National Park Service
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Natural Resource Program Center

Monitoring Water Quality of Inland Lakes, Great Lakes Network, 2009 and 2010

Data Summary Report

Natural Resource Data Series NPS/GLKN/NRDS—2011/163

ON THE COVER
Canoe at Isle Royale National Park, ready for water quality sampling (NPS photo/R. Damstra), and J. LeDuc at Voyageurs National Park, loaded with sampling gear (NPS photo/L. Chetney).

Monitoring Water Quality of Inland Lakes, Great Lakes Network, 2009 and 2010

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Natural Resource Data Series NPS/GLKN/NRDS—2011/163

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U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Fort Collins, Colorado

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols. Additionally, this report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

This report is available from the Great Lakes Inventory and Monitoring Network website (http://science.nature.nps.gov/im/units/GLKN/monitor/InlandLakesWQ/WQ_InlandLakes.cfm) and the Natural Resource Publications Management website (www.nature.nps.gov/publications/nrpm/).

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Abstract

The Great Lakes Inventory and Monitoring Network monitored water quality of inland lakes at six national park units in 2009 and 2010: Voyageurs National Park (VOYA), Apostle Islands National Lakeshore (APIS), Isle Royale National Park (ISRO), Pictured Rocks National Lakeshore (PIRO), Indiana Dunes National Lakeshore (INDU), and Sleeping Bear Dunes National Lakeshore (SLBE). The primary objective of this monitoring program is to monitor water quality in order to describe the current status and to detect trends of common limnological parameters within sampled lakes. We hope to be able to provide early warnings of change, work with researchers to understand the causes of change, and provide interpretation of our results to park staff.

Thirty-three index lakes were sampled during the open water season in 2009 and 2010. Field measurements included depth profiles of temperature, pH, specific conductance, and dissolved oxygen; water clarity; and water level relative to a benchmark. Water samples were collected for laboratory analyses of total phosphorus, total nitrogen, nitrate+nitrite-nitrogen, ammonium-nitrogen, dissolved silica, calcium, sodium, magnesium, potassium, sulfate, chloride, dissolved organic carbon, alkalinity, and chlorophyll-*a*.

Results from 2009 and 2010 are compared across parks. For individual parks, results of some key parameters are compared across years since monitoring began. Results show that many lakes exceed the U.S. Environmental Protection Agency (USEPA) reference criteria for Secchi depth, pH, chlorophyll-*a*, total phosphorus, total nitrogen, and nitrate+nitrite-nitrogen for their ecoregion. The EPA's criteria for defining what constitutes a reference condition are stringent, based on the 25th percentile of all sampled lakes in each EPA-defined ecoregion. Calculations of trophic state indices show most index lakes to be mesotrophic. Mean summer water levels remained constant or declined in most lakes since sampling began, though the influence of beaver activity over-rode the effects of precipitation in several lakes.

Additional park-specific data and comments and recommendations relating to logistics are included. We expect monitoring to continue in 2011 at the same index lakes, with additional sites, visits, and parameters included as funding permits.

Acknowledgments

Without the support of staff at each of the parks, we would not be able to implement the water quality monitoring program successfully. The assistance we receive varies by park, but examples include boat maintenance, lab space, sampling equipment, boat transportation, vehicles, gasoline, housing, and more. Personnel from several divisions, including maintenance, interpretation, law enforcement, and last but not least, natural resources have lent a hand. Special thanks to the primary field staff: Lora Loope, Leah Kainulainen, Chris Otto, Claire Kissane, Jaime LeDuc, Ted Gostomski, and David VanderMeulen. Many thanks also to the literally dozens of people who have assisted with field sampling in 2009 and 2010. We are especially grateful to Brenda Moraska Lafrancois, Lora Loope, Ryan Maki, Chris Otto, and David VanderMeulen for discussions surrounding the interpretation of our results.

Introduction

The Great Lakes Inventory and Monitoring Network (hereafter the Network or GLKN) conducted water quality monitoring at six parks with inland lakes resources in 2009 and 2010: Voyageurs National Park (VOYA), Apostle Island National Lakeshore (APIS), Isle Royale National Park (ISRO), Pictured Rocks National Lakeshore (PIRO), Indiana Dunes National Lakeshore (INDU), and Sleeping Bear Dunes National Lakeshore (SLBE). Water quality as a vital sign ranked highly across Network parks (Route 2004). Because monitoring water quality is mandated by the National Park Service - Water Resources Division (WRD), the Network receives some funding from WRD annually to cover part of the costs. The protocol for monitoring water quality of inland lakes (Elias et al. 2008) encompasses the following vital signs:

- core suite (temperature, dissolved oxygen, conductivity, pH, water clarity)
- water level
- advanced suite (alkalinity, dissolved organic carbon, silica, chloride, sulfate, calcium, sodium, potassium, magnesium, chlorophyll-*a*, total phosphorus, total nitrogen, ammonium-nitrogen, nitrate+nitrite-nitrogen)
- primary productivity (as estimated by chlorophyll-*a* measurements)
- nutrient dynamics (as measured by the phosphorus and nitrogen species)

The Network also monitors diatoms (an additional vital sign) in lake bottom sediments (Ramstack et al. 2008) under a cooperative agreement with the St. Croix Watershed Research Station (SCWRS). Diatom monitoring is closely tied to water quality monitoring and aids in the interpretation of water quality results.

In collaboration with the U.S. Geological Service (USGS), we have continued to collect water samples from five lakes at VOYA for total and methyl mercury (bioaccumulative contaminants vital sign).

The overall goal of the monitoring program for water quality of inland lakes is to contribute to an understanding of the health of ecosystems and provide insights on water quality issues in the parks. The Network's primary objective is to monitor water quality in park lakes in order to describe the current status and to detect trends in common limnological parameters within sampled lakes. While we expect it to take many years to develop a solid baseline of data before a trend can be determined for most parameters, we hope to be able to provide early warnings of change, which may then lead to increased monitoring, research, or management action. As our water quality monitoring program matures, we are getting a better understanding of the natural variability that occurs in a given lake within a season and across years. This understanding is crucial in order to distinguish true change from the 'noise' inherent in the system, as well as that due to sampling equipment, laboratory analyses, and individual bias.

This report provides brief updates on the water quality monitoring program, including results from the 2009 and 2010 field seasons. Results from previous years (Elias 2007, 2009; Elias and VanderMeulen 2008) can be found on the GLKN website (http://science.nature.nps.gov/im/units/glkn/index.cfm).

Methods

Study Sites

In developing the protocol for monitoring water quality of inland lakes, the Network and the parks selected index lakes for annual monitoring. These lakes span gradients of chemical and physical parameters, visitor use, watershed size, and spatial distribution within each park (Elias et al. 2008). We sampled all 33 index lakes (Table 1) in 2009 and 2010. Additional lakes were sampled in both years as follows: 2009 - VOYA (N=14), PIRO (N=1), SLBE (N=4), and INDU (N=1); 2010 - ISRO (N=2), VOYA (N=8), PIRO (N=1), SLBE (N=4), and INDU (N=1) (Table 1).

Water Quality Sampling

Field Methods

In accordance with the protocol (Elias et al. 2008), we conducted field sampling at the deepest part of each lake three times during the open water season (Table 2). Due to the late summer filling of a crucial staff position, ISRO lakes were only sampled twice in 2009. Lakes are sampled at approximately the same location on each site visit, with the location determined by GPS, bathymetric maps, and detailed directions.

We used multi-probe sondes to collect profile data on temperature, dissolved oxygen, specific conductance, and pH. Different sondes were used at different parks: YSI (Model 6820) at PIRO, Eureka Manta (Model 318) at APIS, Eureka Manta (Model 318 and Model 178) and Hydrolab (Model MS5.0) at ISRO, Eureka Manta (Model 132) at VOYA, and Hydrolab (Model DSX5) at SLBE, and Hydrolab (Model MS5.0) at INDU. At each site, we also measured water clarity with a Secchi disk or transparency tube, took a GPS reading, recorded environmental conditions (e.g., wind speed and direction, wave height, sky cover, air temperature), measured water level relative to a benchmark, and noted field personnel and instruments. We used a hand-held eye level and a light-weight stadia rod (or tape measure at INDU) to measure the water level relative to a benchmark.

We collected 0-2 m integrated water samples for laboratory analyses using an integrated tube sampler (MPCA 2004a, b; WDNR 2004). On lakes that were less than 2 m deep, we used the tube sampler on an angle to collect a sample from the full water column or collected a grab sample at approximately elbow depth. Sample water was composited in a high density polyethylene container. See Elias et al. (2008) and Elias and VanderMeulen (2008) for details on collection and handling of water samples.

At index lakes, we collected water samples for nutrients and chlorophyll-*a* (chl-*a*) during each visit; samples for the remaining parameters (Table 3) were collected only during the middle round of sampling (August at ISRO in 2009). Also during the mid-summer sampling, we collected a near-bottom water sample with a Van Dorn for analysis of total phosphorus (and total nitrogen in 2010). This near-bottom sampling was conducted only in lakes that were thermally stratified. At some non-index lakes we took field measurements (core suite) and collected water for laboratory analysis (advanced suite), while at others we only measured field variables (Table 1).

At VOYA, we collected samples for total and methyl mercury at five lakes (Brown, Ek, Peary, Ryan, and Shoepack) following U.S. Geological Survey (USGS) procedures (M. Brigham, USGS, personal communication). As in previous years, this was a collaborative effort with USGS – we collected the samples and sent them to the USGS laboratory in Middleton, Wisconsin; the lab analyzed the samples; M. Brigham managed the data for USGS; we managed the data for GLKN.

Table 1. Lakes/lagoons sampled for water quality in 2009 and 2010 and types of data collected each year. The parks are listed in order from west to east. Index lakes are shown in **bold font**.

Lake or Lagoon	Core Suite	Advanced Suite	Diatom Sample	Mercury Sample
Voyageurs National Park				
Locator	2009, 2010	2009, 2010	2010	
War Club	2009, 2010		2010	
Quill	2009			
Loiten	2009			
Shoepack	2009, 2010	2009, 2010	2010	2009, 2010
Little Shoepack	2009			
Jorgens	2009, 2010		2010	
Quarter Line	2009, 2010		2010	
Ek	2009, 2010	2009, 2010	2010	2009, 2010
Agnes	2009, 2010		2010	
Oslo	2009, 2010		2010	
Brown	2009, 2010	2009, 2010	2010	2009, 2010
Fishmouth	2009			
Peary	2009, 2010	2009, 2010	2010	2009, 2010
Beast	2009			
Cruiser	2009, 2010	2009, 2010	2010	
Ryan	2009, 2010	2009, 2010	2010	2009, 2010
Net	2009			
Tooth	2009, 2010		2010	
O'Leary	2009, 2010		2010	
Little Trout	2009, 2010	2009, 2010	2010	
Mukooda	2009, 2010		2010	
Apostle Islands National Lakeshore				
Michigan Island	2009, 2010	2009, 2010		
Outer Island	2009, 2010	2009, 2010		
Stockton Island	2009, 2010	2009, 2010		
Little Sand Bay	2009, 2010	2009, 2010		
Isle Royale National Park				
Ahmik	2009, 2010	2009, 2010		
Sargent	2009, 2010	2009, 2010		
Richie	2009, 2010	2009, 2010		
Beaver	2009, 2010	2009, 2010		
Harvey	2009, 2010	2009, 2010		
George	2009, 2010	2009, 2010		
Siskiwit	2009, 2010	2009, 2010		
Desor	2009, 2010	2009, 2010		
Feldtmann	2009, 2010	2009, 2010		

Table 1. Lakes/lagoons sampled for water quality in 2009 and 2010 and types of data collected each year. The parks are listed in order from west to east. Index lakes are shown in **bold font** (continued).

Lake or Lagoon	Core Suite	Advanced Suite	Diatom Sample	Mercury Sample
Isle Royale National Park (continued)				
Whittlesey	2010			
Chickenbone	2010			
Pictured Rocks National Lakeshore				
Grand Sable	2009, 2010	2009, 2010		
Legion	2009, 2010	2009, 2010		
Beaver	2009, 2010	2009, 2010		
Little Beaver	2009, 2010	2009, 2010		
Chapel	2009, 2010	2009, 2010		
Miners	2009, 2010	2009, 2010		
Indiana Dunes National Lakeshore				
Long	2009, 2010	2009, 2010		
Middle Lagoon	2009, 2010	2009, 2010		
Sleeping Bear Dunes National Lakeshore				
Manitou	2009, 2010	2009, 2010	2009	
Florence	2009, 2010	2009, 2010	2009	
Narada	2009, 2010	2009, 2010	2009	
Shell	2009, 2010	2009, 2010	2009	
Bass (North)	2009, 2010	2009, 2010	2009	
Otter	2009, 2010	2009, 2010	2009	
Tucker	2009, 2010	2009, 2010	2009	
North Bar	2009, 2010	2009, 2010	2009	
Round	2009, 2010	2009, 2010	2009	
Loon	2009, 2010	2009, 2010	2009	

Table 2. Dates of water quality sampling at index lakes, 2009 and 2010.

	Round 1	Round 2	Round 3
2009			
VOYA	6/08 - 6/17	7/20 - 7/29	8/31 - 9/09
APIS	6/15 - 6/16	7/27 - 7/28	9/08 - 9/09
ISRO	no sampling	8/06 - 8/14	9/02 - 9/10
PIRO	6/15 - 6/19	7/27 - 7/31	9/01 - 9/08
INDU	4/30	7/1	9/3
SLBE	6/13 - 6/26	7/21 - 7/31	9/02 - 9/14
2010			
VOYA	6/9 – 6/19	7/19 – 7/30	8/16 – 8/26
APIS	6/14 – 6/17	7/26 – 7/27	9/1 – 9/2
ISRO*	6/14 – 6/25	7/13 – 7/26	8/18 – 9/1
PIRO	6/14 – 6/22	7/26 – 7/30	8/30 – 9/10
INDU	5/3	6/29	9/1
SLBE	6/14 – 6/25	7/19 – 7/26	9/2 – 9/17

*additional sampling occurred at Richie Lake on 5/28, 8/12, 8/27, and 9/8.

Table 3. Parameters measured and abbreviations used in text. Bold font indicates parameters measured three times per season (twice at ISRO in 2009); remaining parameters measured once during mid-season.

Parameter	Abbreviation	Parameter	Abbreviation
Alkalinity	Alk	**Total Nitrogen**	**TN**
Calcium	Ca^{+2}	**Ammonium-Nitrogen**	**NH_4-N**
Chloride	Cl^-	**Nitrate+Nitrite-Nitrogen**	**NO_3+NO_2-N** or **NO_x**
Chlorophyll-*a*	**chl-*a***	Total Mercury (VOYA only)	THg
Dissolved Organic Carbon	DOC	Methyl mercury (VOYA only)	MHg
Magnesium	Mg^{+2}	**Specific Conductance**	**SC25**
Potassium	K^+	**Dissolved Oxygen**	**DO**
Silica	SiO_2	**pH**	**pH**
Sodium	Na^+	**Temperature**	**Temp**
Sulfate	SO_4^{-2}	**Secchi Disk Depth**	**Secchi**
Total Phosphorus	**TP**	**Transparency Tube**	**T-tube**

Analytical Laboratory

In 2009, we contracted with White Water Associates (WWA) for all laboratory analyses. As this was the first year WWA was conducting analyses of nutrients for us, and because we had received unreliable chl-*a* data from WWA in the past, we collected back-up samples of these constituents. Natural Resource Research Institute (NRRI), with whom we had contracted for nutrient and chl-*a* analysis in previous years, analyzed a limited number of back-up samples at the beginning of the season. Comparisons of these early results showed us we could not rely on WWA for accurate nutrient and chl-*a* results. We further convinced ourselves of WWA's inability to provide accurate results for nutrients by sending blind standards to the lab. We were not able to contract with NRRI as we had in previous years due to contracting rules, but we were able to amend our cooperative agreement with SCWRS to include analysis of the nutrient and chl-*a* samples. The lab at SCWRS is known for providing accurate results at the low concentrations we often find in our lakes. Their results compared favorably with results from previous years.

In 2009 and 2010, WWA analyzed samples for major ions (Ca^{+2}, Cl^-, Mg^{+2}, K^+, Na^+, SO_4^{-2}) alkalinity, dissolved organic carbon (DOC), and dissolved silica (SiO_2). We have confidence in WWA's results for these constituents. Mercury samples from VOYA were analyzed in both years by the USGS lab in Middleton, Wisconsin.

In 2010, SCWRS again analyzed nutrient and chl-*a* samples. The lab began using a different method for analysis of chl-*a* (fluorometric rather than spectrophotometric) after splitting samples and running them both ways (N=110). We used regressions to calculate expected fluorometric values when making comparisons with prior years.

All samples were processed and handled according to standard operating procedures (Axler et al. 2008) and as required by the respective laboratories.

Sediment Sampling

We collected lake bottom sediment samples in spring 2009 from 10 lakes at SLBE and in late summer 2010 from 16 lakes at VOYA (Table 1). Samples were collected with a drop corer and were handled and processed according to standard operating procedures (Ramstack et al. 2008). The bottom sediment samples will be analyzed for diatom community assemblages by researchers at SCWRS. Results from this project will facilitate our understanding of changes in water quality, as particular diatom species only exist under certain water quality conditions. Therefore, diatoms serve as indicators of water quality by responding to environmental stressors with changes in community composition. Analysis of diatom communities complements our discreet water quality sampling as diatoms integrate environmental conditions throughout their lives.

Bathymetric Mapping

Hard-copy bathymetric maps exist for many of the index lakes, though electronic maps for these lakes are often not available. Because only three index lakes at ISRO had any type of bathymetric map at the beginning of this monitoring program, we began constructing bathymetry maps at the park in 2007 using a GPS mapping unit mated with a depth finder, and continued the process in 2008. Depth and location data were collected along transects, crisscrossing each lake. Data were then downloaded into GIS, processed, and draft maps were created. Time constraints prohibited further bathymetric mapping in 2009 and mapping was limited to Lake Harvey in 2010. We plan to construct bathymetric maps for all index lakes over the long term.

Data Handling

Methods for using laboratory data below detection limit and reporting limit (method detection limit [MDL] and method quantitation limit [MQL], respectively; i.e., censored data) in statistical analyses are numerous and diverse (e.g., Helsel 1990, Helsel and Cohn 1988). Because data were summarized but not analyzed statistically for this report, values below MQL, including ‘0’ were used. ‘ND’ (non-detect) is indicated when the laboratory reported it as such. Results of ‘ND’ were reported 15 times, all of which were for single measurements that did not require calculation of a mean.

Quality Assurance and Quality Control

Steps to ensure quality assurance and quality control (QA/QC) were undertaken routinely, according to standard operating procedures (Ledder and Elias 2008), as part of monitoring water quality. The following steps were taken in 2009 and 2010:

- the measurement sensitivity of each sonde was calculated prior to the field season
- sondes were calibrated daily, adhering to acceptance criteria
- calibration logs were maintained with each instrument
- measurements taken in the field with the sondes were saved electronically and backed-up on paper data sheets
- duplicate field measurements were taken at the rate of approximately 10%
- duplicate water samples were collected at the rate of approximately 10%
- equipment blanks were conducted prior to and during the field season to ensure we were not introducing any contamination to the samples.

In addition, contract laboratories conducted their own QA/QC that included blanks, duplicates, and spikes, and generated QA/QC reports that accompanied water sample results.

Network quality assurance criteria stipulate that results for water sample duplicates should be within 10% of each other for all parameters except nutrients and chl-*a*, which should be within 30% of each other (Ledder and Elias 2008). Most of our duplicates fell within the acceptable criteria. Those that did not meet quality assurance criteria were usually very close to laboratory detection or reporting limits. In such cases, actual small differences can result in large relative percent differences (e.g., the actual difference between 1 and 2 µg/L is small, but the relative difference is 67%). We have used all values in this report unless specifically noted otherwise, averaging duplicates even when differences exceeded quality assurance criteria. Values that do not meet our quality assurance criteria are flagged as such in the National Park Service database, NPSTORET, and the EPA database, STORET.

Results and Discussion

Data relative to USEPA reference criteria and trophic status are presented below for all parks, so that comparisons across parks can be easily observed. Water level data are presented within each park's section, as changes may be lake-specific, making comparisons across parks or sometimes even across lakes within a park not particularly informative. Appendices A-F contain all data for the six parks with the exception of profile data measured with multiprobe sondes; only data from 1.0 m (0.5 m in shallow lakes) are included. All data, including all profile data, are posted in EPA's STORET database and can be accessed at http://www.epa.gov/storet/dw_home.html. Graphs of temperature and oxygen profiles are not included in this report, but are available upon request.

EPA Reference Criteria

National park units are often considered to be relatively pristine, and are commonly referred to as representative of reference conditions. The EPA's criteria for defining what constitutes a reference condition are stringent, based on the 25th percentile of all sampled lakes in each EPA-defined ecoregion. Because most of the inland lakes monitored through this protocol have been protected since the parks were created, it is surprising that many of the GLKN index lakes do not meet these criteria. Our data show that many of GLKN's index lakes exceed the EPA reference criteria for Secchi depth, pH, chlorophyll-*a* (chl-*a*), total phosphorus (TP), total nitrogen (TN), and nitrate+nitrite-nitrogen (NO_3+NO_2-N) for their ecoregions (USEPA 2000a, b, c).

Secchi Depth

Many lakes at VOYA, ISRO, PIRO, and SLBE exceed the EPA reference criteria for Secchi depth (Figure 1; USEPA 2000a, b). Reasons for shallow Secchi measurements vary by lake, but are primarily due to tannin-stained water and algae. Changes in Secchi depth over time may indicate a change in trophic status, but confounding factors such as changes in personnel, field conditions (e.g., rough water), and timing of sampling must be taken into consideration.

Water transparency at APIS and INDU was sometimes measured with a transparency tube because the shallow depths of the lakes/lagoons allowed the Secchi to be seen on the bottom. Data are included in Figure 1 for these parks only when at least two Secchi measurements were available. Data in Figure 1 for APIS are from Stockton Island and Little Sand Bay (LSB) lagoons, both of which did not meet EPA reference criteria. Stockton Island lagoon is heavily stained with tannic acid, and LSB lagoon is often turbid from suspended sediment. Secchi data for INDU were only available for 2009; Long Lake had shallow Secchi measurements due to suspended sediments.

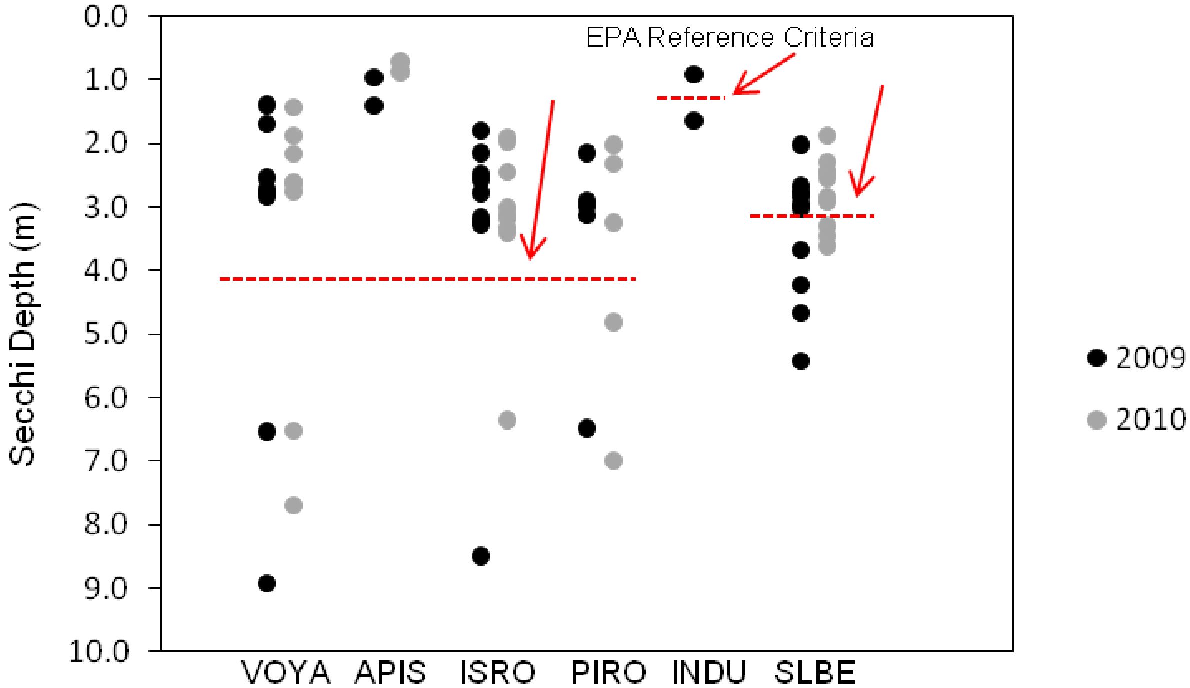

Figure 1. Mean Secchi depth measurements of lakes across six park units in the Great Lakes Network, 2009 and 2010. Points above the dotted lines indicate lakes with mean Secchi depths that did not meet the EPA reference criteria in the approporiate ecoregion (4.2 m for VOYA, APIS, ISRO, PIRO - USEPA 2000a; 1.44m for INDU - USEPA 2000c; and 3.2m for SLBE - USEPA 2000b). Park codes as in text.

pH

Most lakes had pH values within the USEPA limits, though exceptions occurred at VOYA (Shoepack Lake), APIS (Stockton Island Lagoon), and PIRO (Legion Lake) (Figure 2; USEPA 2000a, b, c). Additional lakes at APIS and INDU were at the limit. Lakes on the low end of the pH scale are likely naturally acidic, though the low levels may be problematic for some aquatic life. The borderline high pH at Middle Lagoon, INDU, may be due to eutrophic conditions or contamination, as evidenced by high concentrations of chloride, sodium, and sulfate (Appendix E).

*Chlorophyll-*a

With the exception of SLBE, few lakes fell below the EPA reference criteria for chl-*a* (Figure 3). As mentioned previously, the criteria are stringent and for some ecoregions the number of lakes sampled to develop the criteria was inadequate, which could bias the criteria. Specifically, the chl-*a* criterion using the fluorometric method of analysis for Ecoregion VIII, level III ecoregion 50 (that of VOYA, APIS, ISRO, and PIRO) was derived from only two samples (USEPA 2000a). At this time, it is more important to heed the status and trends in the trophic state of the lakes (see below) than to be concerned about exceeding EPA reference criteria for chl-*a*.

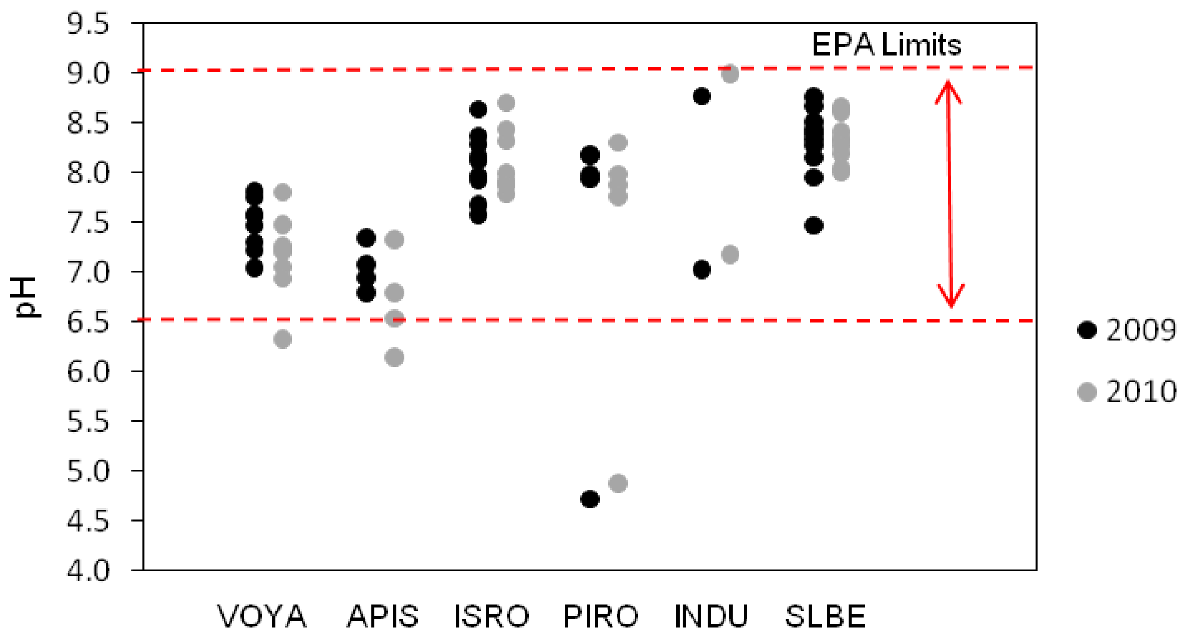

Figure 2. Mean near-surface pH values (1.0 m at VOYA, ISRO, PIRO, and SLBE; 0.5 m at APIS and INDU) of lakes across six park units in the Great Lakes Network, 2009 and 2010. Points between the dotted lines represent lakes that fell within the USEPA limits of 6.5 and 9.0 (USEPA 2000a, b, c). Park codes as in text.

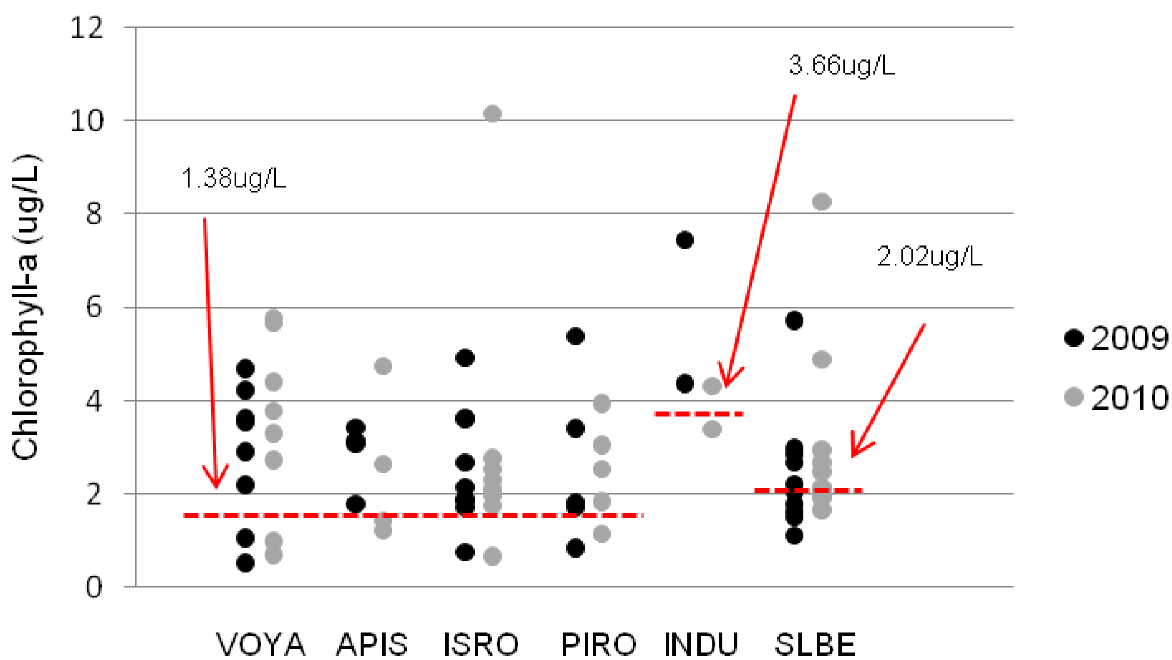

Figure 3. Mean chlorophyll-*a* values of lakes across six park units in the Great Lakes Network, 2009 and 2010. Points above the dotted lines represent lakes that exceed the criteria (USEPA 2000a, b, c). The reference criterion for INDU was calculated via regression so the laboratory method of analysis was consistent across parks (i.e., fluorometric rather than spectrophotometric). Park codes as in text.

Nutrients

The TP and TN reference criteria for Ecoregions and Subregions that include SLBE and INDU are higher than those of VOYA, APIS, ISRO, and PIRO. More lakes at SLBE and INDU had TP and TN concentrations below the criteria than the other four parks (Figures 4 and 5). In fact, at SLBE, only Florence Lake exceeded the reference criteria for both TP and TN. The vast majority of lakes at VOYA, APIS, ISRO, and PIRO do not receive direct anthropogenic inputs (e.g., fertilizer runoff, failing septic systems, sewage treatment plant effluent) and sources of phosphorus and nitrogen are likely from within the lakes (re-suspension from lake sediment during mixing) or from atmospheric deposition. Little Sand Bay Lagoon at APIS is an exception, as it receives runoff from a watershed that lies mostly outside of park borders. Mean TP concentration for the lagoon in 2010 was 52 ug/L. The lagoons at APIS are not really lakes, however, and should probably not be held to the same standards. The lagoons are better classified as wetlands with open water areas. Nutrient criteria have not been developed for wetlands in Wisconsin.

It is difficult to understand why so many lakes at VOYA, ISRO, and PIRO exceed EPA reference criteria. At this time we do not have enough data to say whether nutrient concentrations have increased over time (see individual park sections below), but we know that concentrations are very low in many lakes – near method detection limits for TP and NO_3+NO_2-N and often below method quantitation limits. However, the reference criteria are also very low. An analysis of GLKN lakes vs. lakes used to determine the reference criteria might help to determine whether the criteria are appropriate for park lakes. Such an analysis by Lafrancois et al. (2009) for lakes on the Grand Portage Indian Reservation (MN) showed the criteria were determined based on lakes that differed in chemistry and morphometry from those on the Reservation and are likely not appropriate for the lakes on the Reservation.

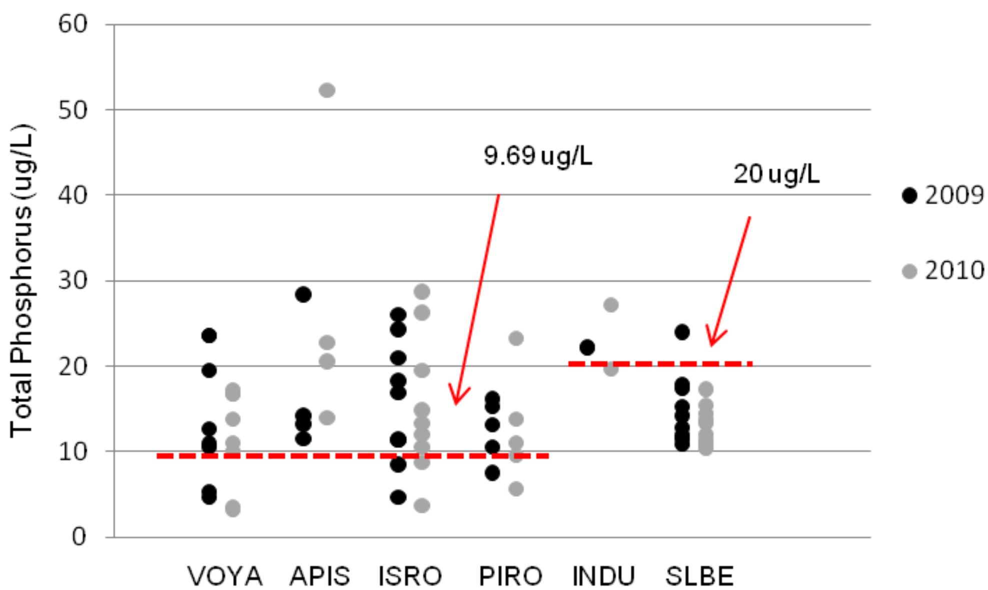

Figure 4. Mean total phosphorus (TP) levels for lakes across six parks in the Great Lakes Network, 2009 and 2010. Points above the dotted lines indicate lakes with mean TP levels greater than the USEPA reference criteria (USEPA 2000a, b, c). Park codes as in text.

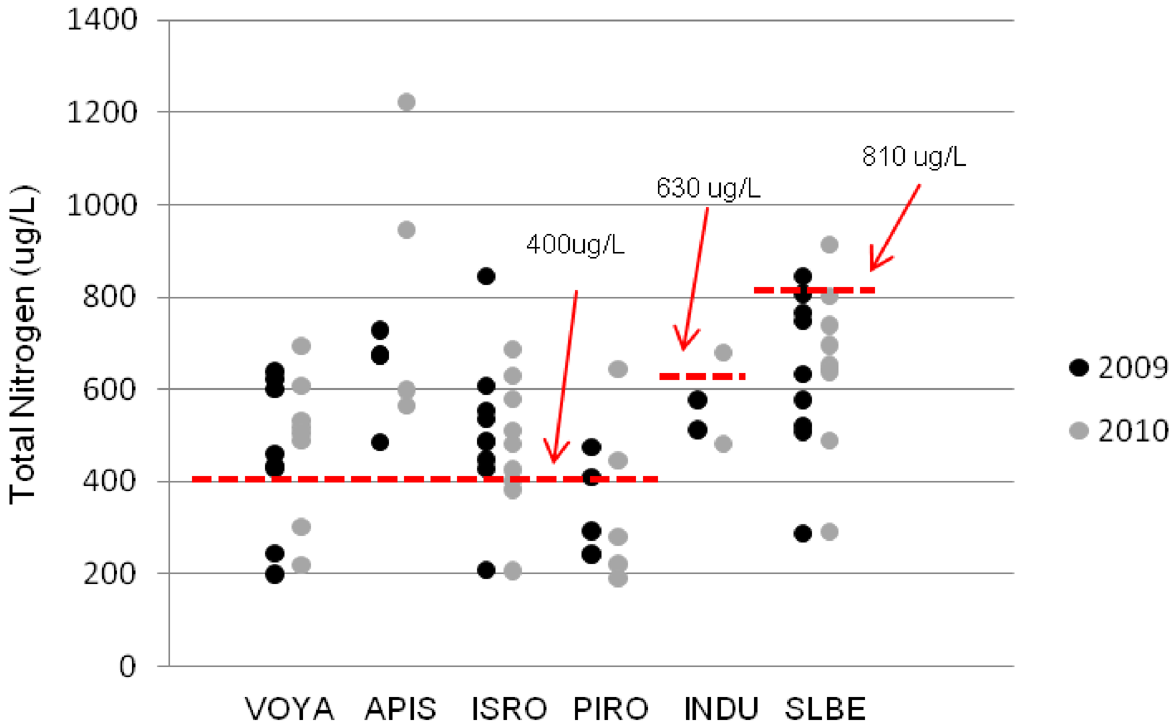

Figure 5. Mean total nitrogen (TN) levels for lakes across six parks in the Great Lakes Network, 2009 and 2010. Points above the dotted lines indicate lakes with mean TN levels greater than the USEPA reference criteria (USEPA 2000a, b, c). Park codes as in text.

All parks except INDU had lakes that exceeded EPA reference criteria for NO_3+NO_2-N (Figure 6). One lake at PIRO (Miners), one lagoon at APIS (Stockton Island), and several lakes at SLBE had unusually high levels of NO_3+NO_2-N. Studies to determine the sources of NO_3+NO_2-N in these lakes are warranted. If sources are anthropogenic, appropriate management actions can be initiated.

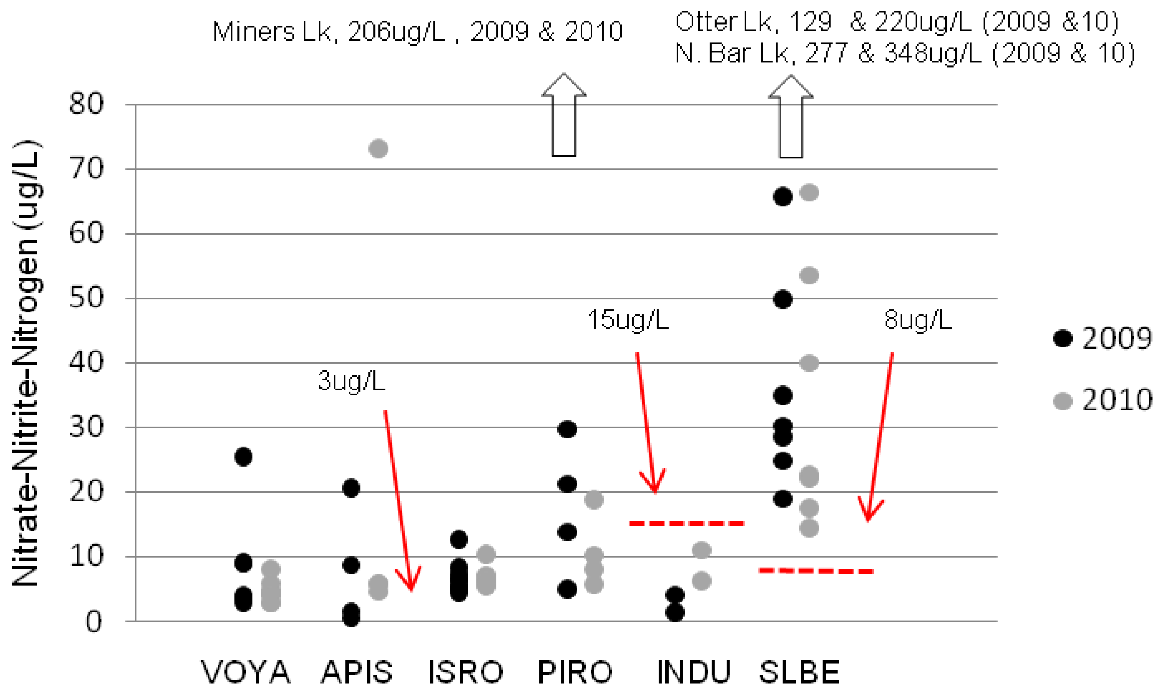

Figure 6. Mean nitrate+nitrite-nitrogen (NO_3+NO_2-N) levels for lakes across six parks in the Great Lakes Network, 2009 and 2010. Points above the dotted lines indicate lakes with mean NO_3+NO_2-N levels greater than the USEPA reference criteria (USEPA 2000a, b, c). Note the break in the scale for lakes at PIRO and SLBE. Park codes as in text.

Trophic State

Carlson and Simpson (1996) define trophic state as the total algal biomass in a waterbody at a given time and location. The Carlson trophic state index (TSI; Carlson 1977) of a lake can be calculated using values of Secchi depth, chl-*a* concentration, or TP concentration. We used chl-*a* concentration, which is the preferred method, to calculate TSI for lakes in 2009 and 2010. Most GLKN index lakes are mesotrophic (Figure 7), with TSI values between 30 and 50. Generally, lakes with a TSI <30 are considered oligotrophic and usually have clear water, while lakes with TSI values >50 are considered eutrophic and usually have limited transparency (Wetzel 2001).

See Appendices A-F for calculations of TSI in 2009 and 2010 based on Secchi, TP, and chl-*a*, and see the individual park sections below for changes in TSI over time.

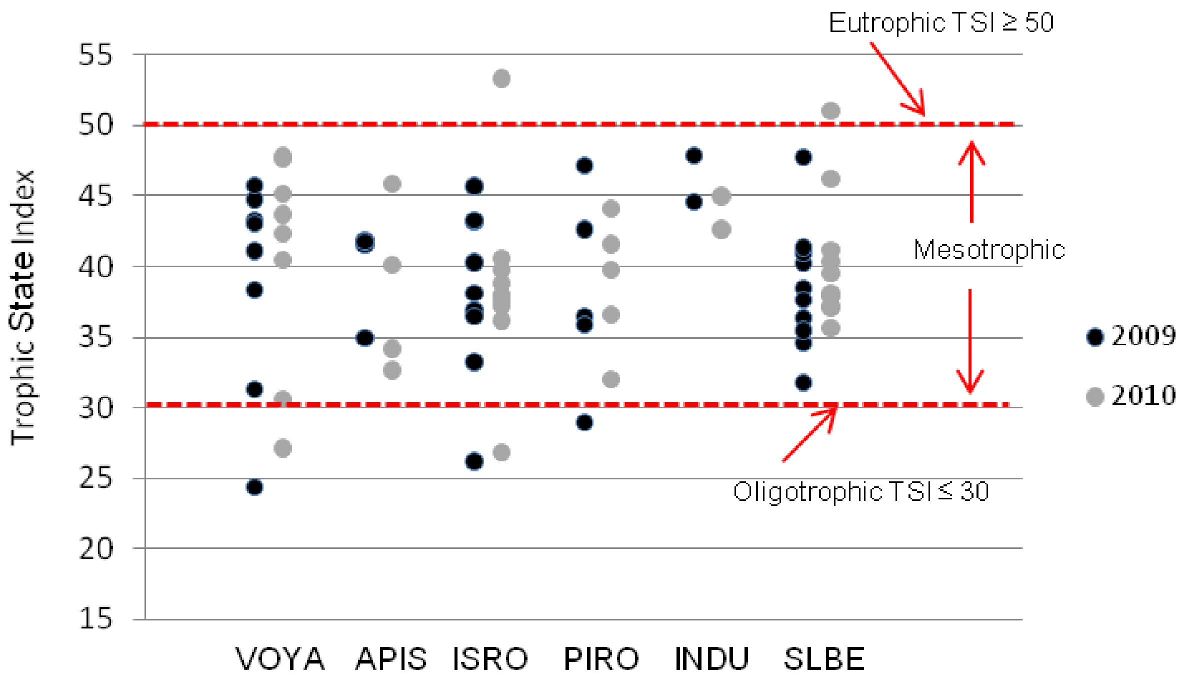

Figure 7. Trophic state indices calculated from mean chlorophyll-*a* measurements of lakes across Great Lakes Network parks, 2009 and 2010. Park codes as in text.

Park-Specific Comments and Additional Results

The water quality monitoring program faces a number of challenges every year. Consistency across parks and years and conducting monitoring at all six parks every year are probably the two biggest challenges. Consistency issues include changes in personnel from year to year, differences in data and sample collection techniques among personnel, differences in the timing of data and sample collection among years and across parks, differences among multiprobes, and differences among contract laboratories.

In the first years of implementation of the monitoring program, some inconsistencies were unavoidable. However, we have been making improvements every year. With multi-year agreements in place for laboratory analyses, we expect to avoid many of the contracting hassles we experienced in prior years and receive more reliable results. The addition of two permanent positions (R. Damstra covering ISRO and assisting with other aspects of the inland lakes monitoring program, and J. LeDuc at VOYA) substantially increases the depth and consistency of the program.

In 2010, we deployed a vertical array of continuously logging thermistors in Lake Richie, ISRO (see ISRO section, below). The data collected over the summer show the rate of warming, the depth to which warm water extended, and mixing events. After downloading the summer data, the array was re-deployed in late fall and will not be downloaded again until May, 2011. This deployment over the winter and spring will allow for data collection during ice-off and early season warming. We selected Lake Richie for this first array because of recent blooms of cyanobacteria, which we suspect are driven by climatic factors (ice-off times, duration of growing season, and frequency of mixing and re-suspension of nutrients).

We are planning to deploy a similar array in one lake at each of VOYA, PIRO, and SLBE. Given the travel restrictions in 2011, we will be working closely with park staff to accomplish as much of the water quality monitoring as possible.

In the following park-specific sections we present water level, TSI, and nutrient data since monitoring began. We have not conducted a statistical analysis of trends yet, as we feel the early monitoring inconsistencies may confound any trends. Instead, we present the data over time as an exploration of potential trends and possible early warning of degradation. We also discuss any additional sampling conducted in each park, and conclude with comments on logistics and plans for future monitoring.

Voyageurs National Park

Additional Data

In 2010, sediment samples were collected from 16 lakes for analysis of diatom communities. This marks the second sampling of these lakes (the first sampling was conducted in 2006) and will allow analysis of change in diatom communities over the last five years. Results of this analysis, expected in 2011, will help us interpret results of our water quality monitoring.

Once again we collaborated with USGS on mercury sampling in five lakes (Ek, Shoepack, Brown, Ryan, and Peary) in both 2009 and 2010. Such collaboration is beneficial to both agencies, as it reduces costs yet continues the flow of data for lakes susceptible to high levels of methylation of mercury.

When our monitoring program began in 2006, drought conditions were extreme and lake levels were low. In subsequent years the amount of precipitation increased, and lake levels generally responded (Figure 8). Notable exceptions are Shoepack and Locator Lakes. In these two lakes, beaver activity over-rode the effects of precipitation.

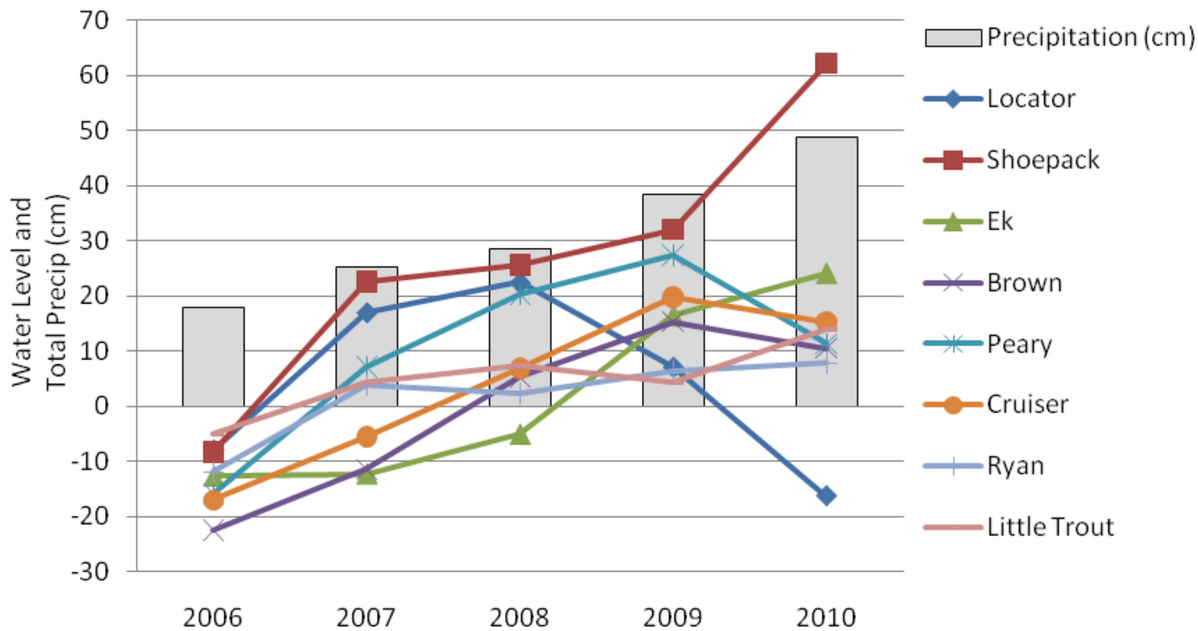

Figure 8. Mean summer lake levels and precipitation, Voyageurs National Park. Water level is measured relative to permanent benchmarks at each lake. All lake water levels are relative to the first measurement taken, which was June 2006 (i.e., June 2006 is set to zero). Mean 2006 water levels are negative because the water levels dropped throughout the course of the summer.

The trophic state index of most lakes at VOYA has changed only slightly since monitoring began in 2006 (Figure 9) and may reflect differences in weather from year to year (e.g., hot, dry years may lead to greater algal production). Shoepack, Ek, and Peary lakes, which are relative shallow, were eutrophic (>50) in 2006 and 2008 (2007 data are not available), but dropped into the mesotrophic range in 2009 and 2010 (between 30 and 50). Cruiser Lake began as mesotrophic, but since has dropped into the oligotrophic category (<30).

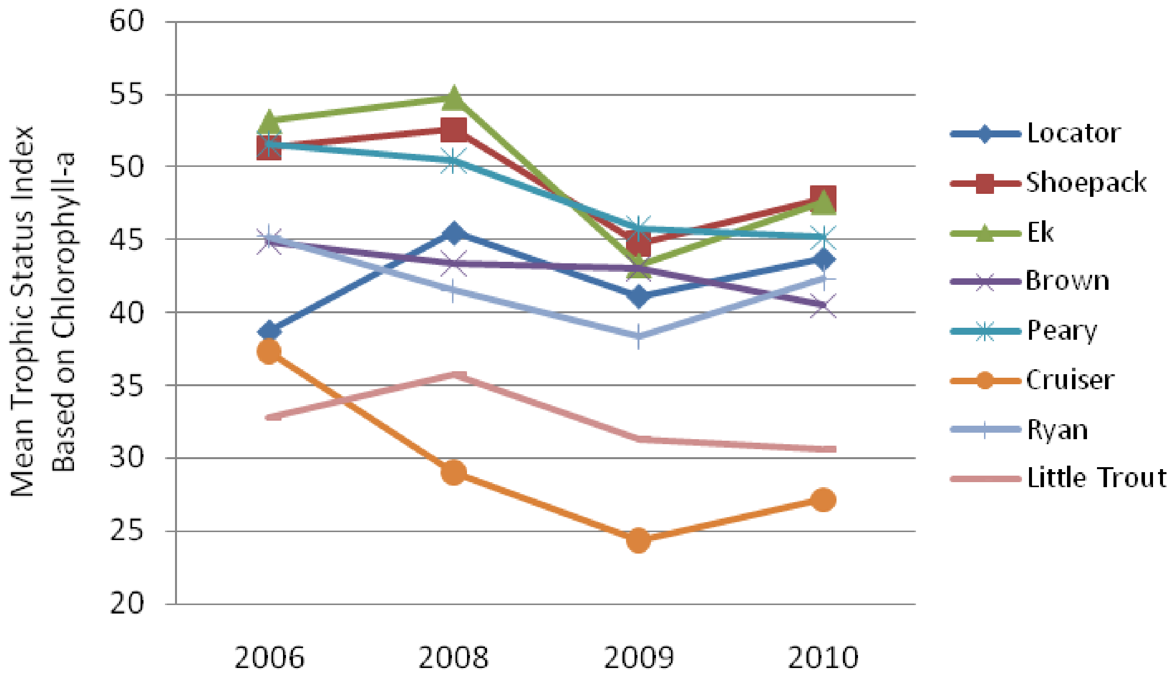

Figure 9. Mean trophic state index values for lakes at Voyageurs National Park, calculated using chlorophyll-*a* concentration. Data are not available for 2007.

Mean concentrations of TP and TN have not changed appreciably since 2006 (Figure10a, b). Cruiser and Little Trout Lakes have consistently been below EPA reference criteria; Shoepack, Ek, and Peary Lakes have been above EPA reference criteria. Locator, Brown, and Ryan Lakes, have shown minor variations above and below the EPA reference criterion for TP, but have been slightly greater than the TN criterion.

Even though several of the index lakes exceed the EPA reference criterion for TP, none of the lakes exceed Minnesota's eutrophication criterion (30 ug/L) for lakes designated as Aquatic Recreation Use (Class 2B) for the Northern Lakes and Forest Ecoregion (Heiskary and Wilson 2008). Minnesota has also established eutrophication criteria for the response variables chl-*a* (9 ug/L) and Secchi depth (2.0 m). Several lakes have occasionally exceeded the chl-*a* criterion and/or had Secchi depth measurements that were shallower than the criterion. Cruiser and Little Trout Lakes, designated as lake trout lakes, are subject to stricter state criteria (TP = 12 ug/L, chl-*a* = 3 ug/L, and Secchi depth = 4.80 m). They have met these criteria.

Variations in the concentrations of NO_3+NO_2-N and NH_4-N are generally consistent across lakes (Figure 10c, d), that is, lakes experience increases and decreases in the same years. Exceptions are Ryan Lake for NO_3+NO_2-N and Shoepack Lake for NO_3+NO_2-N and NH_4-N. Causes for these exceptions are unknown at this time. The unusually high NO_3+NO_2-N value for Locator Lake in 2006 was due to a single sample in July (102 ug/L) that may have been contaminated, as levels have been consistently low since then.

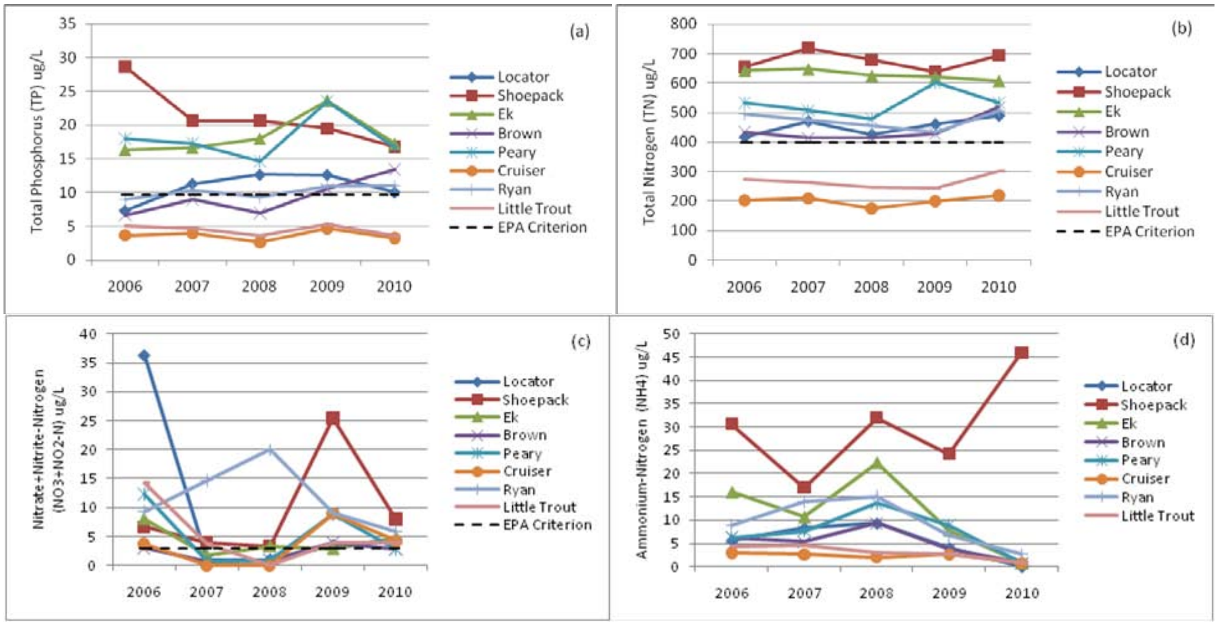

Figure 10. Mean concentration of nutrients in lakes at Voyageurs National Park: total phosphorus (a), total nitrogen (b), nitrate+nitrite-nitrogen (c), and ammonium-nitrogen (d).

Logistics

In 2009, GLKN hired a biological science technician (Claire Kissane) who was stationed at the park. Field assistance was provided by the park in exchange for some of C. Kissane's time. All index lakes were sampled on schedule and 14 additional lakes were sampled once during the season.

GLKN's monitoring was accomplished, though communication was difficult because C. Kissane was stationed at Ash River with limited access to e-mail and telephone. We ran into some difficulties sharing refrigerator and freezer space with other projects, so at the end of the season GLKN purchased an upright refrigerator/freezer for water quality use only. This unit is now in building 95.

In 2010, a position shared by the park and the Network was filled through the Student Career Experience Program (SCEP) (Jaime LeDuc). We have high hopes that this new position will increase consistency in sampling and decrease the amount of time and travel required by the Network. Additional field assistance was acquired by GLKN paying for park staff time. All index lakes were sampled on schedule, though because J. LeDuc had to return to school in August, sampling was completed by the Network with park assistance. The final round of sampling in 2010 occurred approximately two weeks earlier than in prior years. We will likely keep this round in August in the future so as to ensure all three rounds are conducted when lakes are stratified, and to accommodate typical school schedules.

We expect to continue monitoring the eight index lakes in 2011. We hope to work with park staff to deploy an array of continuous logging thermistors in one index lake.

Apostle Islands National Lakeshore

Additional Data

In 2008, when we installed the permanent benchmarks at Stockton Island and Little Sand Bay (LSB) Lagoons and the temporary benchmarks at Michigan and Outer Island Lagoons, we discussed with the park (J. Elias and J. Van Stappen) whether the benchmarks were needed at all four lagoons. (The park was reluctant to grant permission to install permanent benchmarks at the lagoons located in designated wilderness [Michigan and Outer Island lagoons]). If the lagoons acted similar to one another then perhaps two could serve as proxies for all four. The data from 2009 and 2010 show that water levels in the lagoons do not behave similarly across lagoons (Figure 11). It appears that LSB and Michigan Island Lagoons generally track water levels of Lake Superior; Stockton Island Lagoon may or may not track Lake Superior levels, perhaps depending on whether the lagoon is connected to Lake Superior at the time of sampling; and Outer Island Lagoon fluctuates independently of Lake Superior levels. Additional years of monitoring data are needed to understand patterns across lagoons and relative to Lake Superior.

To gather more data in a relatively short time, we could install continuously logging depth probes in the lagoons. Such probes cost approximately $450 each and could be installed discreetly. The disadvantage is that they generate a tremendous amount of data to handle.

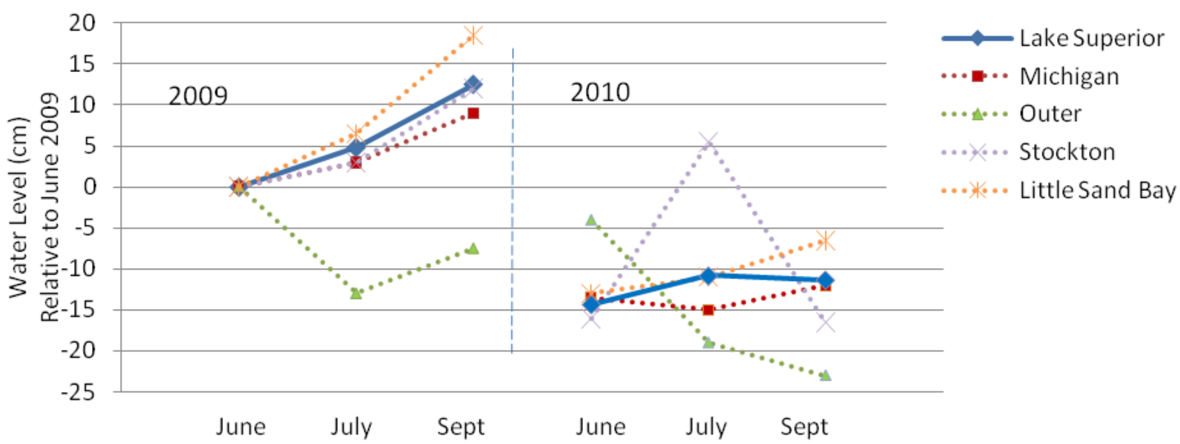

Figure 11. Water levels of Apostle Island lagoons and Lake Superior. All levels are relative to June 2009, which is set to zero. Lake Superior data acquired from the Army Corps of Engineers.

The trophic state of all four lagoons, calculated using chl-*a* concentration, has declined since 2008, though all lagoons remain in the mesotrophic category (TSI between 30 and 50; Figure 12a). This slight decline is interesting given that TSI calculated using TP concentrations has increased over the same time period (Figure 12b). The increases in TP concentrations either have not led to increased algae production perhaps due to the dark tannin-staining of the water, or zooplankton may have reduced the algae biomass through grazing.

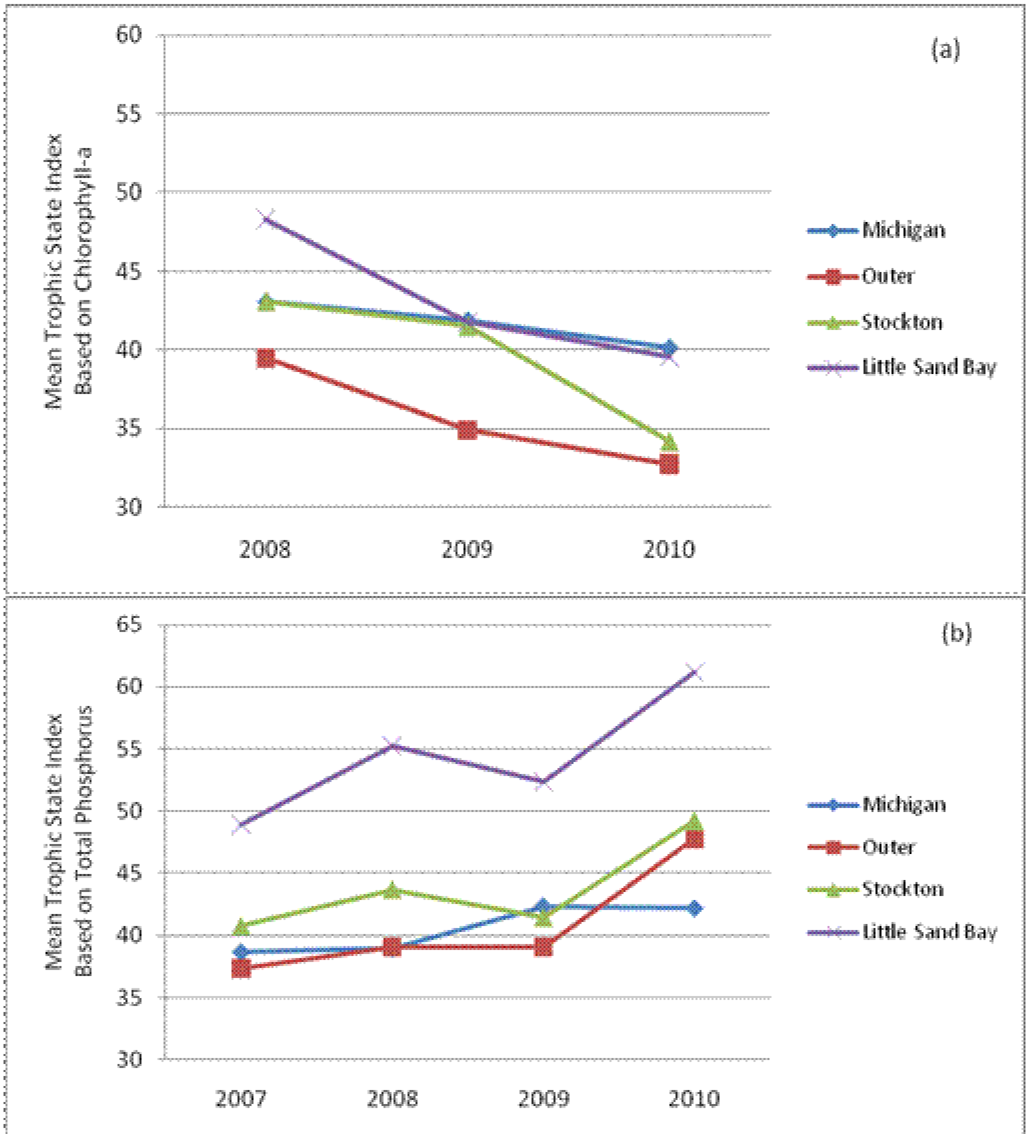

Figure 12. Mean trophic state index values for lakes at Apostle Islands National Lakeshore, calculated using chlorophyll-*a* concentration (a) and total phosphorus concentration (b). Data are not available for chlorophyll-*a* in 2007.

Nutrient concentrations have been remarkably variable since monitoring began in 2007 (Figure 13 a-d). This is likely due in part to the relatively rapid rates of nitrification that occur in these lagoons, which function more like wetlands than like lakes. TP and TN concentrations at LSB and Stockton Island lagoons are affected by the exchange of water with Lake Superior, and in the case of LSB, runoff from the entire watershed is received via the Little Sand River. This watershed differs from those of the other lagoons in land use and ownership, as agriculture occurs on privately held parcels upstream of the park.

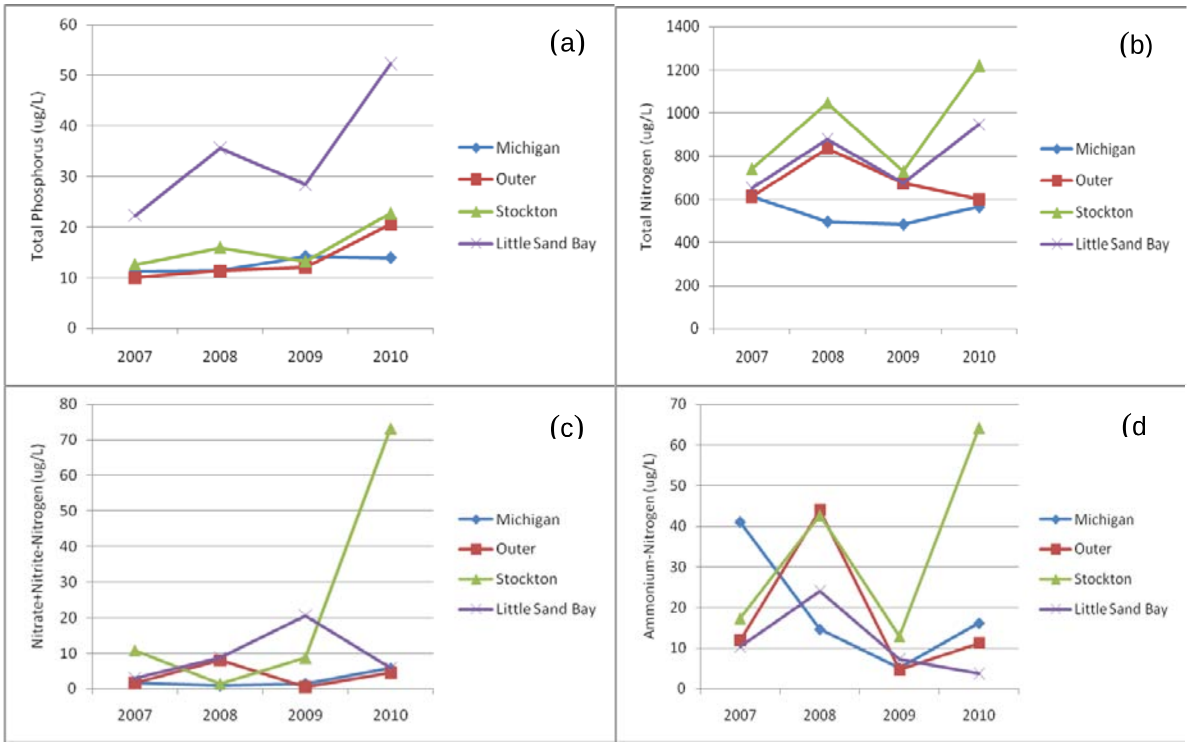

Figure 13. Mean concentration of nutrients in lagoons at Apostle Islands National Lakeshore; total phosphorus (a), total nitrogen (b), nitrate+nitrite-nitrogen (c), and ammonium-nitrogen (d).

Logistics

All sampling was completed by GLKN staff as planned. When possible, we work with park staff to assist with park projects. During each sampling round, we often transported park personnel and outside researchers to sites and islands other than our sampling sites and we assisted the park by picking up or delivering supplies. We will continue to assist with park operations as long as it does not compromise the ability to accomplish sampling at our sites.

We expect to continue monitoring the four lagoons in 2011 and will be collecting bottom sediments from all except LSB for analysis of diatoms. Sediment samples will not be collected from LSB, as the flow prevents sediments from accumulating except in the backwaters.

Isle Royale National Park

Additional Data

In 2009, signs of a cyanobacterial bloom were observed at Sargent Lake late in the season. In 2010, strong cyanobacterial blooms developed on Lake Richie in early August and visitors reported blooms at Chickenbone, Whittlesey, and Desor Lakes. GLKN visited Chickenbone and Whittlesey lakes, both non-index lakes, to check for blooms and to take field measurements with the multiprobe and Secchi disk. No sign of a bloom was observed at Chickenbone Lake. At Lake Whittlesey it appeared as though a bloom had occurred earlier, but had dissipated by the time we sampled (after fall turnover had occurred). No signs of a bloom were detected at Lake Desor during routine sampling.

We suspect that warmer temperatures, longer growing seasons, and increased frequency of mixing in the water column (which re-suspends nutrients) may be causing the recent blooms of cyanobacteria. In order to better understand these processes, GLKN deployed a moored array (Damstra, in prep.) of temperature probes near the deepest part of Lake Richie on May 28, 2010. The temperature probes collect water temperature data hourly throughout the water column, allowing us to determine rate of warming, the depth to which warm water extends, and the frequency and extent of mixing events. Temperature/light probes are located near the top of the array (1.5 m and 3.0 m) to help pinpoint ice-on and ice-off dates.

Data from June through September, 2010 show surface temperatures approached 27 °C in early August, which is quite warm for a lake of this depth (11m) and latitude (Figure 14). Temperatures ≥ 20 °C extended down to depths of over six meters, which is over halfway through the water column. Warm temperatures coincided well with the beginning of the cyanobacteria bloom in early August. Complete mixing of the water column occurred in early- to mid-June during a storm event and in early September during fall turnover. Partial mixing occurred in late June/early July due to two separate rain and sustained wind events.

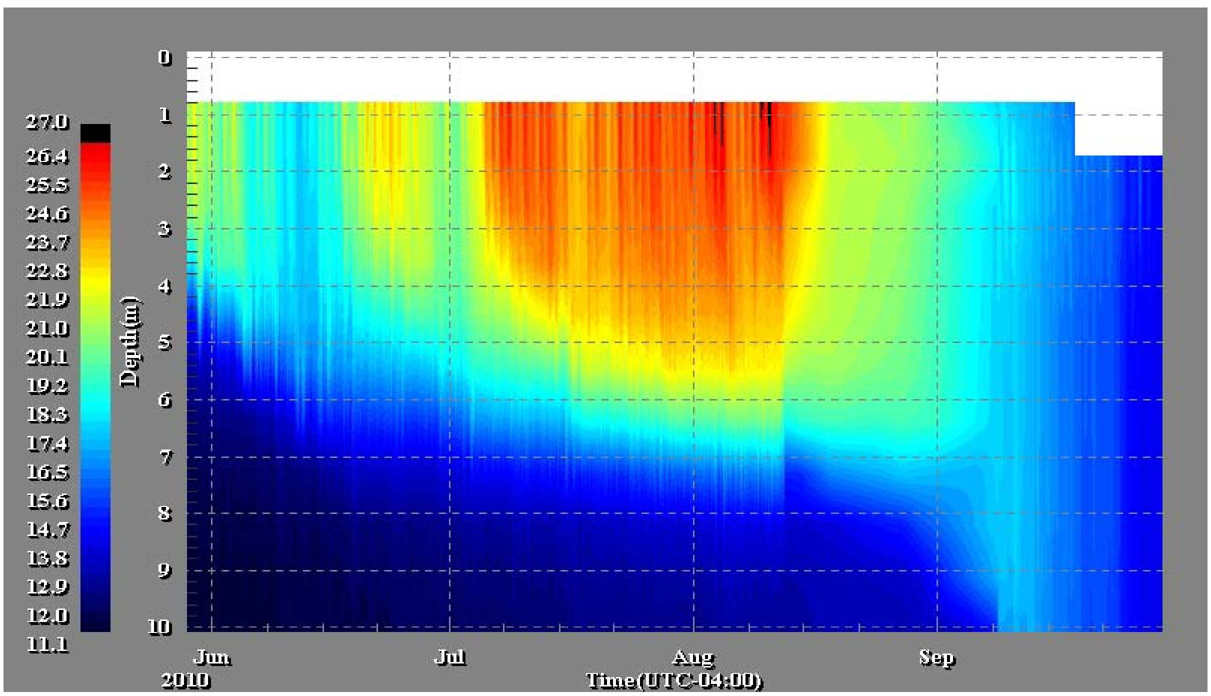

Figure 14. Temperature profiles of Lake Richie, Isle Royale National Park, 28 May 2010 – 29 September 2010. Data were collected at 60 minute intervals, except from mid-August to early September, when the data were collected at approximately seven day intervals.

Water levels of index lakes generally have been highest during the first round of sampling and have gradually declined throughout the season. Since monitoring began in 2007, most lakes experienced their highest mean summer level in 2008 (Figure 15). Lake George is an exception, as it continued to increase in 2009, dropping slightly in 2010. We will investigate beaver activity in the watershed of Lake George as a possible explanation for its water level pattern. The largest changes within a lake have been approximately 30 cm – an increase between 2007 and 2009 at Lake George, and a decrease at Beaver Lake between 2008 and 2010.

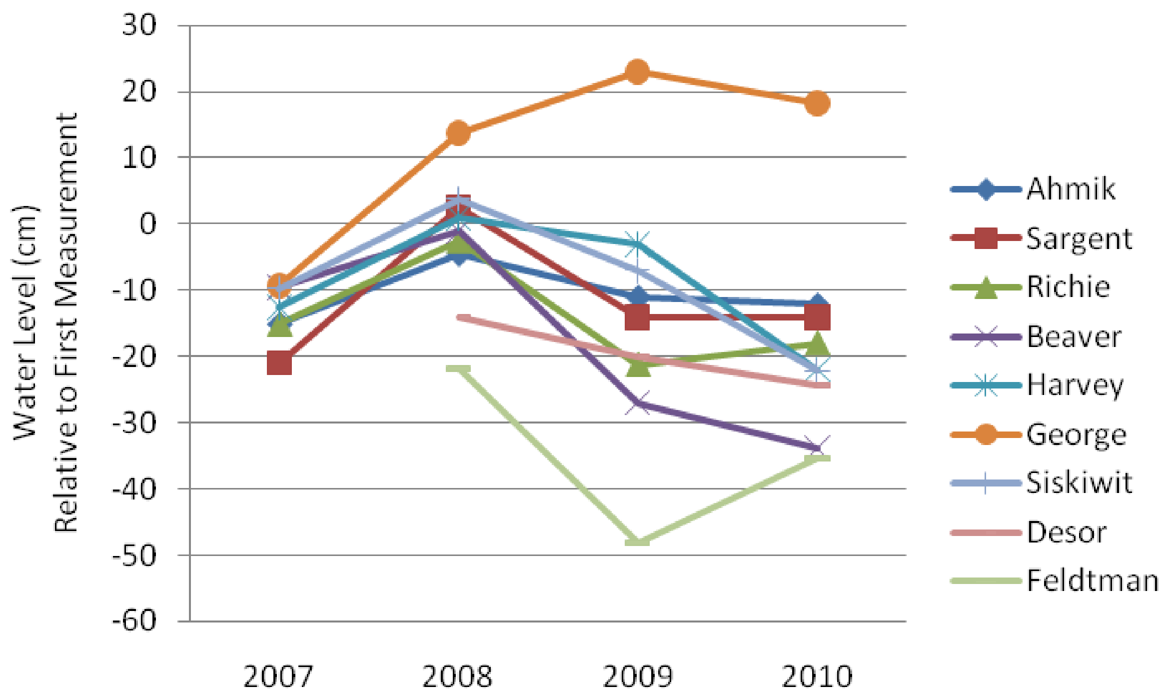

Figure 15. Mean summer water levels of index lakes at Isle Royale National Park. Water levels are relative to the first June measurement (i.e., June 2007 or 2008 set to zero).

The mean trophic state indices as calculated by chl-*a* concentration indicate most lakes are mesotrophic (index values between 30 and 50) and have changed little since monitoring began (Figure 16a). Siskiwit Lake tends to be oligotrophic (TSI<30), while Lake Richie tends to be eutrophic (TSI>50). The TSIs calculated using TP concentration (Figure 16b) show both Lakes Richie and Ahmik to have been eutrophic some years. Blooms of cyanobacteria in Lake Richie make its eutrophic state obvious. Although Lake Ahmik's TSI(TP) scores are high enough to rank it eutrophic, the phosphorus may go into macrophyte production rather than algal production or algae biomass may be limited by zooplankton grazing.

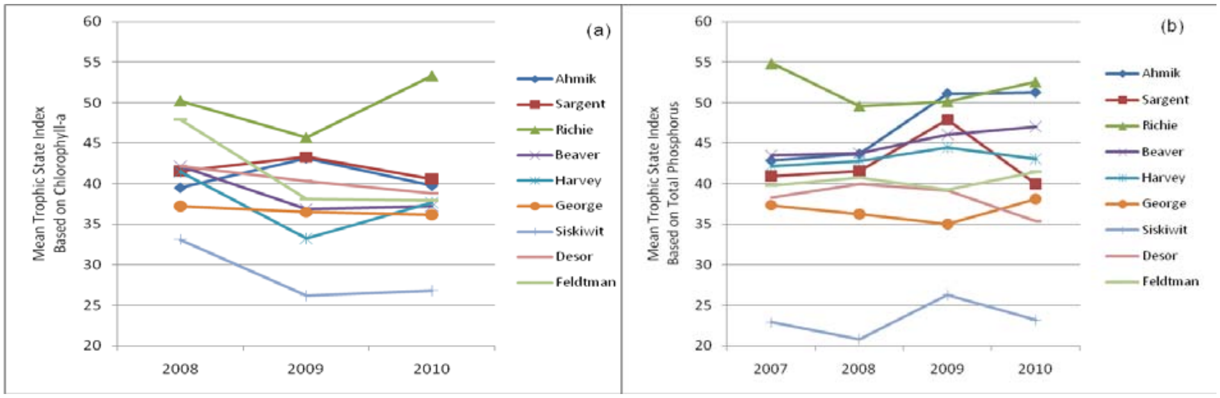

Figure 16. Mean trophic state index of lakes at Isle Royale National Park as calculated by chlorophyll-*a* (a) and total phosphorus (b) concentrations. Chlorophyll-*a* data not available for 2007.

Siskiwit Lake is the only lake with TP and TN concentrations consistently below EPA reference criteria (Figure 17a, b). Variations in TP and TN have occurred in some lakes (notably, Ahmik, Sargent, and Richie), and hints of an increasing trend in TP can be seen at Lake Ahmik and Beaver Lake. With the exception of Siskiwit Lake, all lakes showed a remarkably consistent pattern in NO_3+NO_2-N concentrations (Figure 17c). Relatively consistent patterns in NH_4-N concentrations also occurred, with Lake Ahmik exhibiting an exaggerated version of the variations (Figure 17d).

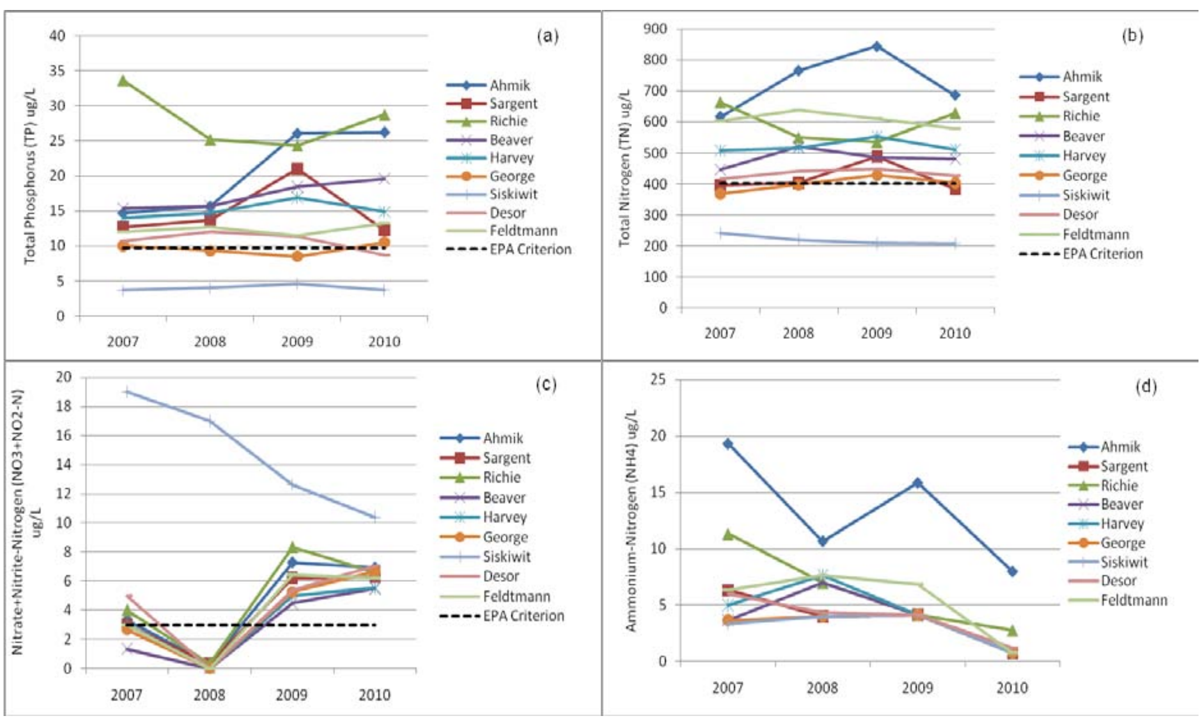

Figure 17. Mean concentration of nutrients in lakes at Isle Royale National Park; total phosphorus (a), total nitrogen (b), nitrate+nitrite-nitrogen (c), and ammonium-nitrogen (d).

Other work completed at ISRO in 2010 included bathymetric mapping on Lake Harvey, establishing sampling sites on Benson and Washington creeks for future wadeable streams monitoring, and assisting USGS with the re-establishment of the stream gauging station on Washington Creek. GLKN staff also assisted park staff with loon surveys and fisheries assessments.

Logistics

Due to delays in the hiring process for the GLKN lakes specialist position, index lakes were not sampled in June 2009. The middle round of sampling in 2009 was completed by a combination of GLKN, ISRO, and MWRO staff, volunteers, and outside researchers from the University of Maine. The final round of sampling in 2009 was conducted by the newly-hired GLKN lakes specialist (R. Damstra) and other GLKN staff.

In 2010, all three rounds of sampling occurred on schedule with the exception of Lake Desor, which was not sampled during the final round due to poor weather. Sampling was conducted by GLKN with assistance from ISRO staff, and GLKN exchanged field assistance with University of Maine researchers. Whenever possible, GLKN staff shared boat operations to save fuel and boating hours with park staff.

Pictured Rocks National Lakeshore

Additional Data

Mean summer water levels dropped substantially at Legion and Chapel Lakes since June 2008 (Figure 18). Beaver activity at the outlet of Chapel Lake likely impacts water levels. The drop in water levels at Legion Lake cannot be as easily explained. It is a seepage lake that is largely influenced by precipitation, and mean summer precipitation increased throughout the area from 2008 to 2010. The rate of evaporation may be out-pacing that of precipitation for small seepage lakes like Legion.

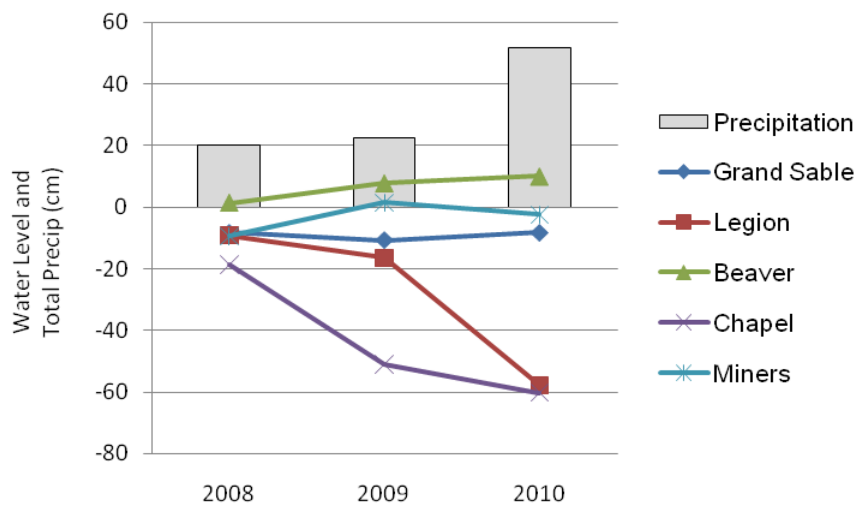

Figure 18. Mean summer lake levels and precipitation, Pictured Rocks National Lakeshore. All lake water levels are relative to June 2008 (i.e., June 2008 levels set to zero).

Index lakes at PIRO have generally been mesotrophic throughout our monitoring tenure, with TSI values between 30 and 50 (Figure 19a, b). Additional monitoring in the future will help us determine whether the declines (TSI based on chl-*a*; Figure 19a) at Miners, Grand Sable, and Beaver Lakes are trends. That TSIs based on TP do not show the same decline in these lakes (Figure 19b) may mean that phosphorus is used by macrophytes rather than fueling algal blooms, or algal biomass is reduced though zooplankton grazing.

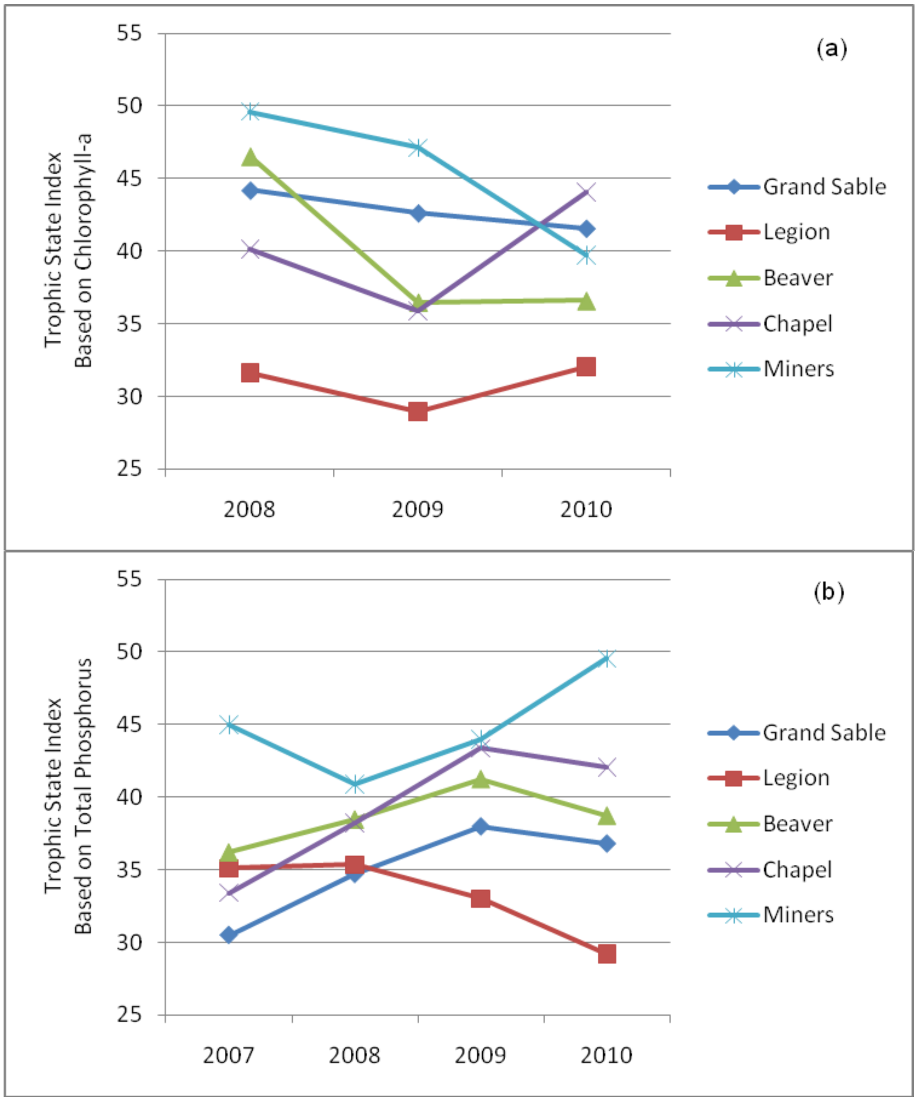

Figure 19. Mean trophic state index of lakes at Pictured Rocks National Lakeshore as calculated by chlorophyll-*a* (a) and total phosphorus (b) concentrations. Chlorophyll-*a* data not available for 2007.

While some variation in nutrient levels occurred in all lakes since monitoring began in 2007, the changes in Miners Lake are the most noteworthy (Figure 20a, b, c, d). Miners Lake is a shallow flow-through lake that is frequently mixed during the growing season. Such mixing brings nutrients that have settled into bottom sediments back into suspension. Miners Lake also receives substantial groundwater inputs along the east side of the lake (L. Loope, personal communication). Park and GLKN staff collaborated on a proposal in 2010 to determine the source of the high NO_3+NO_2-N concentrations in Miners Lake, though we did not receive funding. We will pursue additional funding sources as they arise.

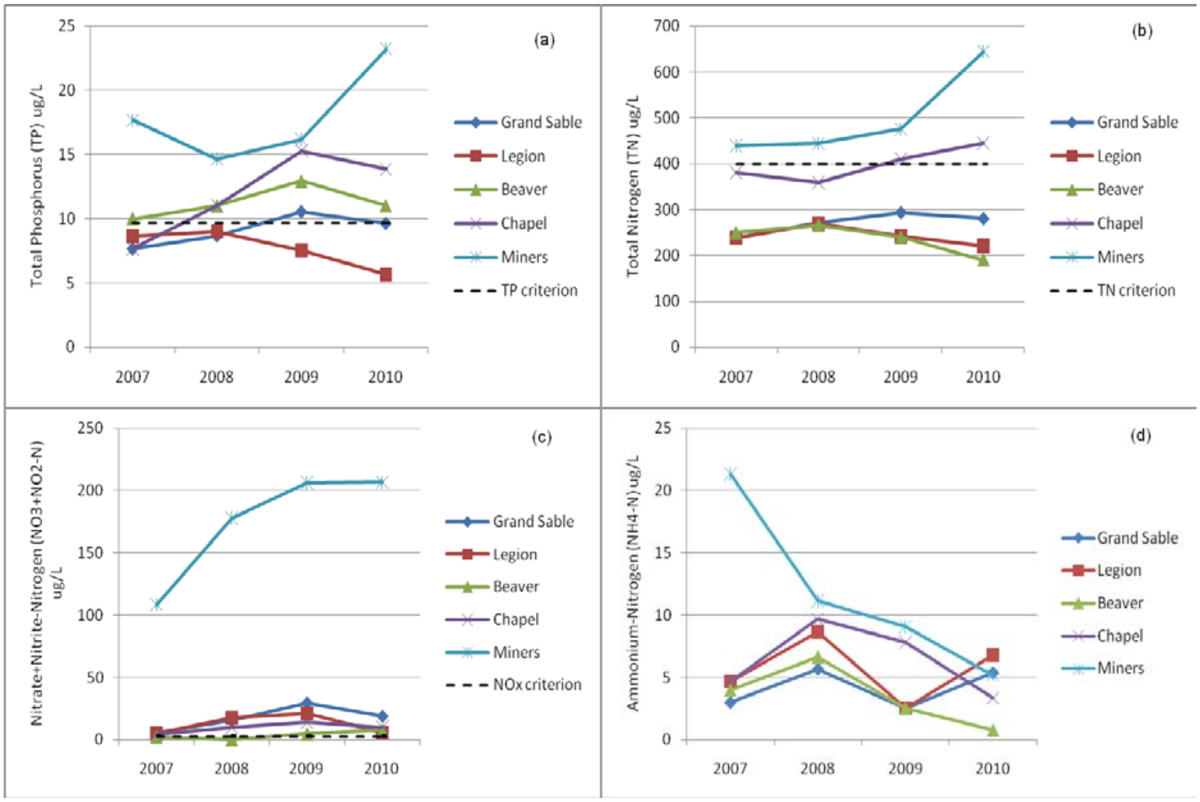

Figure 20. Mean concentration of nutrients in lakes at Pictured Rocks National Lakeshore; total phosphorus (a), total nitrogen (b), nitrate+nitrite-nitrogen (c), and ammonium-nitrogen (d).

Logistics

All sampling was completed by park staff as planned in 2009 and 2010, with assistance from a GLKN staff member (D. VanderMeulen) during the middle round. In addition to the index lakes, field measurements were collected at Little Beaver Lake.

Personnel have been consistent over the last four years; their expertise has been beneficial to the program and has resulted in reliable data. With the assistance of park staff again in 2011, we expect to continue monitoring the five index lakes. We hope to work with park staff to deploy an array of continuous logging temperature probes in one index lake.

Indiana Dunes National Lakeshore

Additional Data

Water level at Long Lake had been measured relative to a USGS groundwater well cap since 2006. In 2010, the USGS replaced the well cap, which would have interrupted our water level record had not USGS maintained their own record of water levels in the lake. We were able to convert our records since 2006 to values that now correspond to the new well cap. As a back-up, a nail was pounded into the boardwalk in 2010, and water level is now measured from both the nail and the well cap.

Water levels at Long Lake have usually been highest during the first round of sampling (late April/early May) and have declined throughout the season (Figure 21a). At Middle Lagoon, the lowest water levels have occurred early in the season (Figure 21b). Prior to 2009, Long Lake received water from an adjacent impoundment that had been used by a water treatment plant to store excess water. This impoundment was taken out of service in 2009 and water levels have dropped to a new all-time low (Figure 22).

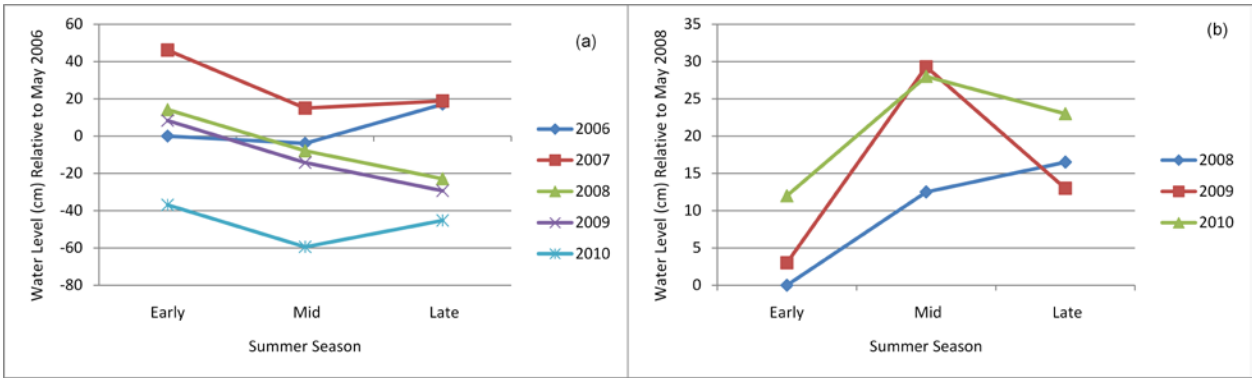

Figure 21. Water levels throughout the summer season for Long Lake (a) and Middle Lagoon (b), Indiana Dunes National Lakeshore, relative to first measurement (i.e., May 2006 in Long Lake and 2008 in Middle Lagoon set to zero).

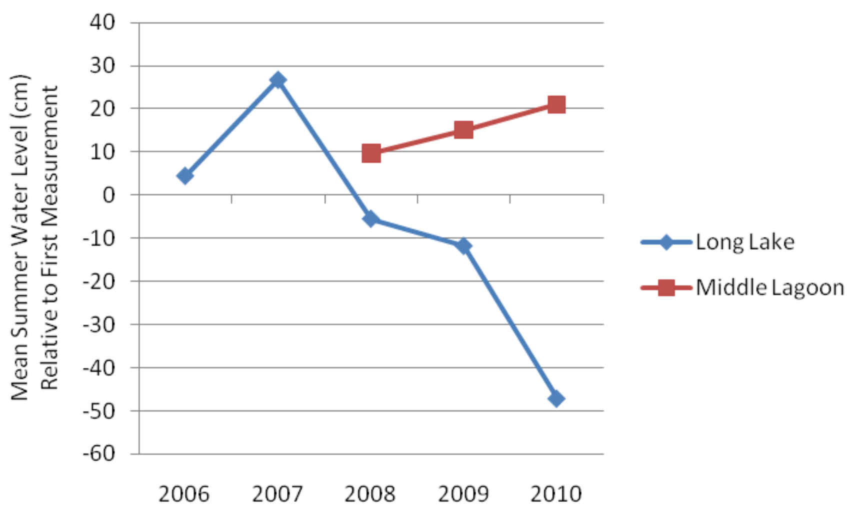

Figure 22. Mean summer water levels at Long Lake and Middle Lagoon, Indiana Dunes National Lakeshore, relative to first measurement (i.e., May 2006 in Long Lake and 2008 in Middle Lagoon set to zero).

Trophic state indices (TSIs) of both Long Lake and Middle Lagoon have remained within the mesotrophic category (between 30 and 50) since monitoring began (Figure 23). Both lakes are dominated by macrophytes; algal blooms have not been observed and chl-*a* concentrations have been moderate.

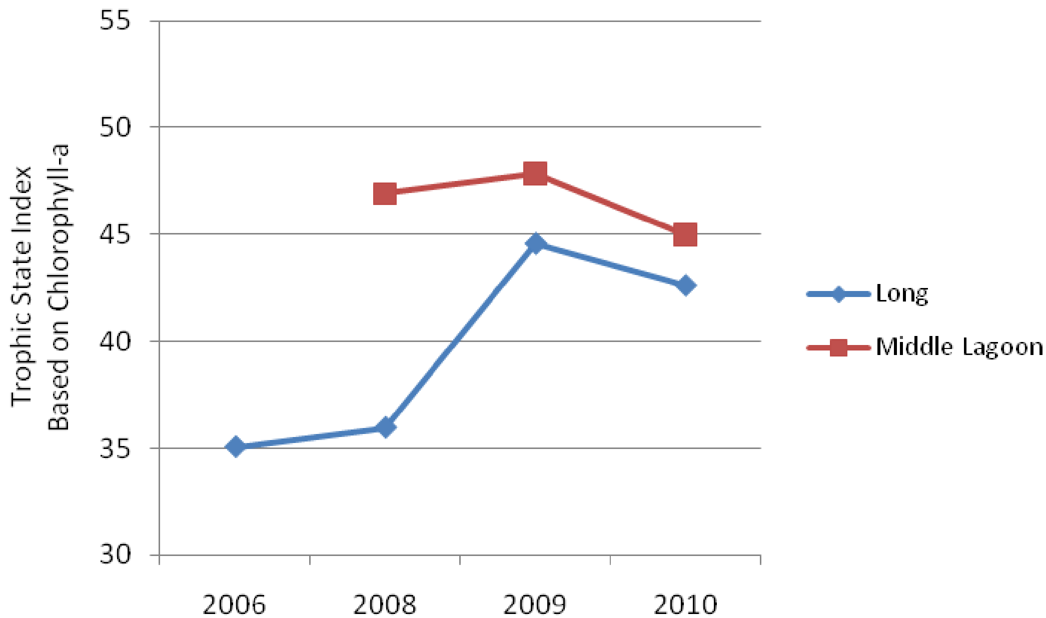

Figure 23. Mean trophic state index of lakes at Indiana Dunes National Lakeshore as calculated by chlorophyll-*a*.

TP and TN concentrations have fluctuated around the levels of the EPA reference criteria (Figure 24a, b). Concentrations of NO_3+NO_2-N and NH_4-N appear to have changed dramatically since monitoring began (Figure 24c, d), but the absolute values are actually quite low and the changes do not represent large ecological shifts.

Logistics
All sampling was completed by INDU and GLKN staff as planned in 2009 and 2010. Although Middle Lagoon is not one of the index lakes in the GLKN monitoring program, all parameters were measured both years. In 2009, we also collected field data on the Little Calumet River three times. This sampling was not conducted in 2010 in anticipation of initiating a wadeable streams monitoring protocol. Results from the Little Calumet River are not included in this report but are available upon request.

We expect to continue monitoring field parameters at Long Lake and Middle Lagoon in 2011. Laboratory parameters will continue to be measured at Long Lake, and as funds permit, at Middle Lagoon. Because of the severe travel ceilings, sampling will be conducted by park staff. GLKN will continue to fund the program (personnel, equipment, laboratory analyses) and will manage the data. We hope to collect sediment samples for analysis of diatom communities and will work with park staff to accomplish this. As we finalize a protocol for wadeable streams, the Little Calumet River will become part of that project.

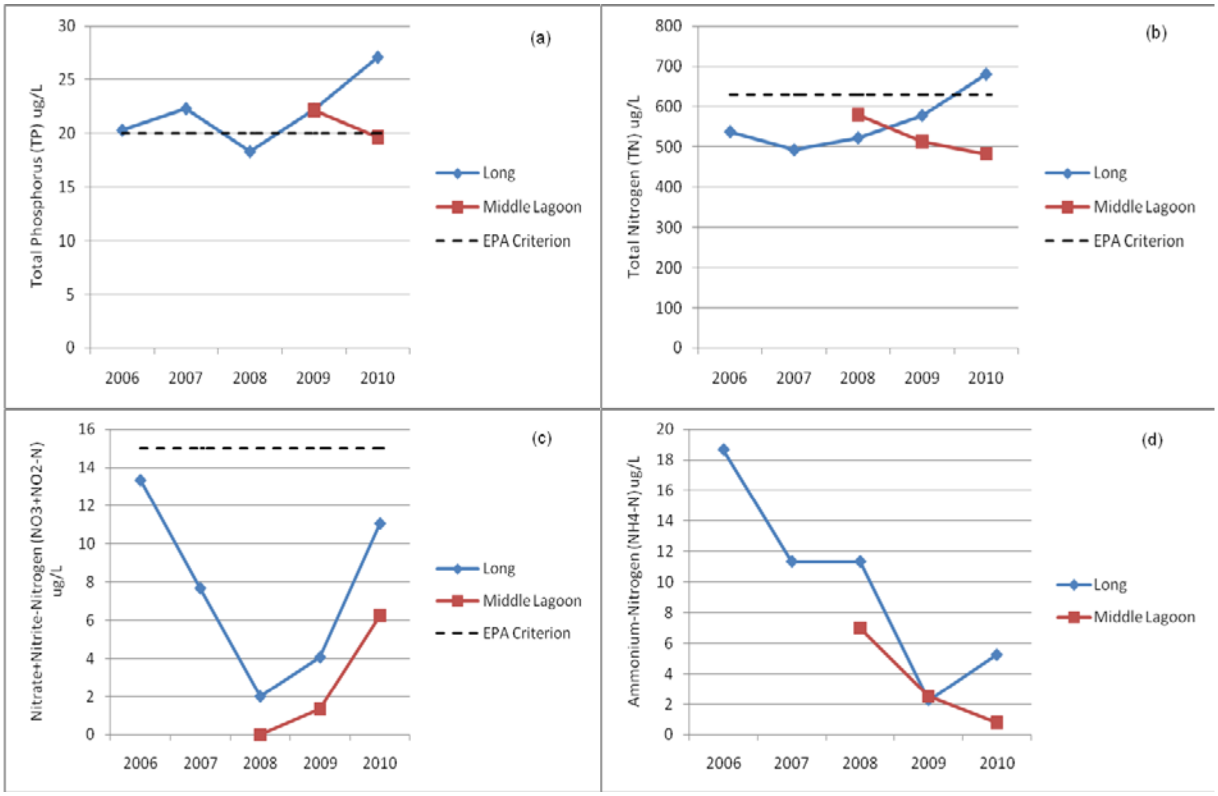

Figure 24. Mean concentration of nutrients in lakes at Indiana Dunes National Lakeshore; total phosphorus (a), total nitrogen (b), nitrate+nitrite-nitrogen (c), and ammonium-nitrogen (d).

Sleeping Bear Dunes National Lakeshore

Additional Data

In 2009, sediment samples were collected from 10 lakes for analysis of diatom communities. This marks the second sampling of these lakes (the first sampling was done in 2005) and will allow analysis of change in diatom communities in recent years. Results of this analysis are included in the final report on GLKN's five-year diatom project (Edlund et al. 2011). These changes will help interpret changes in water quality.

Water levels of most lakes have remained relatively stable since monitoring began (Figure 25). Notable exceptions are North Bar and Bass Lakes. North Bar has an intermittent connection to Lake Michigan and its water level can change dramatically depending on whether the connection is open or closed. The water level of Bass Lake is influenced by beaver activity and the drop in water level from 2008 to 2009 was likely due to the failure or removal of a beaver dam. Though not as dramatic as North Bar or Bass Lakes, Lake Manitou has also experienced a decline in water level since 2008. Anecdotal information suggests that the inlet on the south side of the lake was considerably drier in 2009 compared to 2004 (P. Murphy, personal communication). Since we do not have data extending back to 2004, additional monitoring data are needed to determine whether this is indeed a trend.

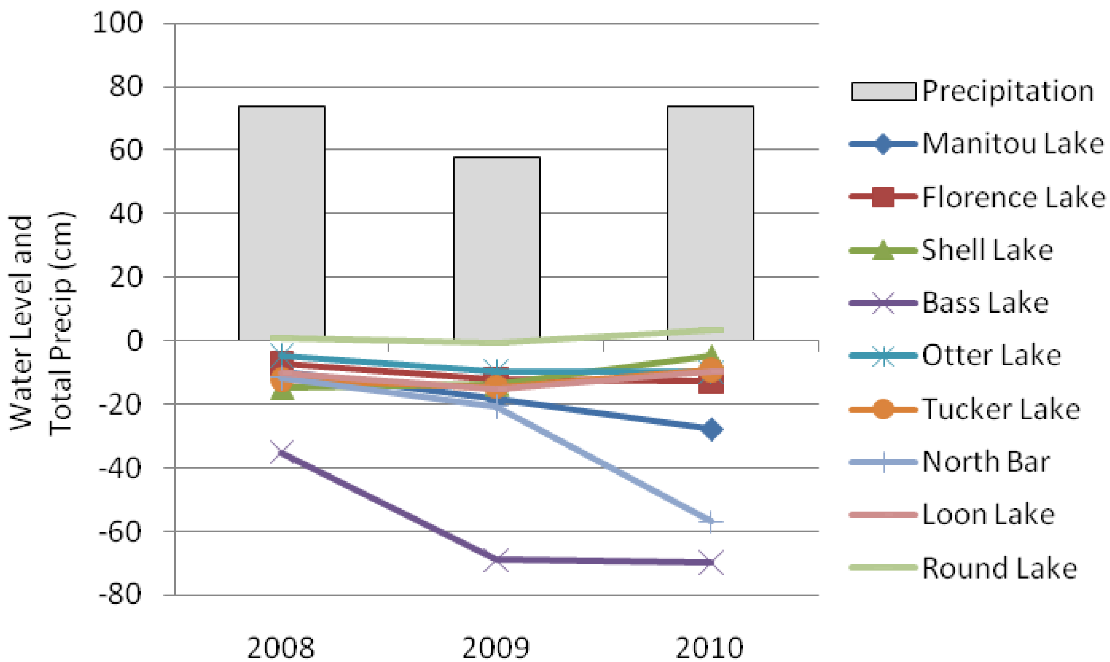

Figure 25. Mean summer water levels of lakes at Sleeping Bear Dunes National Lakeshore relative to June 2008 (i.e., June 2008 levels set to zero).

The mean trophic state index as calculated from chlorophyll-*a* concentration has categorized almost all of the lakes as mesotrophic (between 30 and 50; Figure 26a). Narada Lake had a score >50 in 2010, indicating a eutrophic state. All of Lake Narada's scores are based on a single late season measurement per year, and do not represent seasonal means. TSIs based on TP concentration are shown (Figure 26b) because data from 2007 are included (chl-*a* data are not available from 2007), but TSI(chl-*a*) is the preferred method. In general, when TSI(chl-*a*) is greater than TSI(TP) algae are likely using available phosphorus. When TSI(TP) is greater than TSI(chl-*a*), the algal biomass may be reduced by zooplankton grazing or there may be a lag in algal production.

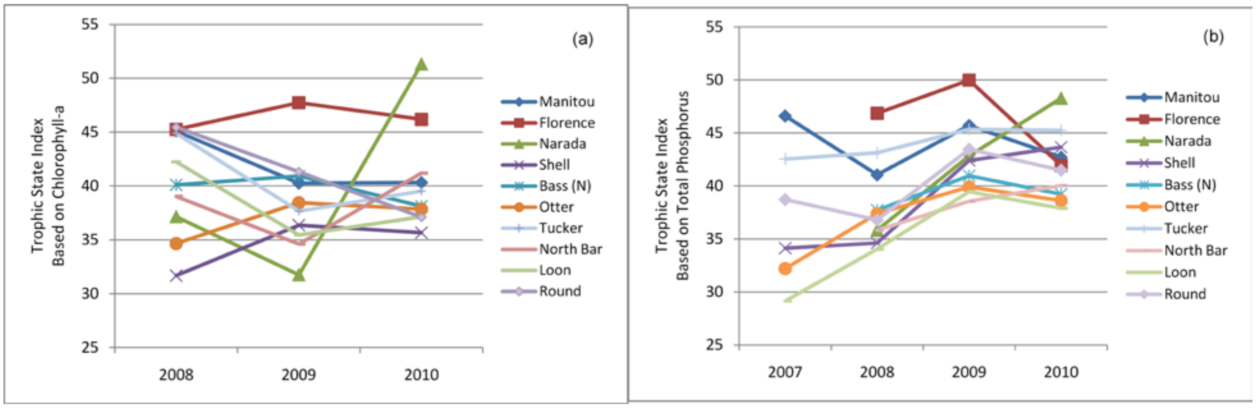

Figure 26. Mean trophic state index of lakes at Sleeping Bear Dunes National Lakeshore as calculated by chlorophyll-*a* (a) and total phosphorus (b) concentrations. Chlorophyll-*a* data not available for 2007.

Mean TP and TN concentrations have generally remained below EPA reference criteria since monitoring began (Figure 27a, b). Mean concentrations of NO_3+NO_2-N, however, have often been above the EPA criterion (Figure 27c). Especially noteworthy are the high levels of NO_3+NO_2-N and NH_4-N (Figure 27c, d) at Otter and North Bar Lakes. Park and GLKN staff collaborated on a proposal in 2010 to determine the source of the high NO_3+NO_2-N concentrations, though we did not receive funding. We will pursue additional funding sources as they arise.

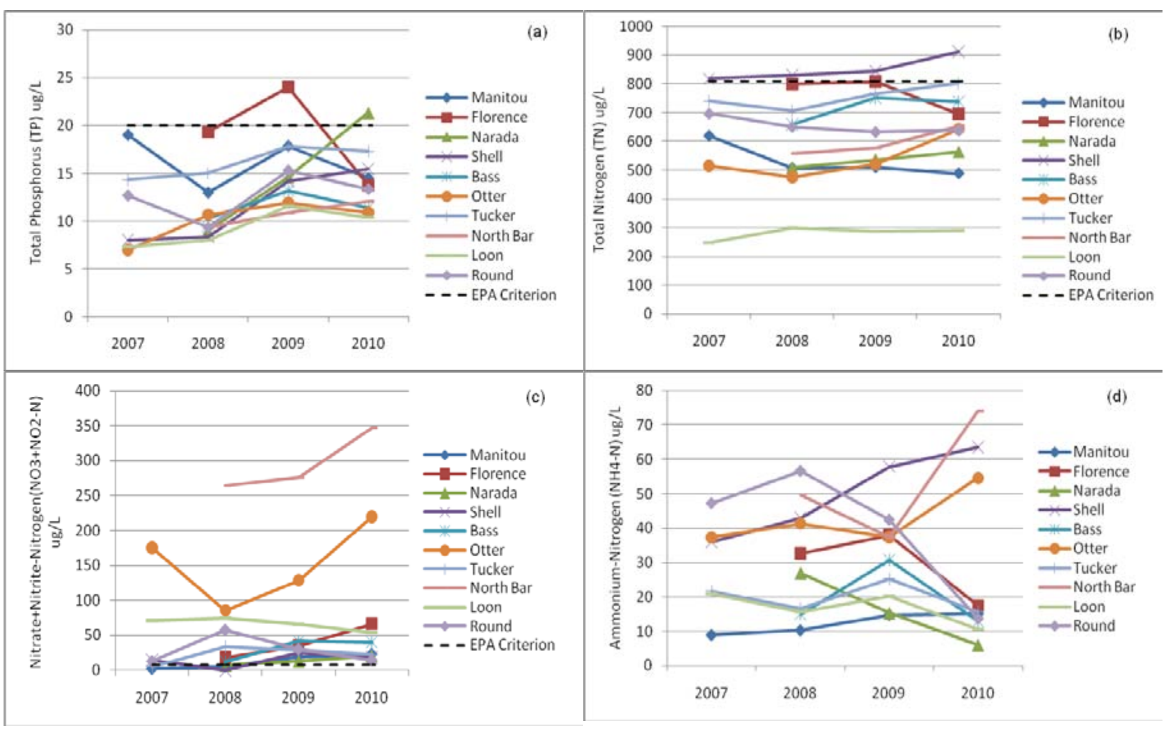

Figure 27. Mean concentration of nutrients in lakes at Sleeping Bear Dunes National Lakeshore; total phosphorus (a), total nitrogen (b), nitrate+nitrite-nitrogen (c), and ammonium-nitrogen (d).

Logistics

All sampling was completed by SLBE staff as planned in 2009 and 2010, with assistance from GLKN during the middle round of sampling in 2010. Four lakes were sampled in addition to the index lakes (North Bar, Otter, Narada, and Tucker) both years. Narada was sampled in September only so as not to disturb nesting loons. All lakes with the exception of Narada now have permanent benchmarks installed.

We expect to continue monitoring all six index lakes in 2011 and will include the additional four lakes as funding (GLKN and/or SLBE) permits. We hope to work with park staff to deploy an array of continuous logging temperature probes in one index lake.

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Appendix A. Field and laboratory results for Voyageurs National Park.

Appendix A1 **–** index lakes, 2009; ***A2*** **–** non-index lakes, 2009; ***A3*** **–** index lakes, 2010; ***A4*** **–** non-index lakes, 2010.

Multiprobe measurements for pH, specific conductance, dissolved oxygen, and temperature are reported from 1.0 m depth. Results in **bold font** indicate values less than the laboratory reporting limit (also known as the method quantitation limit, or MQL). Blank cells indicate that no results are available. Abbreviations used are as follows (units of measurement are in parentheses):

Alk	Alkalinity (mg/L $CaCO_3$)
Ca^{+2}	Calcium (mg/L)
Cl^-	Chloride (mg/L)
DOC	Dissolved Organic Carbon (mg/L)
Mg^{+2}	Magnesium (mg/L)
K^+	Potassium (mg/L)
SiO_2	Silicate (mg/L)
Na^+	Sodium (mg/L)
SO_4^{-2}	Sulfate (mg/L)
NH_4-N	Ammonium-Nitrogen (µg/L)
NO_3+NO_2-N	Nitrate+Nitrite (µg/L)
TN	Total Nitrogen (µg/L)
TP	Total Phosphorus (µg/L)
TN-Hypolimnion	Bottom TN (µg/L)
TP Hypolimnion	Bottom TP (µg/L)
chl-*a*	Chlorophyll-*a* (µg/L)
DO	Dissolved Oxygen (mg/L)
SC25	Specific Conductance (µS/cm)
pH	pH (standard units)
Temp	Temperature (°C)
Secchi	Secchi Depth (m)
Water Level	Water Level (m)
M Hg	Methyl Mercury (ng/L)
T Hg	Total Mercury (ng/L)
TSI(chl-*a*)	Trophic State Index calculated from chlorophyll-*a* concentration
TSI(TP)	Trophic State Index calculated from TP concentration
TSI(Secchi)	Trophic State Index calculated from Secchi depth

Appendix A1. Voyageurs National Park, index lakes, 2009.

		Lake									
Parameter	**Month/Yr**	*Locator*	*Shoepack*	*Ek*	*Brown*	*Peary*	*Cruiser*	*Ryan*	*Little Trout*	**Duplicate**	**Duplicate Location**
Alk	7/09	**6**	**7**	**8**	**ND**	10	**7**	10	17		
Ca^{+2}	7/09	2.5	2.3	2.8	2.0	2.5	2.0	2.4	3.7		
Cl^{-}	7/09	0.7	0.8	0.6	0.5	0.5	0.3	0.5	0.4	0.4	Locator
DOC	7/09	12	17	13	11	10	4.8	15	5.9		
Mg^{+2}	7/09	1.0	0.9	1.2	0.9	1.1	0.7	1.0	1.6		
K^{+}	7/09	0.6	0.5	0.6	0.5	0.5	0.5	0.4	0.4		
SiO_2	7/09	1.9	1.5	1.6	7.9	1.2	0.8	2.6	0.3		
Na^{+}	7/09	1.0	1.0	1.1	0.9	1.0	0.6	0.9	0.8		
SO_4^{-2}	7/09	3.2	3.1	1.7	2.1	2.1	2.5	3.4	3.1		
NH_4-N	6/09	**4.0**	10.0	6.0	**3.0**	12.0	**0.0**	12.0	**0.0**		
NH_4-N	7/09	**4.2**	22.7	**4.2**	**4.2**	11.0	**4.2**	**4.2**	**4.2**		
NH_4-N	10/09	**4.2**	40.0	13.5	**4.2**	**4.2**	**4.2**	**4.2**	**4.2**	**4.2**	Little Trout
NH_4-N	average	4.1	24.2	7.9	3.8	9.1	2.8	6.8	2.8		
NO_3+NO_2-N	6/09	**0.0**	37.0	**0.0**	**0.0**	14.0	16.0	17.0	**0.0**		
NO_3+NO_2-N	7/09	6.2	23.1	5.2	7.4	7.9	5.3	6.0	5.5		
NO_3+NO_2-N	10/09	4.2	16.2	3.4	4.4	4.8	5.4	4.1	5.1	6.4	Little Trout
NO_3+NO_2-N	average	3.5	25.4	2.9	3.9	8.9	8.9	9.0	3.8		
TN	6/09	541	560	564	404	834	205	424	228		
TN	7/09	423	652	627	445	480	215	452	252		
TN	10/09	418	704	673	439	490	181	423	252	256	Little Trout
TN	average	461	639	621	429	601	200	433	245		
TP	6/09	19.0	17.0	24.0	13.0	33.0	**5.0**	12.0	**6.0**		
TP	7/09	10.9	21.2	19.2	8.8	20.8	5.3	10.4	4.9		
TP	10/09	8.1	20.3	27.7	9.8	16.9	3.6	10.4	4.9	5.3	Little Trout
TP	average	12.7	19.5	23.6	10.5	23.6	4.6	10.9	5.3		
TN-Hypolimnion	7/09	550	661	604	650	531	1261	430	370		
TP-Hypolimnion	7/09	16.9	21.8	27.6	20.6	28.7	190.0	10.0	15.5		

Appendix A1. Voyageurs National Park, index lakes, 2009 (continued).

		Lake									
Parameter	**Month/Yr**	*Locator*	*Shoepack*	*Ek*	*Brown*	*Peary*	*Cruiser*	*Ryan*	*Little Trout*	**Duplicate**	**Duplicate Location**
chl-*a*	6/09	1.6	3.3	3.3	2.9	2.5	0.4	1.5	0.9		
chl-*a*	7/09	1.8	4.1	3.3	3.3	5.4	0.2	2.2	0.6		
chl-*a*	10/09	3.7	2.8	2.1	2.3	3.3	0.6	1.6	1.2	1.0	Little Trout
chl-*a*	average	2.3	3.4	2.9	2.8	3.8	0.4	1.8	0.9		
DO	6/09	9.2	9.7	9.7	8.8	8.9	10.4	9.0	10.6		
DO	7/09	9.4	8.6	8.9	9.6	8.8	9.1	9.7	9.2		
DO	7/09			9.2							
DO	10/09	9.1	8.0	8.6	8.7	8.6	9.1	8.4	9.1		
DO	average	9.2	8.8	9.1	9.0	8.8	9.5	9.0	9.6		
SC	6/09	25	22	26	21	24	21	24	37		
SC	7/09	25	22	27	21	25	21	24	37		
SC	7/09			27							
SC	10/09	25	23	27	21	25	21	24	36		
SC	average	25.0	22.3	26.8	21.0	24.7	21.0	24.0	36.7		
pH	6/09	7.2	7.1	7.7	7.3	7.5	7.9	7.2	7.8		
pH	7/09	7.6	7.2	7.6	7.2	7.7	7.6	7.5	7.9		
pH	7/09			7.5							
pH	10/09	7.5	6.9	7.6	7.4	7.5	7.7	7.0	7.8		
pH	average	7.5	7.0	7.6	7.3	7.6	7.7	7.2	7.8		
Temp	6/09	21.3	14.3	14.3	19.9	20.5	13.1	19.4	13.9		
Temp	7/09	20.0	18.3	18.6	19.9	19.6	20.1	20.4	18.9		
Temp	7/09			20.4							
Temp	10/09	20.0	19.0	19.0	21.7	21.0	19.8	20.9	19.5		
Temp	average	20.4	17.2	18.1	20.5	20.4	17.7	20.2	17.4		
Secchi	6/09	2.95	1.45	1.70	3.25	3.20	8.76	2.93	5.55		
Secchi	7/09	2.50	1.35	1.45	2.55	2.00		2.80	6.85		
Secchi	7/09			1.75							
Secchi	10/09	3.05	1.40	1.90	2.55	2.42	9.10	2.45	7.20		
Secchi	average	2.8	1.4	1.7	2.8	2.5	8.9	2.7	6.5		

Appendix A1. Voyageurs National Park, Index Lakes, 2009 (continued).

		Lake									
Parameter	**Month/Yr**	*Locator*	*Shoepack*	*Ek*	*Brown*	*Peary*	*Cruiser*	*Ryan*	*Little Trout*	**Duplicate**	**Duplicate Location**
Water Level	6/09	-0.93	-1.91	-0.86	-0.59	-1.21	-0.79	-1.04	-1.16		
Water Level	7/09	-0.93	-1.93	-0.94	-0.64	-1.26	-0.77	-1.05	-1.24		
Water Level	7/09			-0.94							
Water Level	10/09	-1.77	-1.72	-0.89	-0.63	-1.19	-0.80	-1.03	-1.11		
Water Level	average	-1.21	-1.85	-0.91	-0.62	-1.22	-0.78	-1.04	-1.17		
M Hg	6/09		0.21	0.12	0.14	0.09		0.09		0.09	Ek
M Hg	7/09		0.17	0.12	0.15	0.08		0.11			
M Hg	10/09		0.26	0.12	0.14	0.06		0.10			
M Hg	average		0.21	0.12	0.14	0.08		0.10			
T Hg	6/09		4.09	2.74	2.34	1.88		3.69		2.94	Ek
T Hg	7/09		3.63	2.24	1.99	1.44		2.86			
T Hg	10/09		3.59	2.04	1.81	1.27		2.64			
T Hg	average		3.77	2.34	2.05	1.53		3.06			
TSI(chl-*a*)	6/09	35	42	42	41	40	23	35	30		
TSI(chl-*a*)	7/09	36	44	42	42	47	14	38	26		
TSI(chl-*a*)	10/09	43	41	38	39	42	26	35	32		
TSI(chl-*a*)	average	39	43	41	41	44	22	36	29		
TSI(TP)	6/09	47	45	50	41	55	27	40	30		
TSI(TP)	7/09	39	48	47	35	48	28	38	27		
TSI(TP)	10/09	34	48	52	37	45	23	38	27		
TSI(TP)	average	41	47	50	38	50	26	39	28		
TSI(Secchi)	6/09	44	55	52	43	43	29	45	35		
TSI(Secchi)	7/09	47	56	55	47	50		45	32		
TSI(Secchi)	7/09			52							
TSI(Secchi)	10/09	44	55	51	47	47	28	47	32		
TSI(Secchi)	average	45	55	52	45	47	28	46	33		

Appendix A2. Voyageurs National Park, non-index lakes, 2009.

	Lake (Sample Date)													
Parameter	*War Club* (7/1/09)	*Quill* (6/25/09)	*Loiten* (7/1/09)	*Little Shoepack* (6/19/09)	*Jorgens* (6/23/09)	*Quarterline* (6/24/09)	*Agnes* (6/24/09)	*Oslo* (6/29/09)	*Fishmouth* (6/29/09)	*Beast* (6/26/09)	*Net* (6/30/09)	*Tooth* (6/30/09)	*O'Leary* (7/2/09)	*Mukooda* (7/2/09)
DO	9.1	8.6	9.7	8.8	8.9	7.8	7.9	8.8	9.3	8.4	7.6	8.7	9.2	9.83
SC	24	25	25	22	23	21	18	20	23	22	34	28	61	54
pH	7.4	7.6	7.6	7.5	7.5	6.7	6.6	7.5	7.9	7.5	7.3	7.5	7.9	7.95
Temp	16.9	24.1	17.2	22.1	22.7	23.1	23.9	18.5	19.0	23.7	17.6	17.5	17.1	16.63
Secchi	2.50	4.55	3.35	2.00	2.40	1.30	1.15	2.00	3.50	4.05	1.15	2.40	5.05	4.6
Water Level	-2.52	-1.22	-0.83	-1.24	-0.72	-1.35	-1.07	-0.95	-1.63	-1.49	-2.32	-1.16	-1.55	-1.565

Appendix A3. Voyageurs National Park, index lakes, 2010.

		Lake									
Parameter	**Month/Yr**	*Locator*	*Shoepack*	*Ek*	*Brown*	*Peary*	*Cruiser*	*Ryan*	*Little Trout*	**Duplicate**	**Duplicate Location**
Alk	7/10	**11**	**7**	**10**	**9**	**14**	**8**	**7**	**15**	**6**	Brown
Ca^{+2}	7/10	2.5	2.6	2.9	1.9	2.3	1.9	2.4	3.8	1.9	Brown
Cl^{-}	7/10	0.6	0.9	0.5	0.5	0.5	0.3	0.8	0.4	0.4	Brown
DOC	7/10	12	19	14	11	10	4.1	12	5.1	11	Brown
Mg^{+2}	7/10	1.1	1.0	1.3	0.9	1.1	0.7	1.0	1.6	0.9	Brown
K^{+}	7/10	0.5	0.4	0.6	0.4	0.4	0.4	**0.3**	0.3	0.4	Brown
SiO_2	7/10	2.6	**0.8**	**0.7**	1.5	**1.3**	**0.7**	2.1	**ND**	1.6	Brown
Na^{+}	7/10	0.9	0.9	1.0	0.8	0.9	0.6	0.9	0.8	0.8	Brown
SO_4^{-2}	7/10	3.0	2.6	**ND**	1.7	2.1	2.9	3.5	3.4	2.0	Brown
NH_4-N	6/10	**0.0**	35.8	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	Ek
NH_4-N	7/10	**2.4**	19.6	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**	Brown
NH_4-N	8/10	**0.0**	82.6	**0.0**	**0.0**	**0.0**	**0.0**	**5.5**	**0.0**	**0.0**	Peary
NH_4-N	average	0.8	46.0	0.8	0.8	0.8	0.8	2.6	0.8		
NO_3+NO_2-N	6/10	**3.2**	9.8	**4.5**	**1.9**	**0.0**	**3.9**	**3.6**	**3.4**	**4.3**	Ek
NO_3+NO_2-N	7/10	**6.8**	**7.9**	**6.8**	**5.7**	**5.0**	**4.6**	9.6	**4.5**	**4.3**	Brown
NO_3+NO_2-N	8/10	**3.2**	**6.3**	**3.3**	**1.7**	**3.8**	**4.3**	**4.3**	**4.1**	**3.3**	Peary
NO_3+NO_2-N	average	4.4	8.0	4.8	2.9	2.8	4.2	5.8	4.0		
TN	6/10	480	663	625	462	473	193	468	286	644	Ek
TN	7/10	577	684	615	733	656	281	590	364	576	Brown
TN	8/10	410	735	575	440	465	186	458	254	472	Peary
TN	average	489	694	608	519	533	220	505	301		
TP	6/10	10.8	17.5	18.9	17.6	15.0	**3.4**	9.2	**6.2**	19.6	Ek
TP	7/10	10.6	14.7	17.1	16.0	17.6	**2.3**	12.8	**2.2**	10.6	Brown
TP	8/10	**8.8**	18.3	15.4	10.6	17.6	**4.0**	11.0	**2.4**	17.7	Peary
TP	average	10.1	16.8	17.2	13.8	16.7	3.2	11.0	3.6		
TN-Hypolimnion	7/10	772		1163	1050	966	368	632	421	1021	Brown
TP-Hypolimnion	7/10	20.6		36.7	23.5	45.0	9.7	12.8	12.6	23.1	Brown

Appendix A3. Voyageurs National Park, index lakes, 2010 (continued).

		Lake									
Parameter	**Month/Yr**	*Locator*	*Shoepack*	*Ek*	*Brown*	*Peary*	*Cruiser*	*Ryan*	*Little Trout*	**Duplicate**	**Duplicate Location**
chl-*a*	5/10			3.65							
chl-*a*	6/10	3.2	4.1	4.5	2.7	4.0	0.7	2.3	1.2	5.30	Ek
chl-*a*	7/10	4.5	10.3	6.7	2.3	3.2	0.7	4.5	0.9	3.02	Brown
chl-*a*	8/10	3.7	2.9	7.5	2.8	5.7	0.7	3.1	1.0	6.46	Peary
chl-*a*	average	3.8	5.8	5.7	2.7	4.4	0.7	3.3	1.0		
DO	5/10			10.7							
DO	6/10	9.2	8.1	8.9	9.0	8.2	9.2	8.5	9.3		
DO	7/10	8.1	7.1	7.7	8.2	7.7	8.5	8.1	8.0		
DO	8/10	8.8	6.8	8.0	7.9	8.1	9.0	6.9	9.3		
DO	average	8.7	7.3	8.8	8.4	8.0	8.9	7.8	8.9		
SC	5/10			27							
SC	6/10	22	19	24	18	24	18	23	33		
SC	7/10	25	21	26	20	23	19	23	33		
SC	8/10	25	23	27	20	25	20	24	36		
SC	average	24	21	26	19	24	19	23	34		
pH	5/10			7.3							
pH	6/10	7.2	6.4	7.0	7.4	7.1	7.4	6.8	7.9		
pH	7/10	7.3	6.4	7.2	7.0	7.2	7.5	7.2	7.6		
pH	8/10	7.2	6.2	7.4	6.7	7.4	7.5	6.8	7.9		
pH	average	7.2	6.3	7.3	7.0	7.2	7.5	6.9	7.8		
Temp	5/10			11.2							
Temp	6/10	18.5	17.5	18.6	19.8	19.2	18.0	19.6	18.4		
Temp	7/10	24.9	23.3	23.1	24.4	23.3	22.5	24.7	24.0		
Temp	8/10	21.7	20.3	20.2	19.4	19.5	20.6	20.2	22.0		
Temp	average	21.7	20.4	18.3	21.2	20.7	20.4	21.5	21.5		
Secchi	5/10			1.96							
Secchi	6/10	2.55	1.40	1.74	2.90	2.30	8.95	2.40	6.00		
Secchi	7/10	2.80	1.20	1.75	2.80	2.40	7.40	2.40	7.37		
Secchi	8/10	2.90	1.70	2.05	2.20	1.80	6.75	3.03	6.20		
Secchi	average	2.75	1.43	1.87	2.63	2.17	7.70	2.61	6.52		

Appendix A3. Voyageurs National Park, index lakes, 2010 (continued).

		Lake									
Parameter	**Month/Yr**	*Locator*	*Shoepack*	*Ek*	*Brown*	*Peary*	*Cruiser*	*Ryan*	*Little Trout*	**Duplicate**	**Duplicate Location**
Water Level	5/10			-0.89							
Water Level	6/10	-1.42	-1.32	-0.75	-0.57	-1.09	-0.69	-1.07	-1.10		
Water Level	7/10	-1.45	-1.77	-0.86	-0.72	-1.44	-0.63	-1.01	-1.05		
Water Level	8/10	-1.47	-1.57	-0.86	-0.72	-1.61	-0.69	-1.00	-1.07		
Water Level	average	-1.4	-1.5	-0.8	-0.7	-1.4	-0.7	-1.0	-1.1		
M Hg	6/10		0.25	0.06	0.12	0.07		0.07		0.08	Ek
M Hg	7/10		0.46	0.12	0.17	0.10		0.09			
M Hg	8/10		0.51	0.17	0.09	0.07		0.12			
M Hg	average		0.41	0.12	0.13	0.08		0.09			
T Hg	6/10		3.76	2.14	2.15	1.51		2.65		2.1	Ek
T Hg	7/10		3.58	2.37	2.25	1.86		3.08			
T Hg	8/10		3.93	1.96	1.94	1.48		2.91			
T Hg	average		3.76	2.15	2.11	1.62		2.88			
TSI(chl-*a*)	6/10	42	44	45	40	44	27	39	32		
TSI(chl-*a*)	7/10	45	54	49	39	42	27	45	29		
TSI(chl-*a*)	8/10	43	41	50	41	48	27	42	30		
TSI(chl-*a*)	average	44	48	48	40	45	27	42	31		
TSI(TP)	6/10	38	45	47	46	43	22	36	30		
TSI(TP)	7/10	38	43	45	44	45	16	41	16		
TSI(TP)	8/10	35	46	44	38	45	24	39	17		
TSI(TP)	average	37	45	45	42	45	21	39	23		
TSI(Secchi)	6/10	47	55	52	45	48	28	47	34		
TSI(Secchi)	7/10	45	57	52	45	47	31	47	31		
TSI(Secchi)	8/10	45	52	50	49	52	32	44	34		
TSI(Secchi)	average	45	55	51	46	49	31	46	33		

Appendix A4. Voyageurs National Park, non-index lakes, 2010.

	Lake (Sample Date)						
Parameter	*War Club (8/24/10)*	*Jorgens (8/26/10)*	*Quarterline (8/26/10)*	*Agnes (8/25/10)*	*Oslo (8/17/10)*	*O'Leary (8/23/10)*	*Mukooda (7/29/10)*
DO	8.59	8.47	8.04	6.95	8.5	9.24	8.45
SC	24	23	20	20	20	59	50
pH	7.13	7.35	6.51	6.4	6.72	8.02	8.38
Temp	21.3	19.8	19.6	19.3	19.5	22.4	23.3
Secchi	2.80	2.175	1.0	0.715	1.8	3.975	4.7
Water Level	-3.03	-0.57	-1.30	-1.00	-1.045	-1.55	-1.495

Appendix B. Field and laboratory results for Apostle Islands National Lakeshore.

Appendix B1 – 2009; ***B2*** – 2010.

Multiprobe measurements for pH, specific conductance, dissolved oxygen, and temperature are reported from 0.5 m depth. Results in **bold font** indicate values less than the laboratory reporting limit (also known as the method quantitation limit, or MQL). Blank cells indicate that no results are available. Abbreviations used are as follows (units of measurement are in parentheses):

Alk	Alkalinity (mg/L $CaCO_3$)
Ca^{+2}	Calcium (mg/L)
Cl^-	Chloride (mg/L)
DOC	Dissolved Organic Carbon (mg/L)
Mg^{+2}	Magnesium (mg/L)
K^+	Potassium (mg/L)
SiO_2	Silicate (mg/L)
Na^+	Sodium (mg/L)
SO_4^{-2}	Sulfate (mg/L)
NH_4-N	Ammonium-Nitrogen (µg/L)
NO_3+NO_2-N	Nitrate+Nitrite (µg/L)
TN	Total Nitrogen (µg/L)
TP	Total Phosphorus (µg/L)
TN-Hypolimnion	Bottom TN (µg/L)
TP Hypolimnion	Bottom TP (µg/L)
chl-*a*	Chlorophyll-*a* (µg/L)
DO	Dissolved Oxygen (mg/L)
SC25	Specific Conductance (µS/cm)
pH	pH (standard units)
Temp	Temperature (°C)
Secchi	Secchi Depth (m)
Water Level	Water Level (m)
M Hg	Methyl Mercury (ng/L)
T Hg	Total Mercury (ng/L)
TSI(chl-*a*)	Trophic State Index calculated from chlorophyll-*a* concentration
TSI(TP)	Trophic State Index calculated from TP concentration
TSI(Secchi)	Trophic State Index calculated from Secchi depth

Appendix B1. Apostle Islands National Lakeshore, 2009.

		Lagoon Location					
Parameter	**Month/Yr**	*Michigan Island*	*Outer Island*	*Stockton Island*	*Little Sand Bay*	**Duplicate**	**Duplicate Location**
Alk	7/09	49	6	24	25	**ND**	Outer
Ca^{+2}	7/09	14.5	2.36	8.9	9.02	2.3	Outer
Cl^{-}	7/09	0.9	0.6	1.3	2	1.9	Outer
DOC	7/09	9.3	15.0	14.0	18.0	16	Outer
Mg^{+2}	7/09	3.8	0.9	2.3	3.1	0.9	Outer
K^{+}	7/09	0.2	0.7	0.4	0.4	0.7	Outer
SiO_2	7/09	5.4	0.1	0.2	1.1	0.1	Outer
Na^{+}	7/09	0.8	0.7	1.2	1.9	0.7	Outer
SO_4^{-2}	7/09	0.8	4.6	3.4	2.7	4.6	Outer
NH_4-N	6/09	9.0	9.0	12.0	12.0		
NH_4-N	7/09	**2.5**	**2.5**	12.8	**0.0**		
NH_4-N	10/09	**3.9**	**2.5**	13.9	**9.8**	**2.5**	Outer
NH_4-N	average	5.1	4.7	12.9	7.3		
NO_3+NO_2-N	6/09	**0.0**	**0.0**	26.0	61.0		
NO_3+NO_2-N	7/09	**3.7**	**1.6**	**0.0**	**0.9**		
NO_3+NO_2-N	10/09	**0.8**	**0.0**	**0.0**	**0.0**	**0.0**	Outer
NO_3+NO_2-N	average	1.5	0.5	8.7	20.6		
TN	6/09	416	661	874	567		
TN	7/09	583	735	658	742		
TN	10/09	455	629	653	714	629	Outer
TN	average	485	675	729	674		
TP	6/09	12.0	15.0	13.0	31.0		
TP	7/09	16.5	11.2	14.2	26.1		
TP	10/09	14.3	8.5	12.7	28.0	10.0	Outer
TP	average	14.3	11.6	13.3	28.4		

Appendix B1. Apostle Islands National Lakeshore, 2009 (continued).

		Lagoon Location					
Parameter	**Month/Yr**	*Michigan Island*	*Outer Island*	*Stockton Island*	*Little Sand Bay*	**Duplicate**	**Duplicate Location**
chl-*a*	6/09	3.9	1.9	1.9	2.1		
chl-*a*	7/09	1.4	1.9	2.7	2.5		
chl-*a*	10/09	2.9	0.5	2.9	3.0		
chl-*a*	average	2.7	1.4	2.5	2.5		
DO	6/09	8.9	8.6	6.4	8.8		
DO	7/09	7.4	8.3	8.2	7.9		
DO	10/09	7.8	8.4	8.6	7.0		
DO	average	8.0	8.4	7.7	7.9		
SC	6/09	79	22	41	60		
SC	7/09	99	24	59	70		
SC	10/09	115	25	58	86		
SC	average	98	24	53	72		
pH	6/09	7.6	6.6	6.4	7.1		
pH	7/09	7.4	6.8	7.5	7.0		
pH	10/09	7.1	6.9	7.3	6.7		
pH	average	7.3	6.8	7.1	6.9		
Temp	6/09	19.7	21.5	15.3	15.8		
Temp	7/09	23.0	23.8	23.4	21.0		
Temp	10/09	22.1	22.1	21.2	18.9		
Temp	average	21.6	22.4	20.0	18.6		
Secchi	6/09		bottom	1.20	0.68		
Secchi	7/09	bottom	bottom	1.50			
Secchi	10/09	bottom	bottom	1.55	1.25		
Secchi	average			1.42	0.97		

Appendix B1. Apostle Islands National Lakeshore, 2009 (continued).

		Lagoon Location					
Parameter	**Month/Yr**	*Michigan Island*	*Outer Island*	*Stockton Island*	*Little Sand Bay*	**Duplicate**	**Duplicate Location**
T-tube	6/09	>120		>120	0.59		
T-tube	7/09	>120	>120		>120		
T-tube	10/09			>120			
T-tube	average						
Water Level	6/09	-1.60	-1.60	-1.02	-0.98		
Water Level	7/09	-1.57	-1.73	-0.99	-0.92		
Water Level	10/09	-1.51	-1.68	-0.90	-0.80		
Water Level	average	-1.56	-1.67	-0.97	-0.90		
TSI(chl-*a*)	6/09	44	37	37	38		
TSI(chl-*a*)	7/09	34	37	40	40		
TSI(chl-*a*)	10/09	41	24	41	41		
TSI(chl-*a*)	average	40	34	39	40		
TSI(TP)	6/09	40	43	41	54		
TSI(TP)	7/09	45	39	42	51		
TSI(TP)	10/09	42	35	41	52		
TSI(TP)	average	42	39	41	52		
TSI(Secchi)	6/09			57	66		
TSI(Secchi)	7/09			54			
TSI(Secchi)	10/09			54	57		
TSI(Secchi)	average			55	61		

Appendix B2. Apostle Islands National Lakeshore, 2010.

		Lagoon Location					
Parameter	**Month/Yr**	*Michigan Island*	*Outer Island*	*Stockton Island*	*Little Sand Bay*	**Duplicate**	**Duplicate Location**
Alk	7/10	60	**11**	**13**	39	42	Little Sand Bay
Ca^{+2}	7/10	15.1	2.3	6.07	7.91	8.3	Little Sand Bay
Cl^{-}	7/10	0.9	0.5	2.4	2.3	2.3	Little Sand Bay
DOC	7/10	9.8	15	50	25	24	Little Sand Bay
Mg^{+2}	7/10	4.3	0.9	1.6	2.8	3.0	Little Sand Bay
K^{+}	7/10	0.2	0.5	0.6	0.3	0.3	Little Sand Bay
SiO_2	7/10	7.3	0.4	8.6	0.8	0.8	Little Sand Bay
Na^{+}	7/10	0.7	0.7	0.8	2.2	2.3	Little Sand Bay
SO_4^{-2}	7/10	0.9	3.3	2.4	2.5	2.5	Little Sand Bay
NH_4-N	6/10	30.3	31.4	**0.0**	**0.0**	13.3	Little Sand Bay
NH_4-N	7/10	14.0	**2.4**	116.6	**2.4**	**2.4**	Little Sand Bay
NH_4-N	10/10	**4.1**	**0.0**	76.3	**4.9**	**0.0**	Little Sand Bay
NH_4-N	average	16.2	11.3	64.3	3.8		Little Sand Bay
NO_3+NO_2-N	6/10	4.2	4.8	130.6	9.5	11.0	Little Sand Bay
NO_3+NO_2-N	7/10	10.0	5.5	10.5	6.9	5.3	Little Sand Bay
NO_3+NO_2-N	10/10	**3.0**	**3.3**	78.2	**2.0**	**0.4**	Little Sand Bay
NO_3+NO_2-N	average	5.8	4.5	73.1	5.9		Little Sand Bay
TN	6/10	512	575	810	989	975	Little Sand Bay
TN	7/10	667	633	1915	891	875	Little Sand Bay
TN	10/10	516	590	943	977	976	Little Sand Bay
TN	average	565	600	1223	947		Little Sand Bay
TP	6/10	10.1	11.0	14.6	93.3	94.2	Little Sand Bay
TP	7/10	18.2	43.9	41.2	31.2	31.6	Little Sand Bay
TP	10/10	13.6	**6.8**	12.6	31.2	32.1	Little Sand Bay
TP	average	14.0	20.5	22.8	52.3		

Appendix B2. Apostle Islands National Lakeshore, 2010 (continued).

		Lagoon Location					
Parameter	**Month/Yr**	*Michigan Island*	*Outer Island*	*Stockton Island*	*Little Sand Bay*	**Duplicate**	**Duplicate Location**
chl-*a*	6/10	1.3	1.3	**0.4**	1.1	1.3	Little Sand Bay
chl-*a*	7/10	4.8	1.3	3.0	5.5	6.3	Little Sand Bay
chl-*a*	10/10	1.8	1.2	1.0	7.1	7.3	Little Sand Bay
chl-*a*	average	2.6	1.2	1.4	4.8		
DO	6/10	9.2	9.1	6.9	7.1		
DO	7/10	7.6	8.0	5.8	5.6		
DO	10/10	7.9	8.1	7.8	5.2		
DO	average	8.2	8.4	6.8	5.9		
SC	6/10	76	20	37	47		
SC	7/10	100	21	36	63		
SC	10/10	105	21	69	76		
SC	average	93.7	20.7	47.3	62.0		
pH	6/10	7.6	6.6	6.1	6.4		
pH	7/10	7.2	6.9	5.7	6.7		
pH	10/10	7.1	6.8	6.7	6.4		
pH	average	7.3	6.8	6.1	6.5		
Temp	6/10	19.2	19.8	17.9	12.3		
Temp	7/10	25.5	25.3	23.3	24.2		
Temp	10/10	23.9	23.6	20.6	20.5		
Temp	average	22.9	22.9	20.6	19.0		
Secchi	6/10	*	*	1.38	0.31		
Secchi	7/10		*	0.25	0.90		
Secchi	10/10	1.30	*	*	0.95		
Secchi	average				0.72		

Appendix B2. Apostle Islands National Lakeshore, 2010 (continued).

		Lagoon Location					
Parameter	**Month/Yr**	*Michigan Island*	*Outer Island*	*Stockton Island*	*Little Sand Bay*	**Duplicate**	**Duplicate Location**
T-tube	6/10	>120	>120		29.05		
T-tube	7/10	>120	>120				
T-tube	10/10	>120	>120	>120			
T-tube	average						
Water Level	6/10	-1.74	-1.64	-1.18	-1.11		
Water Level	7/10	-1.75	-1.79	-0.97	-1.09		
Water Level	10/10	-1.72	-1.83	-1.19	-1.05		
Water Level	average	-1.74	-1.75	-1.11	-1.08		
TSI(chl-*a*)	6/10	33	33	22	31		
TSI(chl-*a*)	7/10	46	33	41	47		
TSI(chl-*a*)	10/10	37	32	30	50		
TSI(chl-*a*)	average	40	33	34	46		
TSI(TP)	6/10	37	39	43	70		
TSI(TP)	7/10	46	59	58	54		
TSI(TP)	10/10	42	32	41	54		
TSI(TP)	average	42	48	49	61		
TSI(Secchi)	6/10			55	77		
TSI(Secchi)	7/10			80	62		
TSI(Secchi)	10/10	56			61		
TSI(Secchi)	average			68	66		

Appendix C. Field and laboratory results for Isle Royale National Park.

Appendix C1 **–** Index lakes, 2009; ***C2*** **–** Index lakes, 2010; ***C3*** **–** Non-index lakes 2010; ***C4*** **–** Additional sampling, 2010.

Multiprobe measurements for pH, specific conductance, dissolved oxygen, and temperature are reported from 1.0 m depth. Results in **bold font** indicate values less than the laboratory reporting limit (also known as the method quantitation limit or MQL). Blank cells indicate that no results are available. Abbreviations used are as follows (units of measurement are in parentheses):

Alk	Alkalinity (mg/L $CaCO_3$)
Ca^{+2}	Calcium (mg/L)
Cl^-	Chloride (mg/L)
DOC	Dissolved Organic Carbon (mg/L)
Mg^{+2}	Magnesium (mg/L)
K^+	Potassium (mg/L)
SiO_2	Silicate (mg/L)
Na^+	Sodium (mg/L)
SO_4^{-2}	Sulfate (mg/L)
NH_4-N	Ammonium-Nitrogen (µg/L)
NO_3+NO_2-N	Nitrate+Nitrite (µg/L)
TN	Total Nitrogen (µg/L)
TP	Total Phosphorus (µg/L)
TN-Hypolimnion	Bottom TN (µg/L)
TP Hypolimnion	Bottom TP (µg/L)
chl-*a*	Chlorophyll-*a* (µg/L)
DO	Dissolved Oxygen (mg/L)
SC25	Specific Conductance (µS/cm)
pH	pH (standard units)
Temp	Temperature (°C)
Secchi	Secchi Depth (m)
Water Level	Water Level (m)
M Hg	Methyl Mercury (ng/L)
T Hg	Total Mercury (ng/L)
TSI(chl-*a*)	Trophic State Index calculated from chlorophyll-*a* concentration
TSI(TP)	Trophic State Index calculated from TP concentration
TSI(Secchi)	Trophic State Index calculated from Secchi depth

Appendix C1. Isle Royale National Park, index lakes, 2009.

		Lake										
Parameter	**Month/Yr**	*Ahmik*	*Sargent*	*Richie*	*Beaver*	*Harvey*	*George*	*Siskiwit*	*Desor*	*Feldtmann*	**Duplicate**	**Duplicate Location**
Alk	8/09	45.0	36.0	32.0	43.0	41.0	53.0	32.0	50.0	26.0	47.0	Beaver
Ca^{+2}	8/09	11.0	10.0	9.3	9.9	9.5	19.6	8.8	12.6	10.4	10.0	Beaver
Cl^{-}	8/09	0.7	0.8	1.1	0.6	0.5	0.5	0.4	0.6	0.9	**ND**	Beaver
DOC	8/09	18.0	8.9	9.6	13.0	10.0	11.0	5.7	7.3	15.0	13.0	Beaver
Mg^{+2}	8/09	5.6	3.8	2.9	5.3	4.0	1.9	2.5	4.3	2.4	5.3	Beaver
K^{+}	8/09	0.2	0.2	0.2	0.2	**0.08**	**ND**	0.3	0.4	0.4	0.2	Beaver
SiO_2	8/09	10.0	5.7	7.7	10.0	1.7	0.8	2.6	1.3	0.5	9.3	Beaver
Na^{+}	8/09	2.2	2.1	1.5	2.5	2.0	0.8	1.1	1.7	1.3	2.5	Beaver
SO_4^{-2}	8/09	4.4	4.9	4.5	3.2	3.8	3.2	5.2	3.9	7.0	3.2	Beaver
NH_4-N	8/09	18.7	**4.16**	**4.16**	**4.16**	**4.16**	**4.16**	**4.16**	**4.16**	**9.57**		
NH_4-N	10/09	13.0	**4.16**	**4.16**	**4.16**	**4.16**	**4.16**	**4.16**	**4.16**	**4.16**	**4.16**	Feldtmann
NH_4-N	average	15.9	4.2	4.2	4.2	4.2	4.2	4.2	4.2	6.9		
NO_3+NO_2-N	8/09	8.8	6.6	8.8	4.1	4.8	4.9	15.4	5.0	6.1		
NO_3+NO_2-N	10/09	5.8	5.8	7.8	4.8	5.2	5.5	9.9	5.8	7.1	6.6	Feldtmann
NO_3+NO_2-N	average	7.29	6.21	8.34	4.48	5.00	5.24	12.64	5.41	6.57		
TN	8/09	836	542	531	491	607	428	217	441	632	488	Beaver
TN	10/09	853	435	540	481	499	430	201	457	583	602	Feldtmann
TN	average	845	488	535	486	553	429	209	449	608		
TP	8/09	24.0	24.2	24.5	17.8	21.0	8.9	4.4	10.9	11.3	18.8	Beaver
TP	10/09	28.2	17.8	24.1	18.7	12.8	8.1	4.9	11.8	11.6	12.0	Feldtmann
TP	average	26.1	21.0	24.3	18.3	16.9	8.5	4.6	11.4	11.4		
TN-Hypolimnion	8/09		418	721	514	510		296	388		407	Sargent
TP-Hypolimnion	8/09		16.1	98.0	21.3	14.5		5.5	8.1		15.1	Sargent
chl-*a*	8/09	2.9	2.9	5.3	1.4	0.5	1.2	0.3	2.1	1.7		
chl-*a*	10/09	2.9	2.9	2.6	1.6	2.3	1.9	0.9	2.2	1.8		
chl-*a*	average	2.9	2.9	3.9	1.5	1.4	1.5	0.6	2.2	1.7		

Appendix C1. Isle Royale National Park, index lakes, 2009 (continued).

		Lake										
Parameter	**Month/Yr**	*Ahmik*	*Sargent*	*Richie*	*Beaver*	*Harvey*	*George*	*Siskiwit*	*Desor*	*Feldtmann*	**Duplicate**	**Duplicate Location**
DO	8/09	8.0	10.8	7.7	8.9	9.6	9.9	8.6	8.5	8.7		
DO	10/09	7.8	9.6	9.6	9.0	9.7	8.9	9.5	8.8	8.9		
DO	average	7.9	10.2	8.6	8.9	9.7	9.4	9.0	8.7	8.8		
SC	8/09	104	87	76	99	87	114	70	104	77		
SC	10/09	97	90	80	97	88	115	72	106	74		
SC	average	101	89	78	98	87	115	71	105	75		
pH	8/09	7.6	8.0	7.9	8.0	8.6	8.5	8.0	8.2	7.6		
pH	10/09	7.5	8.7	8.4	7.9	8.7	7.8	7.9	8.3	7.8		
pH	average	7.6	8.4	8.1	7.9	8.6	8.2	8.0	8.3	7.7		
Temp	8/09	23.5	19.2	19.5	22.1	20.0	21.4	18.3	19.7	21.5		
Temp	10/09	21.0	21.3	20.0	18.8	20.5	19.5	17.2	19.9	17.3		
Temp	average	22.3	20.2	19.7	20.4	20.2	20.5	17.7	19.8	19.4		
Secchi	8/09	2.38	2.51	1.75	3.20	3.23	3.00	8.86	2.53	2.54		
Secchi	10/09	1.93	3.05	1.86	3.35	3.10	3.48	8.13	2.60	2.44		
Secchi	average	2.15	2.78	1.81	3.27	3.17	3.24	8.49	2.57	2.49		
Water Level	8/09	-0.56	-1.47	-1.09	-1.43	-1.17	-0.58	-0.77	-0.94	-0.94		
Water Level	10/09	-0.45	-1.41	-1.03	-1.35	-1.13	-0.39	-0.71	-0.91	-0.88		
Water Level	average	-0.45	-1.41	-1.03	-1.35	-1.13	-0.39	-0.71	-0.91	-0.88		
TSI(chl-*a*)	8/09	41	41	47	34	23	32	18	38	36		
TSI(chl-*a*)	10/09	41	41	40	35	39	37	30	38	36		
TSI(chl-*a*)	average	41	41	44	35	34	35	26	38	36		
TSI(TP)	8/09	50	50	50	46	48	36	26	39	39		
TSI(TP)	10/09	52	46	50	46	41	34	27	40	39		
TSI(TP)	average	51	48	50	46	44	35	26	39	39		
TSI(Secchi)	8/09	48	47	52	43	43	44	29	47	47		
TSI(Secchi)	10/09	51	44	51	43	44	42	30	46	47		
TSI(Secchi)	average	49	45	51	43	43	43	29	46	47		

Appendix C2. Isle Royale National Park, index lakes, 2010.

		Lake										
Parameter	**Month/Yr**	*Ahmik*	*Sargent*	*Richie*	*Beaver*	*Harvey*	*George*	*Siskiwit*	*Desor*	*Feldtmann*	**Duplicate**	**Duplicate Location**
Alk	7/10	50	46	36	45	44	62	34	52	28	40	Richie
Ca^{+2}	7/10	12.0	11.6	11.3	11.8	10.9	24.5	9.8	14.4	12.1	11.7	Richie
Cl^{-}	7/10	0.7	0.8	1.1	0.5	**ND**	0.6	**ND**	0.6	0.9	1.1	Richie
DOC	7/10	15.0	7.9	9.4	11.0	9.3	9.3	4.7	6.8	14.0	9.6	Richie
Mg^{+2}	7/10	5.4	4.3	3.4	5.7	4.6	2.2	2.7	4.7	2.7	3.6	Richie
K^{+}	7/10	**0.2**	**0.2**	0.3	0.3	**0.1**	**0.1**	0.3	0.4	0.4	0.3	Richie
SiO_2	7/10	5.5	3.2	1.7	9.5	2.1	1.4	2.6	**0.9**	**0.8**	1.8	Richie
Na^{+}	7/10	2.4	2.4	7.8	3.0	2.2	1.2	1.3	1.9	1.6	6.8	Richie
SO_4^{-2}	7/10	2.7	4.8	4.1	3.1	3.2	2.8	4.9	3.8	5.6	4.4	Richie
NH_4-N	6/10	**9.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	George
NH_4-N	7/10	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**	Richie
NH_4-N	8/10	12.3	**0.0**	**5.9**	**0.0**	**0.0**	**0.0**	**0.0**		**0.0**	**0.0**	Beaver
NH_4-N	average	8.0	0.8	2.8	0.8	0.8	0.8	0.8	1.2	0.8		
NO_3+NO_2-N	6/10	5.5	4.7	4.4	4.5	**3.8**	5.4	17.7	6.3	7.9	**3.6**	George
NO_3+NO_2-N	7/10	9.4	9.1	6.9	6.3	5.9	7.4	6.6	7.9	5.0	6.7	Richie
NO_3+NO_2-N	8/10	6.0	5.1	8.6	5.4	7.0	8.0	6.9		5.7	6.0	Beaver
NO_3+NO_2-N	average	6.9	6.3	6.6	5.5	5.5	6.7	10.4	7.1	6.2		
TN	6/10	520	376	558	468	452	344	241	443	530	392	George
TN	7/10	764	385	532	479	533	407	187	409	582	519	Richie
TN	8/10	776	391	803	488	547	435	194		627	505	Beaver
TN	average	687	384	629	481	511	403	207	426	580		
TP	6/10	19.2	11.4	29.3	17.3	15.0	9.8	4.1	9.2	12.6	12.2	George
TP	7/10	29.2	12.1	23.1	19.7	14.7	10.5	**3.8**	**8.2**	12.7	23.7	Richie
TP	8/10	30.3	12.4	33.5	21.5	14.8	10.1	**3.3**		14.5	21.6	Beaver
TP	average	26.2	12.0	28.7	19.5	14.9	10.5	3.7	8.7	13.3		
TN-Hypolimnion	7/10		399	458	492	524		254	976		678	Richie
TP-Hypolimnion	7/10		13.7	78.5	24.8	14.5		7.5	20.7		81.7	Richie

Appendix C2. Isle Royale National Park, index lakes, 2010 (continued).

		Lake										
Parameter	**Month/Yr**	*Ahmik*	*Sargent*	*Richie*	*Beaver*	*Harvey*	*George*	*Siskiwit*	*Desor*	*Feldtmann*	**Duplicate**	**Duplicate Location**
chl-*a*	6/10	2.1	3.2	4.6	1.4	1.2	1.5	0.6	2.4	2.2	1.8	George
chl-*a*	7/10	3.5	2.7	6.8	1.6	2.2	2.3	0.6	2.3	2.8	7.3	Richie
chl-*a*	8/10	2.1	2.4	18.8	3.1	2.8	1.4	0.9		1.4	2.7	Beaver
chl-*a*	average	2.5	2.8	10.2	2.0	2.1	1.8	0.7	2.3	2.1		
DO	6/10	8.4	9.0	9.3	8.4	9.3	8.3	10.2	9.3	9.1		
DO	7/10	7.9	8.5	8.5	8.1	9.2	7.8	8.8	8.6	7.8		
DO	8/10	9.0	8.7	7.9	8.5	9.1	8.2	8.3		8.4		
DO	average	8.5	8.7	8.6	8.4	9.2	8.1	9.1	8.9	8.4		
SC	6/10	88	92	81	96	89	130	71	106	75		
SC	7/10	97	92	84	98	92	132	72	107	78		
SC	8/10	102	94	85	100	89	131	73		81		
SC	average	96	93	83	98	90	131	72	106	78		
pH	6/10	7.5	8.3	8.0	7.8	8.4	7.8	7.9	8.4	7.8		
pH	7/10	7.8	8.4	8.2	8.0	9.1	7.9	8.2	8.5	7.8		
pH	8/10	8.0	8.3	8.7	7.9	8.6	7.9	7.9		8.0		
pH	average	7.8	8.3	8.3	7.9	8.7	7.9	8.0	8.4	7.9		
Temp	6/10	20.4	21.3	19.8	21.8	19.0	21.5	15.4	20.1	17.8		
Temp	7/10	24.0	22.9	22.7	23.4	25.3	24.0	22.4	22.6	23.5		
Temp	8/10	19.2	21.6	20.9	22.5	21.7	20.7	20.9		22.5		
Temp	average	21.2	21.9	21.1	22.6	22.0	22.1	19.6	21.4	21.3		
Secchi	6/10	2.08	3.44	2.15	3.38	3.92	3.03	6.60	2.98	2.55		
Secchi	7/10	1.43	3.55	2.38	3.45	3.25	3.00	6.50	3.25	2.35		
Secchi	8/10	2.20	3.00	1.40	2.70	3.05	bottom	5.95		bottom		
Secchi	average	1.90	3.33	1.98	3.18	3.41	3.01	6.35	3.11	2.45		

Appendix C2. Isle Royale National Park, index lakes, 2010 (continued).

		Lake										
Parameter	**Month/Yr**	*Ahmik*	*Sargent*	*Richie*	*Beaver*	*Harvey*	*George*	*Siskiwit*	*Desor*	*Feldtmann*	**Duplicate**	**Duplicate Location**
Water Level	6/10	-0.43	-1.40	-0.92	-1.35	-1.07	-0.53	-1.01	-0.88	-0.67		
Water Level	7/10	-0.52	-1.48	-1.04	-1.47	-1.31	-0.54	-0.80	-0.94	-0.75		
Water Level	8/10	-0.61	-1.54	-1.12	-1.56	-1.35	-0.53	-0.87	-1.10	-0.92		
Water Level	average	-0.5	-1.5	-1.0	-1.5	-1.2	-0.5	-0.9	-1.0	-0.8		
TSI(chl-*a*)	6/10	38	42	45	34	32	35	26	39	38		
TSI(chl-*a*)	7/10	43	40	49	35	38	39	25	39	41		
TSI(chl-*a*)	8/10	38	39	59	42	41	34	29		34		
TSI(chl-*a*)	average	40	41	53	37	38	36	27	39	38		
TSI(TP)	6/10	47	39	53	45	43	37	25	36	41		
TSI(TP)	7/10	53	40	49	47	43	38	23	35	41		
TSI(TP)	8/10	53	41	55	48	43	37	21		43		
TSI(TP)	average	51	40	53	47	43	38	23	35	41		
TSI(Secchi)	6/10	49	42	49	42	40	44	33	44	47		
TSI(Secchi)	7/10	55	42	48	42	43	44	33	43	48		
TSI(Secchi)	8/10	49	44	55	46	44		34				
TSI(Secchi)	average	51	43	50	43	42	44	33	44	47		

Appendix C3. Isle Royale National Park, non-index lakes, 2010.

	Lake (Sample Date)	
Parameter	*Whittlesey (9/9/10)*	*Chickenbone (8/22/10)*
DO	8.43	8.58
SC	70.2	108.9
pH		8.07
Temp	17.96	21.55
Secchi	2.5	3.26

Appendix C4. Isle Royale National Park, additional sampling, 2010.

Parameter	**Date**	**Lake Richie**
DO	5/28/2010	9.4
DO	8/12/2010	11.2
DO	8/27/2010	7.9
DO	9/8/2010	6.4
SC	5/28/2010	82
SC	8/12/2010	89
SC	8/27/2010	85
SC	9/8/2010	83
pH	5/28/2010	8.0
pH	8/12/2010	9.6
pH	8/27/2010	8.7
pH	9/8/2010	7.6
Temp	5/28/2010	21.0
Temp	8/12/2010	25.2
Temp	8/27/2010	20.9
Temp	9/8/2010	17.5
Secchi	5/28/2010	2.25
Secchi	8/12/2010	0.9
Secchi	8/27/2010	1.4
Secchi	9/8/2010	1.5
Water Level	5/28/2010	-1.175
Water Level	8/12/2010	
Water Level	8/27/2010	-1.12
Water Level	9/8/2010	-1.12

Appendix D. Field and Laboratory Results for Pictured Rocks National Lakeshore.

Appendix D1 – 2009; ***D2*** – 2010.

Multiprobe measurements for pH, specific conductance, dissolved oxygen, and temperature are reported from 1.0 m depth. Results in **bold font** indicate values less than the laboratory reporting limit (also known as the method quantitation limit or MQL). Blank cells indicate that no results are available. Abbreviations used are as follows (units of measurement are in parentheses):

Alk	Alkalinity (mg/L $CaCO_3$)
Ca^{+2}	Calcium (mg/L)
Cl^-	Chloride (mg/L)
DOC	Dissolved Organic Carbon (mg/L)
Mg^{+2}	Magnesium (mg/L)
K^+	Potassium (mg/L)
SiO_2	Silicate (mg/L)
Na^+	Sodium (mg/L)
SO_4^{-2}	Sulfate (mg/L)
NH_4-N	Ammonium-Nitrogen (µg/L)
NO_3+NO_2-N	Nitrate+Nitrite (µg/L)
TN	Total Nitrogen (µg/L)
TP	Total Phosphorus (µg/L)
TN-Hypolimnion	Bottom TN (µg/L)
TP Hypolimnion	Bottom TP (µg/L)
chl-*a*	Chlorophyll-*a* (µg/L)
DO	Dissolved Oxygen (mg/L)
SC25	Specific Conductance (µS/cm)
pH	pH (standard units)
Temp	Temperature (°C)
Secchi	Secchi Depth (m)
Water Level	Water Level (m)
M Hg	Methyl Mercury (ng/L)
T Hg	Total Mercury (ng/L)
TSI(chl-*a*)	Trophic State Index calculated from chlorophyll-*a* concentration
TSI(TP)	Trophic State Index calculated from TP concentration
TSI(Secchi)	Trophic State Index calculated from Secchi depth

Appendix D1. Pictured Rocks National Lakeshore, 2009.

		Lake							
Parameter	**Month/Yr**	*Grand Sable*	*Legion*	*Beaver*	*Little Beaver*	*Chapel*	*Miners*	**Duplicate**	**Duplicate Location**
Alk	7/09	53	**ND**	82		92	152	90	Chapel
Ca^{+2}	7/09	15.5	0.6	26.1		24.5	37.1	25.1	Chapel
Cl^{-}	7/09	0.5	0.3	0.5		0.6	1.9	0.7	Chapel
DOC	7/09	7.4	3.7	4.7		10.0	6.5	10.0	Chapel
Mg^{+2}	7/09	5.9	0.2	6.0		12.2	20.2	12.4	Chapel
K^{+}	7/09	1.0	0.4	0.8		0.8	0.8	0.8	Chapel
SiO_2	7/09	4.8	**0.0**	7.2		3.7	6.2	4.2	Chapel
Na^{+}	7/09	1.1	0.2	1.1		0.8	1.6	0.8	Chapel
SO_4^{-2}	7/09	5.7	2.3	7.5		8.7	7.3	7.8	Chapel
NH_4-N	6/09	**2.5**	**2.5**	**2.5**		18.5	22.1		
NH_4-N	7/09	**2.5**	**2.5**	**2.5**		**2.5**	**2.5**		
NH_4-N	10/09	**2.5**	**2.5**	**2.5**		**2.5**	**2.5**		
NH_4-N	average	2.5	2.5	2.5		7.8	9.1		
NO_3+NO_2-N	6/09	78.4	57.3	**1.8**		30.6	229		
NO_3+NO_2-N	7/09	4.7	**2.5**	**2.1**		9.7	221		
NO_3+NO_2-N	10/09	6.2	**3.9**	11.0		1.3	169		
NO_3+NO_2-N	average	29.8	21.2	4.9		13.9	206		
TN	6/09	325	275	244		445	444		
TN	7/09	275	224	230		412	493		
TN	10/09	282	226	258		372	488	232.74	Beaver
TN	average	294	242	244		410	475		
TP	6/09	12.4	5.9	12.3		14.3	11.9		
TP	7/09	9.3	7.3	12.0		18.0	18.3		

Appendix D1. Pictured Rocks National Lakeshore, 2009 (continued).

		Lake							
Parameter	**Month/Yr**	*Grand Sable*	*Legion*	*Beaver*	*Little Beaver*	*Chapel*	*Miners*	**Duplicate**	**Duplicate Location**
TP	10/09	9.8	9.3	15.3		13.6	18.3	13.7	Beaver
TP	average	10.5	7.5	13.2		15.3	16.2		
TN-Hypolimnion	7/09	380	495	274		3472			
TP-Hypolimnion	7/09	20.9	32.0	24.1		21.5			
chl-*a*	6/09	1.8	0.8	1.6		1.4	0.2		
chl-*a*	7/09	2.8	1.1	1.4		1.3	7.3		
chl-*a*	10/09	3.6	0.1	1.5		1.4	5.4		
chl-*a*	average	2.7	0.7	1.5		1.4	4.3		
DO	6/09	9.5	9.7	9.8		9.6	9.8		
DO	7/09	9.1	8.8	8.9		9.0	9.4		
DO	10/09	8.8	8.8	8.7	9.1	9.8	11.7		
DO	average	9.1	9.1	9.2		9.5	10.3		
SC	6/09	112	11	170		150	263		
SC	7/09	116	10	173		202	306		
SC	10/09	117	10	174	155	192	305		
SC	average	115	10	172		181	291		
pH	6/09	7.9	4.8	8.1		7.7	7.9		
pH	7/09	8.4	4.6	8.4		8.0	7.9		
pH	10/09	8.2	4.8	8.0	8.0	8.2	8.0		
pH	average	8.2	4.7	8.2		8.0	7.9		
Temp	6/09	19.0	17.6	19.9		18.7	13.1		
Temp	7/09	19.8	19.9	20.0		19.9	14.3		
Temp	10/09	19.1	18.5	18.6	19.1	20.2	12.3		
Temp	average	19.3	18.7	19.5		19.6	13.2		

Appendix D1. Pictured Rocks National Lakeshore, 2009 (continued).

		Lake							
Parameter	**Month/Yr**	*Grand Sable*	*Legion*	*Beaver*	*Little Beaver*	*Chapel*	*Miners*	**Duplicate**	**Duplicate Location**
Secchi	6/09	3.22	6.93	2.23		2.65	2.00		
Secchi	7/09	3.18	5.45	3.60		2.68	2.25		
Secchi	10/09	2.55	7.07	3.58	1.78	3.40	2.22		
Secchi	average	2.98	6.48	3.14		2.91	2.16		
Water Level	6/09	0.53	-1.12	-0.96		-1.75	-0.88		
Water Level	7/09	0.39	-1.22	-0.99		-1.84	-0.96		
Water Level	10/09	0.35	-1.23	-0.98		-1.92	-1.11		
Water Level	average	0.42	-1.19	-0.98		-1.83	-0.98		
TSI(chl-*a*)	6/09	36	29	35		34	17		
TSI(chl-*a*)	7/09	41	31	34		33	50		
TSI(chl-*a*)	10/09	43	11	34		34	47		
TSI(chl-*a*)	average	40	27	34		34	45		
TSI(TP)	6/09	40	30	40		43	40		
TSI(TP)	7/09	36	33	40		46	46		
TSI(TP)	10/09	37	36	43		42	46		
TSI(TP)	average	38	33	41		43	44		
TSI(Secchi)	6/09	43	32	48		46	50		
TSI(Secchi)	7/09	43	36	42		46	48		
TSI(Secchi)	10/09	47	32	42	52	42	49		
TSI(Secchi)	average	44	33	44		45	49		

Appendix D2. Pictured Rocks National Lakeshore, 2010.

		Lake							
Parameter	**Month/Yr**	*Grand Sable*	*Legion*	*Beaver*	*Little Beaver*	*Chapel*	*Miners*	**Duplicate**	**Duplicate Location**
Alk	7/10	52	**ND**	82		94	164	**ND**	Legion
Ca^{+2}	7/10	16.0	0.5	27.3		25.4	41.4	0.5	Legion
Cl^{-}	7/10	0.5	**ND**	0.5		0.8	2.1	**ND**	Legion
DOC	7/10	7.4	2.8	4.2		14.0	8.5	3.1	Legion
Mg^{+2}	7/10	5.8	0.2	5.9		11.9	20.9	0.2	Legion
K^{+}	7/10	0.8	**0.2**	0.5		0.6	0.6	**0.2**	Legion
SiO_2	7/10	4.4	0.0	6.3		4.4	6.3	0.0	Legion
Na^{+}	7/10	0.9	**ND**	0.9		0.6	1.5	**ND**	Legion
SO_4^{-2}	7/10	5.2	2.3	6.6		7.2	6.1	2.2	Legion
NH_4-N	6/10	13.7	17.9	**0.0**		**7.6**	15.6	**0.0**	Miners
NH_4-N	7/10	**2.4**	**2.4**	**2.4**		**2.4**	**2.4**	**2.4**	Legion
NH_4-N	10/10	**0.0**	**0.0**	**0.0**		**0.0**	**5.4**	**4.9**	Miners
NH_4-N	average	5.4	6.8	0.8		3.3	5.1		
NO_3+NO_2-N	6/10	30.7	**3.9**	4.9		12.8	166	149	Miners
NO_3+NO_2-N	7/10	7.2	6.7	15.7		7.9	239	6.9	Legion
NO_3+NO_2-N	10/10	18.7	6.4	**3.5**		10.1	219	226.8	Miners
NO_3+NO_2-N	average	18.8	5.7	8.0		10.2	206.4		
TN	6/10	277	179	195		304	570	592	Miners
TN	7/10	294	293	172		629	950	273	Legion
TN	10/10	270	201	204		403	414	391	Miners
TN	average	280.5	221.3	190.4		445.5	644.7		
TP	6/10	9.7	**4.5**	9.5		11.4	18.9	18.9	Miners
TP	7/10	9.2	**3.8**	9.3		12.6	21.7	**6.0**	Legion
TP	10/10	10.0	**7.7**	14.3		17.5	14.1	44.3	Miners
TP	average	9.6	5.7	11.0		13.8	23.3		

Appendix D2. Pictured Rocks National Lakeshore, 2010 (continued).

		Lake							
Parameter	**Month/Yr**	*Grand Sable*	*Legion*	*Beaver*	*Little Beaver*	*Chapel*	*Miners*	**Duplicate**	**Duplicate Location**
TN-Hypolimnion	7/10	389	356	306		3242		388	Legion
TP-Hypolimnion	7/10	18.5	17.1	15.6		21.5		17.5	Legion
chl-*a*	6/10	2.1	0.5	1.3		1.3	1.2	1.3	Miners
chl-*a*	7/10	3.3	1.4	1.7		6.2	5.0	1.1	Legion
chl-*a*	10/10	3.8	1.7	2.5		4.4	1.4	1.2	Miners
chl-*a*	average	3.1	1.2	1.8		3.9	2.5		
DO	6/10	8.2	8.9	9.3	8.9	9.6	9.2		
DO	7/10	8.0	8.1	8.5	8.0	8.7	9.5		
DO	10/10	8.2	8.3	7.6		9.3	8.3		
DO	average	8.1	8.4	8.5	8.4	9.2	9.0		
SC	6/10	118	20	171	141	187	258		
SC	7/10	120	10	177	152	192	316		
SC	10/10	115	10	170		194	334		
SC	average	118	13	173	147	191	303		
pH	6/10	7.8	5.0	8.2	7.6	7.9	7.9		
pH	7/10	8.0	5.0	8.4	7.9	8.2	7.6		
pH	10/10	7.8	4.7	8.4		7.8	7.8		
pH	average	7.9	4.9	8.3	7.8	8.0	7.8		
Temp	6/10	21.3	19.1	18.1	17.3	17.1	13.5		
Temp	7/10	23.4	24.1	24.0	23.8	24.0	15.6		
Temp	10/10	17.6	22.9	22.2		16.4	17.3		
Temp	average	20.8	22.0	21.4	20.5	19.2	15.5		
Secchi	6/10	3.98	8.77	4.93	1.58	2.2	1.6		
Secchi	7/10	3.03	6.85	5.53	2.15	2.275	1.97		
Secchi	10/10	2.73	5.35	4.00		2.5	2.5		
Secchi	average	3.25	6.99	4.82	1.86	2.33	2.02		

Appendix D2. Pictured Rocks National Lakeshore, 2010 (continued).

		Lake							
Parameter	**Month/Yr**	*Grand Sable*	*Legion*	*Beaver*	*Little Beaver*	*Chapel*	*Miners*	**Duplicate**	**Duplicate Location**
Water Level	6/10	0.51	-1.36	-0.92		-1.94	-0.93		
Water Level	7/10	0.42	-1.41	-1.00	-1.00	-1.98	-1.03		
Water Level	10/10	0.41	-1.51	-0.95		-1.85	-1.10		
Water Level	average	0.45	-1.42	-0.95	-1.00	-1.92	-1.02		
TSI(chl-*a*)	6/10	38	25	34		33	33		
TSI(chl-*a*)	7/10	42	34	36		48	46		
TSI(chl-*a*)	10/10	44	36	40		45	34		
TSI(chl-*a*)	average	42	32	37		44	40		
TSI(TP)	6/10	37	26	37		39	47		
TSI(TP)	7/10	36	23	36		41	49		
TSI(TP)	10/10	37	34	42		45	42		
TSI(TP)	average	37	29	39		42	50		
TSI(Secchi)	6/10	40	29	37	53	49	53		
TSI(Secchi)	7/10	44	32	35	49	48	50		
TSI(Secchi)	10/10	46	36	40		47	47		
TSI(Secchi)	average	43	32	37	51	48	50		

Appendix E. Field and laboratory results for Indiana Dunes National Lakeshore.

Appendix E1 **–** 2009; ***E2*** **–** 2010.

Multiprobe measurements for pH, specific conductance, dissolved oxygen, and temperature are reported from 0.5 m depth. Results in **bold font** indicate values less than the laboratory reporting limit (also known as the method quantitation limit or MQL). Blank cells indicate that no results are available. Abbreviations used are as follows (units of measurement are in parentheses):

Alk	Alkalinity (mg/L $CaCO_3$)
Ca^{+2}	Calcium (mg/L)
Cl^{-}	Chloride (mg/L)
DOC	Dissolved Organic Carbon (mg/L)
Mg^{+2}	Magnesium (mg/L)
K^{+}	Potassium (mg/L)
SiO_2	Silicate (mg/L)
Na^{+}	Sodium (mg/L)
SO_4^{-2}	Sulfate (mg/L)
TSS	Total Suspended Solids
NH_4-N	Ammonium-Nitrogen (µg/L)
NO_3+NO_2-N	Nitrate+Nitrite (µg/L)
TN	Total Nitrogen (µg/L)
TP	Total Phosphorus (µg/L)
TN-Hypolimnion	Bottom TN (µg/L)
TP Hypolimnion	Bottom TP (µg/L)
chl-*a*	Chlorophyll-*a* (µg/L)
DO	Dissolved Oxygen (mg/L)
SC25	Specific Conductance (µS/cm)
pH	pH (standard units)
Temp	Temperature (°C)
Secchi	Secchi Depth (m)
Water Level	Water Level (m)
M Hg	Methyl Mercury (ng/L)
T Hg	Total Mercury (ng/L)
TSI(chl-*a*)	Trophic State Index calculated from chlorophyll-*a* concentration
TSI(TP)	Trophic State Index calculated from TP concentration
TSI(Secchi)	Trophic State Index calculated from Secchi depth

Appendix E1. Indiana Dunes National Lakeshore, 2009.

		Site				
Parameter	**Date**	*Long Lake*	*Middle Lagoon*	*Little Calumet River*	**Duplicate**	**Duplicate Location**
Alk	7/1/2009	78	82	249	80	Middle Lagoon
Ca^{+2}	7/1/2009	23.4	18.1	88.1	17.0	Middle Lagoon
Cl^{-}	7/1/2009	20.3	100	48.2	100	Middle Lagoon
DOC	7/1/2009	11.0	6.0	6.3	6.8	Middle Lagoon
Mg^{+2}	7/1/2009	7.1	15.8	32.2	15.1	Middle Lagoon
K^{+}	7/1/2009	0.8	1.6	2.5	1.5	Middle Lagoon
SiO_2	7/1/2009	1.1	1.5	12.0	2.5	Middle Lagoon
Na^{+}	7/1/2009	11.6	66.3	26.7	64.5	Middle Lagoon
SO_4^{-2}	7/1/2009	2.4	22.2	64.3	21.7	Middle Lagoon
TSS	7/1/2009			3.0		
NH_4-N	4/30/2009	**2.5**	**2.5**	**5.9**		
NH_4-N	7/1/2009	**1.9**	**2.5**	30.7		
NH_4-N	9/3/2009	**2.5**	**2.5**	23.4		
NH_4-N	average	2.3	2.5	20.0		
NO_3+NO_2-N	4/30/2009	**2.2**		483		
NO_3+NO_2-N	7/1/2009	7.2	**2.7**	1159		
NO_3+NO_2-N	9/3/2009	**2.8**	**0.0**	1013		
NO_3+NO_2-N	average	4.1	1.3	885		
TN	4/30/2009	438	644	1150		
TN	7/1/2009	654	417	1652		
TN	9/3/2009	642	479	1315		
TN	average	578	513	1372		
TP	4/30/2009	16.8	32.7	92.4		
TP	7/1/2009	23.5	15.3	98.5		
TP	9/3/2009	26.5	18.5	77.6		
TP	average	22.3	22.2	89.5		

Appendix E1. Indiana Dunes National Lakeshore, 2009 (continued).

		Site				
Parameter	**Date**	*Long Lake*	*Middle Lagoon*	*Little Calumet River*	**Duplicate**	**Duplicate Location**
chl-*a*	4/30/2009	2.2	12.1	5.8		
chl-*a*	7/1/2009	4.8	2.6	0.3		
chl-*a*	9/3/2009	3.6	3.1	1.4		
chl-*a*	average	3.5	6.0	2.5		
DO	4/30/2009	7.4	8.1	8.1		
DO	7/1/2009	1.2	8.3	7.3		
DO	9/3/2009	1.7	12.8	8.3		
DO	average	3.4	9.7	7.9		
SC	4/30/2009	215	737	537		
SC	7/1/2009	226	532	711		
SC	9/3/2009	238	538	749		
SC	average	226	602	666		
pH	4/30/2009	7.5	8.0	7.7		
pH	7/1/2009	7.1	9.3	7.9		
pH	9/3/2009	6.5	9.0	7.9		
pH	average	7.0	8.8	7.8		
Temp	4/30/2009	14.7	14.8	13.2		
Temp	7/1/2009	20.1	21.9	17.5		
Temp	9/3/2009	16.9	20.3	16.6		
Temp	average	17.2	19.0	15.7		
Secchi	4/30/2009	1.30	1.20			
Secchi	7/1/2009	0.78				
Secchi	9/3/2009	0.68	2.10			
Secchi	average	0.92	1.65			
T-tube	4/30/2009	>120	79.45	47.25		
T-tube	7/1/2009	90.90	>120	39.40		

Appendix E1. Indiana Dunes National Lakeshore, 2009 (continued).

		Site				
Parameter	**Date**	*Long Lake*	*Middle Lagoon*	*Little Calumet River*	**Duplicate**	**Duplicate Location**
T-tube	9/3/2009	64.80	>120	56.50		
T-tube	average	77.85		47.72		
Water Level	4/30/2009	-41.8	-584.0	-289.0		
Water Level	7/1/2009	-64.4	-557.7	-353.0		
Water Level	9/3/2009	-79.5	-574.0	-360.0		
Water Level	average	-61.9	-571.9	-334.0		
TSI(chl-*a*)	4/30/2009	38	55	48		
TSI(chl-*a*)	7/1/2009	46	40	17		
TSI(chl-*a*)	9/3/2009	43	42	34		
TSI(chl-*a*)	average	43	48	40		
TSI(TP)	4/30/2009	45	54	69		
TSI(TP)	7/1/2009	50	43	70		
TSI(TP)	9/3/2009	51	46	67		
TSI(TP)	average	49	49	69		
TSI(Secchi)	4/30/2009	56	57			
TSI(Secchi)	7/1/2009	64				
TSI(Secchi)	9/3/2009	66	49			
TSI(Secchi)	average	61	53			

Appendix E2. Indiana Dunes National Lakeshore, 2010.

		Site			
Parameter	**Date**	*Long Lake*	*Middle Lagoon*	**Duplicate**	**Duplicate Location**
Alk	6/29/2010	84	82	90	Long
Ca^{+2}	6/29/2010	23.8	15.5	23.9	Long
Cl^{-}	6/29/2010	34.6	86.9	34.9	Long
DOC	6/29/2010	10.0	5.6	10.0	Long
Mg^{+2}	6/29/2010	7.4	13.9	7.3	Long
K^{+}	6/29/2010	1.1	1.6	1.1	Long
SiO_2	6/29/2010	2.4	4.1	2.4	Long
Na^{+}	6/29/2010	21.9	54.9	22.0	Long
SO_4^{-2}	6/29/2010	2.1	16.2	2.1	Long
NH_4-N	5/3/2010	**0.0**	**0.0**	**0.0**	Middle Lagoon
NH_4-N	6/29/2010	**8.8**	**2.4**	**8.7**	Long
NH_4-N	9/1/2010	**6.9**	**0.0**	**0.0**	Middle Lagoon
NH_4-N	average	5.2	0.8		
NO_3+NO_2-N	5/3/2010	9.1	6.5	7.4	Middle Lagoon
NO_3+NO_2-N	6/29/2010	13.6	4.5	11.1	Long
NO_3+NO_2-N	9/1/2010	11.7	8.1	6.6	Middle Lagoon
NO_3+NO_2-N	average	11.1	6.3		
TN	5/3/2010	548	361	347	Middle Lagoon
TN	6/29/2010	713	434	687	Long
TN	9/1/2010	794	669	651	Middle Lagoon
TN	average	681	483		
TP	5/3/2010	27.3	16.8	15.4	Middle Lagoon
TP	6/29/2010	24.4	15.9	21.6	Long
TP	9/1/2010	31.1	28.6	25.2	Middle Lagoon
TP	average	27.1	19.6		

Appendix E2. Indiana Dunes National Lakeshore, 2010 (continued).

		Site			
Parameter	**Date**	*Long Lake*	*Middle Lagoon*	**Duplicate**	**Duplicate Location**
chl-*a*	5/3/2010	1.5	2.0	1.8	Middle Lagoon
chl-*a*	6/29/2010	2.4	2.0	2.5	Long
chl-*a*	9/1/2010	6.2	9.4	8.8	Middle Lagoon
chl-*a*	average	3.4	4.3		
DO	5/3/2010	7.9	10.2		
DO	6/29/2010	0.4	13.1		
DO	9/1/2010	0.8	8.5		
DO	average	3.1	10.6		
SC	5/3/2010	296	664		
SC	6/29/2010	290	474		
SC	9/1/2010	345	492		
SC	average	310	543		
pH	5/3/2010	8.1	8.2		
pH	6/29/2010	6.7	9.7		
pH	9/1/2010	6.8	9.0		
pH	average	7.2	9.0		
Temp	5/3/2010	19.7	19.1		
Temp	6/29/2010	22.7	27.2		
Temp	9/1/2010	23.7	25.8		
Temp	average	22.0	24.0		
Secchi	5/3/2010	bottom	bottom		
Secchi	6/29/2010	0.39			
Secchi	9/1/2010	0.30	0.98		
Secchi	average				

Appendix E2. Indiana Dunes National Lakeshore, 2010 (continued).

		Site			
Parameter	**Date**	*Long Lake*	*Middle Lagoon*	**Duplicate**	**Duplicate Location**
T-tube	5/3/2010	>120	>120		
T-tube	6/29/2010	52.80	>120		
T-tube	9/1/2010	40.55	106.15		
T-tube	average				
Water Level	5/3/2010	-87.0	-575		
Water Level	6/29/2010	-81.2	-559		
Water Level	9/1/2010	-67.0	-564		
Water Level	average				
TSI(chl-*a*)	5/3/2010	35	38		
TSI(chl-*a*)	6/29/2010	39	37		
TSI(chl-a)	9/1/2010	49	53		
TSI(chl-*a*)	average	43	45		
TSI(TP)	5/3/2010	52	45		
TSI(TP)	6/29/2010	50	44		
TSI(TP)	9/1/2010	54	53		
TSI(TP)	average	52	47		
TSI(Secchi)	5/3/2010				
TSI(Secchi)	6/29/2010	74			
TSI(Secchi)	9/1/2010	77	60		
TSI(Secchi)	average				

Appendix F. Field and laboratory results for Sleeping Bear Dunes National Lakeshore.

Appendix F1 – 2009; ***F2*** – 2010.

Multiprobe measurements for pH, specific conductance, dissolved oxygen, and temperature are reported from 1.0 m depth. Results in **bold font** indicate values less than the laboratory reporting limit (also known as the method quantitation limit or MQL). Blank cells indicate that no results are available. Abbreviations used are as follows (units of measurement are in parentheses):

Alk	Alkalinity (mg/L $CaCO_3$)
Ca^{+2}	Calcium (mg/L)
Cl^{-}	Chloride (mg/L)
DOC	Dissolved Organic Carbon (mg/L)
Mg^{+2}	Magnesium (mg/L)
K^{+}	Potassium (mg/L)
SiO_2	Silicate (mg/L)
Na^{+}	Sodium (mg/L)
SO_4^{-2}	Sulfate (mg/L)
NH_4-N	Ammonium-Nitrogen (µg/L)
NO_3+NO_2-N	Nitrate+Nitrite (µg/L)
TN	Total Nitrogen (µg/L)
TP	Total Phosphorus (µg/L)
TN-Hypolimnion	Bottom TN (µg/L)
TP Hypolimnion	Bottom TP (µg/L)
chl-*a*	Chlorophyll-*a* (µg/L)
DO	Dissolved Oxygen (mg/L)
SC25	Specific Conductance (µS/cm)
pH	pH (standard units)
Temp	Temperature (°C)
Secchi	Secchi Depth (m)
Water Level	Water Level (m)
M Hg	Methyl Mercury (ng/L)
T Hg	Total Mercury (ng/L)
TSI(chl-*a*)	Trophic State Index calculated from chlorophyll-*a* concentration
TSI(TP)	Trophic State Index calculated from TP concentration
TSI(Secchi)	Trophic State Index calculated from Secchi depth

Appendix F1. Sleeping Bear Dunes National Lakeshore, 2009.

		Lake											
Parameter	**Month/Yr**	*Manitou*	*Florence*	*Narada**	*Shell*	*Bass (North)*	*Otter*	*Tucker*	*North Bar*	*Loon*	*Round*	**Duplicate**	**Duplicate Location**
Alk	7/09	137	54	150	92	86	127	116	149	122	126	88	Bass (N)
Ca^{+2}	7/09	33.4	15.3	37.9	26.0	27.1	33.9	34.8	42.6	37.7	28.6	26.8	Bass (N)
Cl^-	7/09	0.8	0.8	9.7	1.1	7.0	7.6	1.1	4.3	9.3	22.9	6.9	Bass (N)
DOC	7/09	6.9	9.0	8.1	11.0	11.0	5.2	14.0	4.5	4.6	7.7	11.0	Bass (N)
Mg^{+2}	7/09	16.1	6.6	13.4	17.4	10.2	14.1	12.1	15.1	13.5	17.2	10.2	Bass (N)
K^+	7/09	0.6	0.7	0.3	0.6	1.2	0.9	0.3	0.7	0.8	0.7	1.1	Bass (N)
SiO_2	7/09	2.4	0.4	8.3	7.7	2.5	6.8	5.1	6.7	5.9	8.8	2.9	Bass (N)
Na^+	7/09	1.4	0.7	5.7	1.9	3.5	4.3	1.0	1.7	6.7	14.3	3.3	Bass (N)
SO_4^{-2}	7/09	10.3	4.9	3.4	31.2	9.1	8.8	5.0	10.9	11.6	9.2	9.2	Bass (N)
NH_4-N	6/09	11.4	40.9		35.8	29.4	44.2	27.9	28.3	32.9	73.6	30.9	North Bar
NH_4-N	7/09	15.0	27.9		42.8	32.1	30.2	23.0	45.4	14.1	30.1	39.1	Bass (N)
NH_4-N	10/09	17.9	45.2	15.3	95.0	27.4	37.8	24.1	37.2	13.9	23.9	25.6	Tucker
NH_4-N	average	14.8	38.0		57.9	29.6	37.4	25.0	36.9	20.3	42.5	31.9	
NO_3+NO_2-N	6/09	13.6	26.4		24.5	24.0	203.3	16.0	318	89.2	27.0	316	North Bar
NO_3+NO_2-N	7/09	21.3	35.0		32.5	106	83.4	56.2	289	95.9	38.9	55.1	Bass (N)
NO_3+NO_2-N	10/09	22.1	43.5	12.7	17.6	19.4	99.9	13.4	224	12.3	24.5	13.7	Tucker
NO_3+NO_2-N	average	19.0	35.0		24.9	49.8	128.9	28.5	277	65.8	30.1	128	
TN	6/09	491	811		750	739	574	754	598	346	731	596	North Bar
TN	7/09	591	804		853	784	462	761	580	239	583	805	Bass (N)
TN	10/09	446	810	536	932	723	526	787	553	277	586	788	Tucker
TN	average	509	808		845	749	521	767	577	287	634	729	
TP	6/09	15.8	39.4		12.1	12.3	10.6	19.3	10.0	12.8	15.5	10.2	North Bar
TP	7/09	19.9	16.0		14.0	13.8	12.7	16.8	11.6	10.2	13.3	14.2	Bass (N)
TP	10/09	17.9	16.6	14.6	16.5	12.4	12.5	16.2	11.0	11.7	17.0	18.4	Tucker
TP	average	17.9	24.0		14.2	12.8	11.9	17.4	10.9	11.6	15.3	14.3	
TN-Hypolimnion	7/09	1697	817	2282					1266	750			
TP-Hypolimnion	7/09	84.4	16.8	636					34.4	37.3			

* sampled in September only.

Appendix F1. Sleeping Bear Dunes National Lakeshore, 2009 (continued).

		Lake											
Parameter	**Month/Yr**	*Manitou*	*Florence*	*Narada**	*Shell*	*Bass (North)*	*Otter*	*Tucker*	*North Bar*	*Loon*	*Round*	**Duplicate**	**Duplicate Location**
chl-*a*	6/09	0.7	1.5		1.0	2.5	0.6	1.6	0.8	1.0	2.5		
chl-*a*	7/09	1.4	4.0		1.4	3.2	2.8	2.0	1.9	1.6	2.8	1.8	Bass (N)
chl-*a*	10/09	4.3	8.3	0.9	2.0	1.9	2.0	1.4	0.9	1.4	1.9		
chl-*a*	average	2.1	4.6		1.4	2.5	1.8	1.6	1.2	1.3	2.4		
DO	6/09	11.3	10.3		11.4	10.3	9.9	12.2	10.3	10.6	9.7		
DO	7/09	10.3	9.4		13.1	18.1	19.6	18.8	17.0	14.0	15.2		
DO	10/09	13.8	12.2	13.7	13.5	12.5	14.6	16.1	14.1	14.8	16.7		
DO	average	11.8	10.6		12.7	13.7	14.7	15.7	13.8	13.1	13.9		
SC	6/09	289	120		265	223	296	251	331	322	343		
SC	7/09	278	123		244	212	282	247	327	306	330		
SC	10/09	257	115	312	258	202	293	247	318	304	316		
SC	average	275	120		256	213	290	248	325	311	329		
pH	6/09	5.5	8.3		8.7	8.7	8.4	8.4	8.4	8.4	8.6		
pH	7/09	8.5	8.4		8.7	8.7	8.4	7.9	8.2	8.5	8.5		
pH	10/09	8.4	8.5	8.0	8.7	8.9	8.2	8.1	8.2	8.3	8.4		
pH	average	7.5	8.4	8.0	8.7	8.8	8.3	8.1	8.3	8.4	8.5		
Temp	6/09	20.5	21.4		21.2	25.3	24.5	22.0	25.3	26.3	25.5		
Temp	7/09	22.1	23.3		22.9	22.6	23.3	23.0	21.9	22.1	22.9		
Temp	10/09	20.2	19.3	21.3	22.3	21.7	22.2	22.7	21.9	21.8	22.9		
Temp	average	20.9	21.3		22.1	23.2	23.3	22.5	23.1	23.4	23.7		
Secchi	6/09	2.95	3.13		3.95	2.75	3.48	2.75	2.18	6.45	5.95		
Secchi	7/09	1.69	1.59			2.64	2.63	2.84	3.25	2.50	3.40		
Secchi	10/09	3.38	1.35	5.43	3.40	3.10	2.93	3.30	2.88	3.73	4.66		
Secchi	average	2.7	2.0	5.4	3.7	2.8	3.0	3.0	2.8	4.2	4.7		
Water Level	6/09	-0.79	-0.76		-0.53	-0.85	-0.73	-0.58	-0.83	-0.64	-1.11		
Water Level	7/09	-0.89	-0.85		-0.69	-1.18	-0.74	-0.70	-0.88	-0.67	-1.13		
Water Level	10/09	-0.86	-0.70		-0.78	-1.55	-0.74	-0.71	-0.94	-0.65	-1.07		
Water Level	average	-0.8	-0.8		-0.7	-1.2	-0.7	-0.7	-0.9	-0.7	-1.1		

* sampled in September only.

Appendix F1. Sleeping Bear Dunes National Lakeshore, 2009 (continued).

		Lake											
Parameter	**Month/Yr**	*Manitou*	*Florence*	*Narada**	*Shell*	*Bass (North)*	*Otter*	*Tucker*	*North Bar*	*Loon*	*Round*	**Duplicate**	**Duplicate Location**
TSI(chl-*a*)	6/09	28	35		30	39	25	35	29	30	40		
TSI(chl-*a*)	7/09	34	44		34	42	41	37	37	35	41		
TSI(chl-*a*)	10/09	45	51	30	37	37	37	34	29	34	37		
TSI(chl-*a*)	average	38	46		34	40	36	35	32	33	39		
TSI(TP)	6/09	44	57		40	40	38	47	37	41	44		
TSI(TP)	7/09	47	44		42	42	41	45	39	38	41		
TSI(TP)	10/09	46	45	43	45	40	41	44	39	40	45		
TSI(TP)	average	46	50		42	41	40	45	39	39	43		
TSI(Secchi)	6/09	44	44		40	45	42	45	49	33	34		
TSI(Secchi)	7/09	52	53			46	46	45	43	47	42		
TSI(Secchi)	10/09	42	56	36	42	44	45	43	45	41	38		
TSI(Secchi)	average	46	50			45	44	44	45	39	38		

* sampled in September only.

Appendix F2. Sleeping Bear Dunes National Lakeshore, 2010.

		Lake											
Parameter	**Month/Yr**	*Manitou*	*Florence*	*Narada**	*Shell*	*Bass (North)*	*Otter*	*Tucker*	*North Bar*	*Loon*	*Round*	**Duplicate**	**Duplicate Location**
Alk	7/09	122	58	159	105	94	134	124	147	139	115	118	Round
Ca^{+2}	7/09	27.6	15.6	43.1	31.6	27.8	40.4	37.4	43.8	40.0	25.4	18.4	Round
Cl^{-}	7/09	0.7	0.8	10.1	1.3	6.8	7.7	1.1	4.3	8.6	18.4	8.5	Round
DOC	7/09	6.7	7.4	7.8	11.0	11.0	5.7	13.0	**4.5**	**4.8**	9.1	8.8	Round
Mg^{+2}	7/09	17.0	6.4	13.1	17.6	10.3	14.7	12.3	16.1	13.7	18.4	25.0	Round
K^{+}	7/09	0.6	0.7	0.4	0.6	1.1	0.9	0.3	0.7	0.8	0.7	12.7	Round
SiO_2	7/09	4.9	**0.4**	6.1	9.4	2.6	7.7	6.4	4.3	7.0	9.7	18.1	Round
Na^{+}	7/09	1.3	0.6	3.0	2.0	3.4	4.6	0.9	1.9	6.8	13.5	0.7	Round
SO_4^{-2}	7/09	9.6	3.6		30.0	5.5	8.6	5.2	11.2	10.2	8.8	9.6	Round
NH_4-N	6/09	43.0	19.8		24.3	25.7	24.7	84.9	23.8	**8.6**	**0.0**	7.7	Tucker
NH_4-N	7/09	**2.4**	**2.4**		61.5	**2.4**	32.6	15.4	19.6	**2.4**	**2.4**	**2.4**	Round
NH_4-N	10/09	**0.0**	30.2	**6.2**	104	**10.8**	106	15.9	179	20.8	38.9	106	Shell
NH_4-N	average	15.1	17.5	6.2	63.5	13.0	54.6	25.8	74.1	10.6	13.8		
NO_3+NO_2-N	6/09	3.1	4.9		11.5	9.4	318	7.3	407	77.6	12.0	7.1	Tucker
NO_3+NO_2-N	7/09	58.2	178		27.3	101	202	45.1	421	47.3	19.4	20.7	Round
NO_3+NO_2-N	10/09	6.6	15.9	20.7	14.8	9.1	140	14.0	215	35.9	11.5	12.9	Shell
NO_3+NO_2-N	average	22.6	66.4	20.7	17.5	40.0	220	22.1	347.6	53.6	14.5		
TN	6/09	450	671		817	701	715	755	690	323	618	971	Tucker
TN	7/09	481	665		981	797	584	812	581	264	641	627	Round
TN	10/09	534	753	563	963	719	631	732	687	286	665	918	Shell
TN	average	488	696	563	913	739	643	802	653	291	639		
TP	6/09	12.7	14.7		12.4	8.9	9.7	14.3	8.4	9.1	9.7	26.6	Tucker
TP	7/09	12.1	12.0		18.5	12.5	10.0	15.8	8.5	10.3	14.1	13.5	Round
TP	10/09	18.7	14.5	21.3	14.7	12.8	13.1	15.6	19.3	11.8	16.5	16.6	Shell
TP	average	14.5	13.7	21.3	15.5	11.4	10.9	17.3	12.0	10.4	13.3		
TN-Hypolimnion	7/09	518	728			930			885	781	578	569	Round
TN-Hypolimnion	10/09	5154	799	1595									

* sampled in September only

Appendix F2. Sleeping Bear Dunes National Lakeshore, 2010 (continued).

		Lake											
Parameter	**Month/Yr**	*Manitou*	*Florence*	*Narada**	*Shell*	*Bass (North)*	*Otter*	*Tucker*	*North Bar*	*Loon*	*Round*	**Duplicate**	**Duplicate Location**
TP-Hypolimnion	7/09	15.5	11.3			13.9			22.5	19.4	16.5	16.5	Round
TP-Hypolimnion	10/09	141	13.9	138									
chl-*a*	6/09	1.4	2.7		1.8	2.1	1.5	3.1	2.5	0.7	1.5	3.1	Tucker
chl-*a*	7/09	2.3	4.8		1.6	2.1	2.0	2.7	1.7	2.8	2.5	1.9	Round
chl-*a*	10/09	4.3	7.2	8.3	1.5	2.2	2.7	1.7	4.7	2.4	2.1	1.7	Shell
chl-*a*	average	2.7	4.9		1.7	2.2	2.1	2.5	2.9	2.0	1.9		
DO	6/09	10.3	9.4		9.8	9.8	10.0	9.0	10.3	10.1	10.4		
DO	7/09	10.5	8.2		8.1	9.1	9.4	6.8	8.7	8.8	9.2		
DO	10/09	9.2	9.2	9.7	8.0	9.2	9.2	10.0	9.6	9.3	9.7		
DO	average	10.0	8.9		8.6	9.3	9.5	8.6	9.5	9.4	9.7		
SC	6/09	274	121		264	223	311	241	331	320	310		
SC	7/09	245	124		258	218	299	254	317	301	299		
SC	10/09	239	125	331	262	204	291	251	325	306	300		
SC	average	253	123		262	215	300	248	324	309	303		
pH	6/09	8.7	8.4		8.4	8.6	8.2	8.1	8.4	8.2	8.6		
pH	7/09	8.7	8.1		8.5	8.7	8.4	7.9	8.3	8.4	8.8		
pH	10/09	8.7	8.1	8.0	8.3	8.6	8.3	8.2	8.3	8.2	8.5		
pH	average	8.7	8.2	8.0	8.4	8.6	8.3	8.0	8.3	8.3	8.6		
Temp	6/09	22.2	22.4		20.6	20.9	20.7	20.7	22.0	20.3	21.4		
Temp	7/09	25.9	25.7		26.0	26.2	26.5	25.3	24.6	24.7	26.8		
Temp	10/09	18.3	17.9	17.4	24.8	24.8	18.1	17.8	16.6	17.1	17.5		
Temp	average	22.2	22.0		23.8	23.9	21.8	21.2	21.1	20.7	21.9		
Secchi	6/09	3.20	2.33		3.08	2.70	3.53	2.50	3.43	4.90	4.05		
Secchi	7/09	2.00	1.73		3.80	3.50	2.95	2.43	2.49	2.41	4.33		
Secchi	10/09	2.20	1.60	2.3	3.03	2.55	2.05	2.40	1.71	3.08	2.45		
Secchi	average	2.5	1.9	2.3	3.3	2.9	2.8	2.4	2.5	3.5	3.6		
Water Level	6/09	-0.87	-0.74		-0.47	-0.92	-0.70	-0.52	-1.35	-0.53	-1.05		

* sampled in September only

Appendix F2. Sleeping Bear Dunes National Lakeshore, 2010 (continued).

		Lake											
Parameter	**Month/Yr**	*Manitou*	*Florence*	*Narada**	*Shell*	*Bass (North)*	*Otter*	*Tucker*	*North Bar*	*Loon*	*Round*	**Duplicate**	**Duplicate Location**
Water Level	7/09	-0.90	-0.83		-0.61	-1.24	-0.77	-0.65	-1.44	-0.63	-1.07		
Water Level	10/09	-1.05	-0.92		-0.66	-1.43	-0.75	-0.66	-0.95	-0.63	-1.08		
Water Level	average	-0.9	-0.8		-0.6	-1.2	-0.7	-0.6	-1.2	-0.6	-1.1		
TSI(chl-*a*)	6/09	34	40		37	38	35	42	39	28	35		
TSI(chl-*a*)	7/09	39	46		35	38	37	40	36	41	39		
TSI(chl-*a*)	10/09	45	50	51	35	38	40	36	46	39	38		
TSI(chl-*a*)	average	40	46		36	38	38	40	41	37	37		
TSI(TP)	6/09	41	43		40	36	37	43	35	36	37		
TSI(TP)	7/09	40	40		46	41	37	44	35	38	42		
TSI(TP)	10/09	46	43	48	43	41	41	44	47	40	45		
TSI(TP)	average	43	42		44	39	39	45	40	38	42		
TSI(Secchi)	6/09	43	48		44	46	42	47	42	37	40		
TSI(Secchi)	7/09	50	52		41	42	44	47	47	47	39		
TSI(Secchi)	10/09	49	53	48	44	47	50	47	52	44	47		
TSI(Secchi)	average	47	51	48	43	45	45	47	47	42	42		

* sampled in September only

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