfowl, and amphibians are dependent upon the health of the State's lakes, and continued statewide monitoring needs to occur to ensure these communities prosper for generations.

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