



Monitoring Water Quality of Inland Lakes, 2008

Annual Summary Report

Joan Elias – Great Lakes Inventory and Monitoring Network



On the cover: Left - Leah Kainulainen and Lora Loope, paddling on Chapel Lake, Pictured Rocks National Lakeshore (photo by J. Elias). Right – Valena Hofman, portage between Rainbow Cove and Feldtmann Lake, Isle Royale National Park (photo by Charly Kearns).

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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 resource managers have lent a hand. Special thanks to the primary field staff: Lora Loope, Leah Kainulainen, Chris Otto, Valena Hofman, Charly Kearns, Ted Gostomski, and David VanderMeulen. Many thanks also to Leslie Jagger, Rebecca Key, Sara Forni, Emily Kobernik, and Jim Meeker, who lent a hand with field work. Crucial logistical and boat support were provided by Ryan Maki and Dave Schroeder. Rebecca Key spent many hours (intriguing or agonizing, she won't say) processing bathymetric data and constructing maps and metadata, for which I'm most grateful. Finally, I especially appreciate conversations with Lora Loope, Ryan Maki, Brenda Moraska Lafrancois, and David VanderMeulen regarding data interpretation and future improvements to data collection.

Abstract

The Great Lakes Inventory and Monitoring Network monitored water quality of inland lakes at six national park units in 2008: 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 trends of common limnological parameters within sampled lakes. We hope to be able to provide early warnings of change, which may then provide justification for increased monitoring, research, or management action.

Thirty-three index lakes were sampled three times during the open water season in 2008. Field measurements included depth profiles of temperature, pH, conductivity, and dissolved oxygen; water clarity; and water level relative to a benchmark. Water samples were collected for laboratory analyses of nutrients (total phosphorus, total nitrogen, nitrate+nitrite-nitrogen, ammonium-nitrogen, dissolved silica), major ions (calcium, sodium, magnesium, potassium, sulfate, chloride), dissolved organic carbon, alkalinity, and chlorophyll-*a*.

Results from 2008 are compared across parks; individual park results are included in appendices. Results show that many lakes exceed the U.S. Environmental Protection Agency (USEPA) water quality reference criteria for their ecoregion. Calculations of trophic state indices show most index lakes to be mesotrophic. Water levels generally declined over the course of the season.

Park specific comments and recommendations relating to the sampling season are provided. We expect monitoring to continue in 2009 at the same index lakes, with additional sites included as funding permits.

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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 2008: 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 high 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:

- core suite (temperature, dissolved oxygen, conductivity, pH, 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)
- diatoms (not included within the water quality monitoring protocol, but closely tied to it; Ramstack et al. 2008)

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 likely 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 trends of 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 provide justification for increased monitoring, research, or management action. Because 2008 marks the third year of monitoring water quality at some parks, we are now getting a better understanding of the challenges related to maintaining the consistency needed in order to distinguish a real trend from the natural variability inherent in the lakes as well as in the sampling equipment and laboratory analyses.

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

Methods

Study Sites

The Network, in collaboration with the parks, selected index lakes in which to monitor water quality annually. 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 2008. Additional lakes were sampled at SLBE (N=4) and INDU (N=1).

Water Quality Sampling

Field Methods

In accordance with the Water Quality Monitoring Protocol for Inland Lakes (Elias et al. 2008), we conducted field sampling at the deepest part of each lake three times during the open water season (Table 2). 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 at PIRO; Eureka Manta (Model 318) at APIS; Eureka Manta (Model 132) at ISRO and VOYA; and Hydrolab 5X at SLBE. 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 equivalent of a 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. Sample water was composited in a 4.3 L high density polyethylene container. See Elias et al. (2008) and Elias and VanderMeulen (2008) for details on collection and handling of water samples.

Water samples were collected for nutrients and chlorophyll-a (chl-a) during all three site visits. Samples for the remaining parameters (Table 3) were collected only during the middle round of sampling. Also during the mid-summer sampling, we collected a near-bottom water sample with a Van Dorn for analysis of total phosphorus. This sampling was conducted only in lakes that were thermally stratified.

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). 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. Index lakes sampled for water quality in 2008. The parks are listed in order from west to east.

Park	Lake or Lagoon	Maximum Depth (m)	Surface Area (ha)
Voyageurs National Park	Brown	8.9	31
	Cruiser	26.2	47
	Ek	5.7	36
	Little Trout	27.5	97
	Locator	15.1	57
	Peary	4.8	45
	Ryan	3.6	14
	Shoepack	5.2	124
Apostle Islands National Lakeshore	Little Sand Bay	1.5	0.8
	Michigan Island	1.0	3
	Outer Island	1.0	22
	Stockton Island	1.3	4
Isle Royale National Park	Ahmik	2.6	10
	Beaver	5.3	20
	Desor	15.0	428
	Feldtmann	2.6	186
	George	2.8	3.8
	Harvey	4.3	55
	Richie	10.5	216
	Sargent	12.7	143
Pictured Rocks National Lakeshore	Siskiwit	45.1	1635
	Beaver	9.2	310
	Chapel	45	28
	Grand Sable	19.2	255
	Legion	11.9	14
	Miners	3.3	5
Indiana Dunes National Lakeshore	Long	1.5	33
Sleeping Bear Dunes National Lakeshore	Bass (North)	7.0	38
	Florence	8.0	32
	Loon	19.0	37
	Manitou	10.7	104
	Round	6.9	6
	Shell	4.3	41

Table 2. Dates of water quality sampling, 2008.

	Round 1	Round 2	Round 3
VOYA	6/3 - 6/11	7/8 - 7/16	9/3 - 9/11
APIS	6/16 - 6/18	7/28 - 7/31	9/8 - 9/12
ISRO*	6/17 - 6/27	7/22 - 8/1	8/20 - 8/29
PIRO	6/16 - 6/20	7/28 - 8/1	9/2 - 9/10
INDU	5/1	7/1	9/2
SLBE	6/2 - 6/17	7/16 - 7/24	9/4 - 9/10

* Additional sampling at ISRO: 5/27, 8/14, 8/15 and 9/22

Table 3. Parameters measured and abbreviations used in text. **Bold** font indicates parameters measured three times per season; remaining parameters measured once during mid-season.

Parameter	Abbreviation	Parameter	Abbreviation
Alkalinity	Alk	Total Nitrogen	TN
Calcium	Ca ⁺²	Ammonium-Nitrogen	NH₄-N
Chloride	Cl ⁻	Nitrate+Nitrite-Nitrogen	NO₃+NO₂-N
Chlorophyll-a	Chl-a	Total Phosphorus-Hypolimnion	TP Hypo
Pheophytin	Pheo	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

We contracted with White Water Associates (WWA) and Natural Resource Research Institute (NRRI) for analytical laboratory services. WWA analyzed samples for major ions, alkalinity, dissolved organic carbon (DOC), and dissolved silica (SiO₂); NRRI analyzed samples for nutrients and chl-a. All samples were processed and handled according to standard operating procedures (Axler et al. 2008) and as detailed in the 2007 annual water quality report (Elias and VanderMeulen 2008). Select duplicate samples were analyzed by the Wisconsin State Laboratory of Hygiene (WSLH), largely for GLKN confidence in other contracted lab results. Results from WSLH are not included in this report. Mercury samples from VOYA were analyzed by the USGS lab in Middleton, Wisconsin.

Sediment Sampling

We collected surface sediment samples in June from Lake Desor and Siskiwit Lake, both at ISRO, because inadequate samples were collected in 2007. In October, we collected surface sediment cores at four PIRO lakes (Miners, Beaver, Chapel, and Grand Sable). Samples were collected with a drop corer according to standard operating procedures (Ramstack et al. 2008).

The samples from PIRO are the second round of surface sediment cores collected at this park; the first were collected in 2005. These 2008 PIRO samples will be analyzed for changes in the diatom communities since 2005 and will help inform our interpretation of water chemistry results.

The principal investigators of the diatom project (Edlund and Engstrom; Biomonitoring prospects for diatoms and paleolimnology in the Western Great Lakes National Parks) collected long cores in 2008 from Bass (North) and Florence Lakes at SLBE and Beaver Lake at PIRO. These are the final long cores scheduled for collection for the diatom project and were collected to fill gaps in data coverage. Cores and samples were handled and processed according to Ramstack et al. (2008).

Results from this project will complement our water quality program through analysis of diatom communities relative to past and current water quality conditions. Progress reports are available from GLKN and a final report for this project will be completed in late 2009.

Bathymetric Mapping

Hard-copy bathymetric maps exist for many of the index lakes, though electronic maps for these lakes are 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 ISRO 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.

Data Handling

Methods for using laboratory data below detection limit (i.e., censored data) in statistical analyses are numerous and diverse (e.g., Helsel 1990, Helsel and Cohen 1988). Because I did not conduct statistical analyses for this report, but rather simply calculated means, I used the value of '0' if that is what the lab reported. I used 'ND' (non-detect) when the lab reported it as such. Results of 'ND' were reported only twice, both times 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 measurement sensitivity of each sonde was calculated prior to the field season; sondes were calibrated daily following acceptance criteria and 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 mg/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.

Results and Discussion

Data relative to USEPA reference criteria, trophic status, and changes in water level are presented below. 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, total phosphorus (TP), total nitrogen (TN), and nitrate+nitrite-nitrogen (NO₃+NO₂-N) for their ecoregions (USEPA 2000a, b, c).

Most lakes at VOYA, ISRO, and PIRO, and approximately half of the sampled lakes at 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. Decreases in Secchi depth over time indicate increasing eutrophication, but confounding factors such as changes in personnel and field conditions (e.g., rough water) must be taken into consideration.

Water transparency at APIS and INDU was measured with a transparency tube because of the shallow depths of the lakes/lagoons. One or more of the T-tube measurements was >120 cm, the equipment maximum, at each of the waterbodies. In such cases, comparisons against the USEPA criteria are not possible.

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 were borderline at APIS and INDU. Lakes on the low end of the pH scale are likely naturally acidic, though the pH 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).

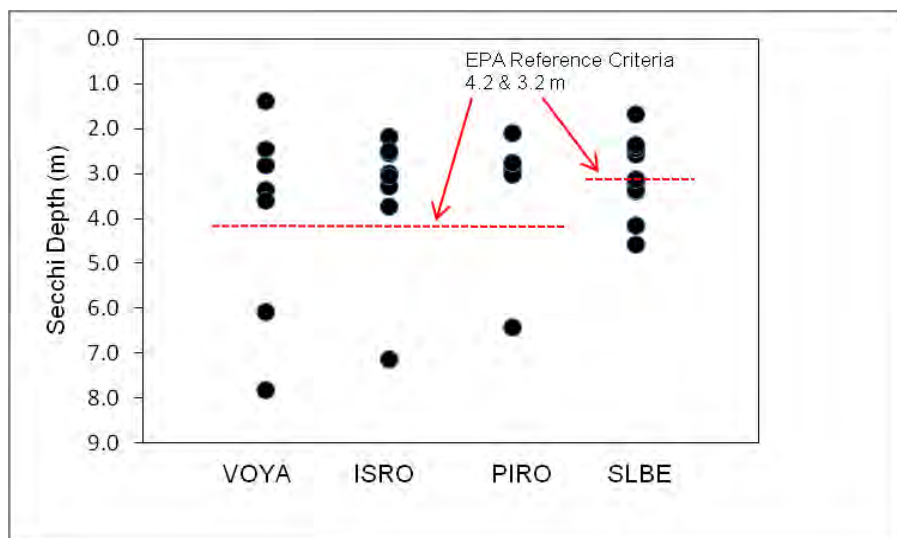


Figure 1. Mean Secchi depth measurements of lakes across four park units in the Great Lakes Network, 2008. Points above the dotted lines indicate lakes with mean Secchi depths that did not meet the EPA reference criteria in the appropriate ecoregion (USEPA 2000a, b). Park codes as in text.

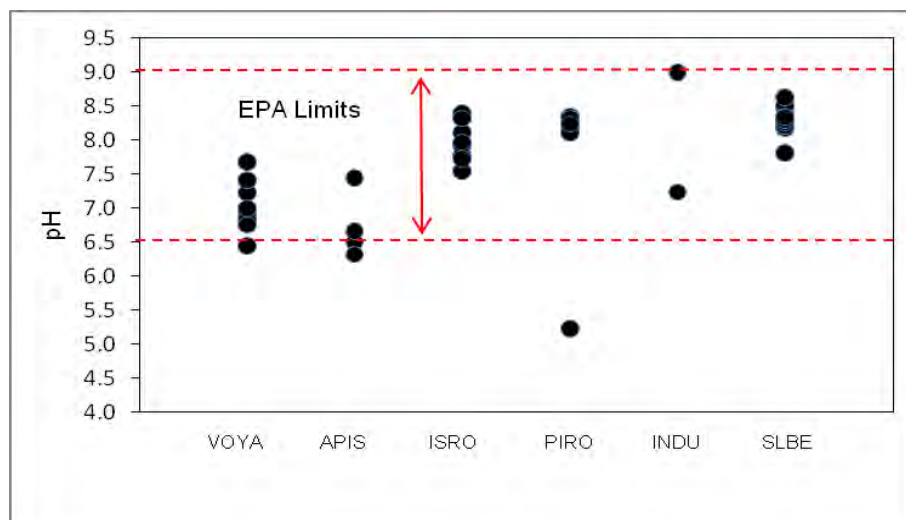


Figure 2. Mean near-surface pH values (1.0m at VOYA, ISRO, PIRO, and SLBE; 0.5m at APIS and INDU) of lakes across six park units in the Great lakes Network, 2008. Points between the dotted lines represent lakes that fell within the USEPA limits (USEPA 2000a, b, c). Park codes as in text.

The TP and TN reference criteria for Ecoregions and Subregions that include SLBE and INDU are higher than those that include VOYA, APIS, ISRO, and PIRO; most of the SLBE and INDU lakes fall below their reference criteria (Figures 3 and 4). At the remaining parks, however, many lakes have mean TP and TN values above the reference criteria. As many of these lakes do not receive direct anthropogenic inputs (e.g., fertilizer runoff, failing septic systems, sewage treatment plant effluent), sources of phosphorus and nitrogen are likely from within the lakes

(resuspension) or from atmospheric deposition. Some lakes may be receiving anthropogenic inputs, however.

All parks except INDU had lakes that exceeded EPA reference criteria for nitrate+nitrite-nitrogen ($\text{NO}_3+\text{NO}_2\text{-N}$; Figure 5). One lake at PIRO (Miners) and several SLBE lakes had unusually high levels of $\text{NO}_3+\text{NO}_2\text{-N}$. Studies to determine the sources of $\text{NO}_3+\text{NO}_2\text{-N}$ in these lakes may be warranted, so that if they are anthropogenic, appropriate actions can be undertaken.

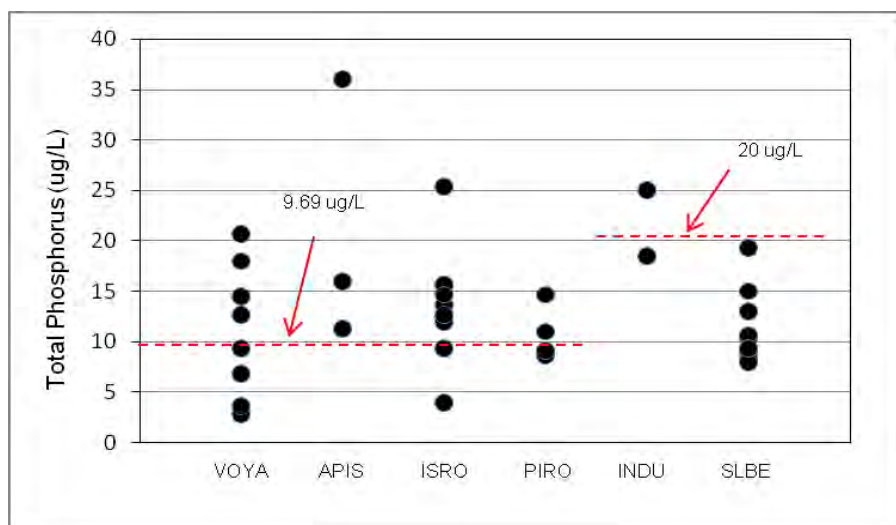


Figure 3. Mean total phosphorus (TP) levels for lakes across six parks in the Great Lakes Network, 2008. Points above the dotted lines indicate lakes with mean TP levels greater than the USEPA reference criteria (USEPA 2000a, b, c). Park codes as in text.

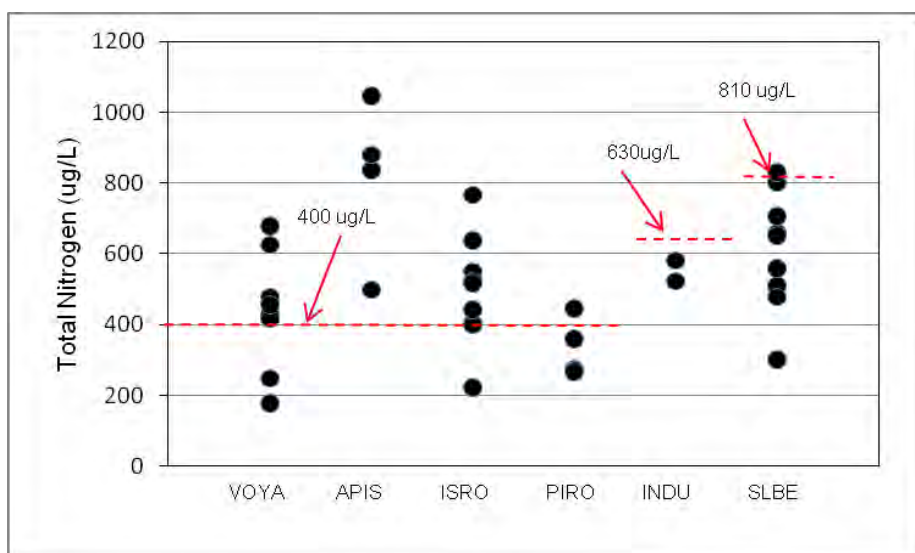


Figure 4. Mean total nitrogen (TN) levels for lakes across six parks in the Great Lakes Network, 2008. Points above the dotted lines indicate lakes with mean TN levels greater than the USEPA reference criteria (USEPA 2000a, b, c). Park codes as in text.

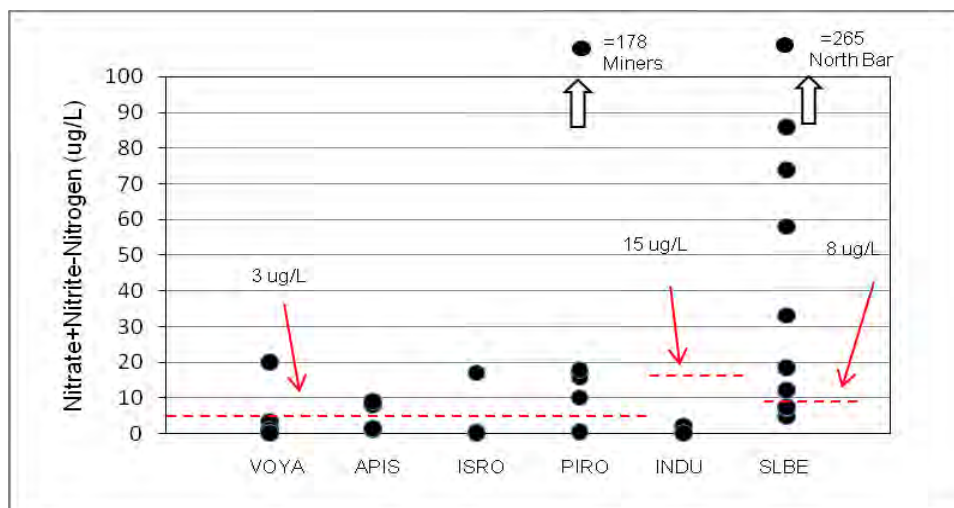


Figure 5. Mean total nitrate+nitrite-nitrogen (NO₃+NO₂-N) levels for lakes across six parks in the Great Lakes Network, 2008. Points above the dotted lines indicate lakes with mean NO₃+NO₂-N levels greater than the USEPA reference criteria (USEPA 2000a, b, c). Note the break in the scale for one lake each at PIRO and SLBE. Park codes as in text.

Nutrient Limitation and Trophic State

Ratios of TN to TP are used to indicate which of the two nutrients might be the limiting factor controlling plant growth (including algae) in a waterbody. High values of TN:TP usually indicate that phosphorus is the limiting nutrient for plant growth, while low values of the ratio usually indicate that nitrogen is limiting. The critical value for phosphorus limitation is defined as 10 according to Scheffer (2004), 7 according to Dillon et al. (2004), and 15 according to Shaw et al. (1996). Production of algae in lakes has been thought to be limited by phosphorus (Wetzel 2001), but recent research suggests nitrogen may be equally limiting (Lewis and Wurtsbaugh 2008). As atmospheric deposition of nitrogen has increased in recent years (Bergström and Jansson 2006), we are alert to potential changes in nutrient dynamics and algal responses in our study lakes. Lower TN:TP ratios may provide conditions that favor cyanobacteria, as this group can fix nitrogen. Cyanobacteria are usually not common at TN:TP ratios greater than 29 (Wetzel 2001) and often dominate at ratios less than 5 to 10 (Bulgakov and Levich, accessed 6/30/06). Most of the index lakes throughout the Network were phosphorus limited. In almost all cases, TN:TP values were greater than 20, and often much higher (Figure 6). The noxious bloom of *Lyngbya gerbirea* (a cyanobacterium) that occurred in Lake Richie, ISRO, in 2007 did not occur in 2008, even though the mean TN:TP was only slightly higher in 2008 (22) than in 2007 (20).

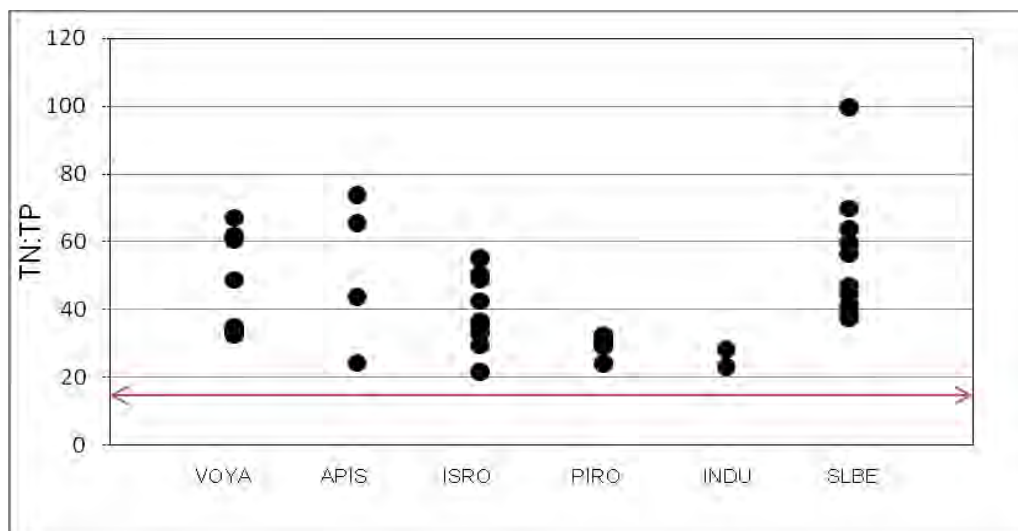


Figure 6. Mean total nitrogen to total phosphorus ratios (TN:TP) of lakes across Great Lakes Network parks, 2008. Points above the red bar indicate lakes where phosphorus is thought to be the nutrient limiting algal production. Park codes as in text.

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 chl-a concentration. Our calculations of TSI based on chl-a showed the majority of sampled lakes in 2008 were categorized as 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).

Although chl-a is preferentially used to calculate TSI, total phosphorus and Secchi depth are also commonly used to calculate TSI, and differences from the chlorophyll TSI may help to explain lake processes. In 2007, we used TP to calculate TSI because we did not have reliable chl-a data and some lakes were too shallow for Secchi disk measurements. See Appendices A-F for calculations of TSI in 2008, based on all three variables (when available).

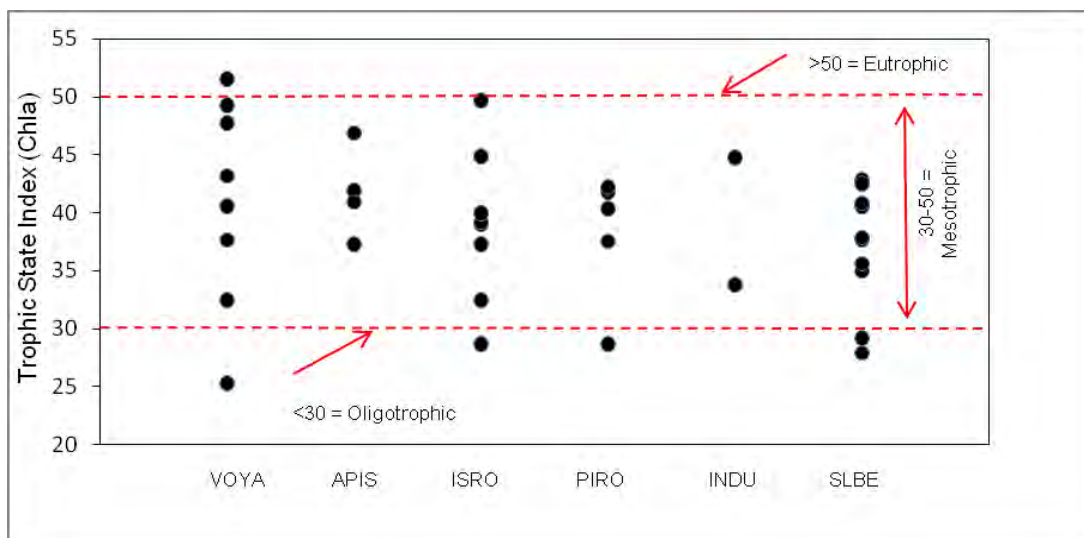


Figure 7. Trophic state indices as calculated from mean chlorophyll-a measurements of lakes across Great Lakes Network parks, 2008. Park codes as in text.

Water Level

The water levels of most lakes dropped throughout the season, usually around 20 to 30 cm (Figure 8). Middle Lagoon, INDU, was an exception, as levels increased approximately 17 cm. Reasons for a water level pattern opposite of most lakes across GLKN are unknown, but may be related to activities conducted by U.S. Steel, which owns the western part of Calumet Lagoon (hydrologically connected to Middle Lagoon; D. VanderMeulen, personal communication). Another exception occurred at Bass Lake (North), SLBE, where the water level dropped nearly 80 cm over the course of the season. Beaver activity between Bass and School Lakes can alter the water levels of these lakes dramatically, though I'm unaware of such activity in 2008.

Water level changes within a sampling season are likely to vary by lake based on physical characteristics such as watershed size, connection to groundwater, ratio of surface area to mean depth, and others. After several years of collecting data on water levels we will be able to analyze for trend over time on a lake-by-lake basis.

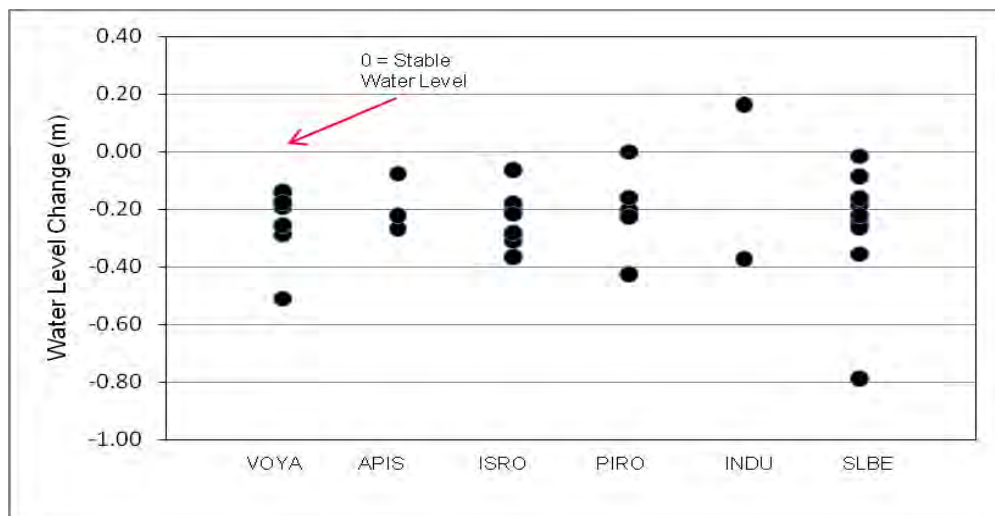


Figure 8. Change in lake water levels throughout the sampling season at Great Lakes Network parks, 2008. Park codes as in text.

Comments and Recommendations

The water quality monitoring program faces a number of challenges every year. Consistency across parks and years and covering all 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. A few specific examples follow:

- In 2008, we conducted comparisons among four multiprobes: two GLKN Eureka Mantas, a GLKN Hydrolab, and a SLBE Hydrolab. Even though all multiprobes were calibrated and met calibration checks, statistically significant differences occurred among all multiprobes for one or more parameters.
- The first year we sampled in each park, we collected water samples for analysis of all lab parameters three times (four times for PIRO and SLBE). In subsequent years, we collected nutrient and chl-a samples three times, but the remaining parameters only once, which is the intent for future years. In 2007, we collected samples for the full suite of parameters during the first round of sampling. This proved to be too much for new personnel to handle, so in 2008 we changed it to the second round of sampling. Because some parameters show fluctuations within a season, trend analyses across years may not be warranted until we have an adequate number of samples collected at the same time of the season.
- In 2007 and 2008, sampling at ISRO and VOYA depended on a single crew travelling between the two parks. This arrangement meant that the two parks, which share a similar phenology, could not be sampled at the same time (not to mention crew burn-out). In 2009, we intend to hire additional people so that the timing of sampling is not as restricted. This means that the timing of sampling in 2009 will likely be different at one or both parks compared to previous years (e.g., the first two weeks of June instead of the last two weeks at ISRO).

- In 2006, 2007, and 2008 we contracted with WWA and NRRI for laboratory analysis of water samples. Due to changes in contracting rules, we will be sending samples only to WWA in 2009. The change in labs for some parameters means we need to send an adequate number of samples to both labs to determine whether results differ consistently between the labs, so that we can apply a correction factor to previous years' data if necessary. The duplicate samples will be an additional burden on the program's budget.

As this monitoring program is still very young, some inconsistencies have been unavoidable. However, we are making improvements every year.

Park-Specific Comments

Voyageurs National Park

Despite crew burn-out, sampling went well at VOYA in 2008. All sampling was completed by GLKN staff as planned. Sharing the GLKN boat with the vegetation monitoring crew was somewhat inconvenient for both crews, but worked out adequately. GLKN required less assistance from park staff in 2008 compared to 2007.

Collaboration with USGS on mercury sampling was beneficial to both agencies. With minimal cost to both agencies, we were able to fill what we hope is only a temporary gap in funding for monitoring mercury levels in lakes susceptible to high levels of methylation of mercury.

We expect to continue monitoring the eight index lakes in 2009.

Apostle Islands National Lakeshore

Permanent benchmarks were installed at Stockton and Little Sand Bay Lagoons, and temporary benchmarks were installed at Michigan and Outer Islands Lagoons. The benchmark at Michigan Island Lagoon was installed in September, while the other three were installed in July.

In July, when we installed the benchmark at Stockton, the connection to Lake Superior was closed. When we went back the next day (because we forgot something), the connection had opened and the water level in the lagoon had dropped 19 cm overnight. In September, the connection was closed again, and the water level had dropped another approximately 7 cm.

With the exception of water level measurements, all sampling was completed by GLKN staff as planned. We did not measure water levels at any sites in June; Michigan Island Lagoon also was not measured in July.

We expect to continue monitoring the four lagoons in 2009.

Isle Royale National Park

Despite the same crew burn-out problems as at VOYA, sampling went well at ISRO in 2008 and all sampling was completed by GLKN staff as planned. Additional sampling occurred at Siskiwit, Richie, and Feldtman Lakes. The remaining permanent benchmarks were installed, replacing temporary markers at several lakes.

Responses of common loons to the sampling crew were logged. No negative reactions of loons to the presence of the crew were noticed (acceptable to moderately-low stress responses were recorded).

All index lakes have now had some bathymetry mapping. Learning to use the new GPS mapping unit with the transducer proved challenging. Even more challenging, however, was learning to download and process the data to make maps. The draft maps we have to date are rough (Figures 9 and 10), but serve to show where we need to collect additional points. We will need to decide how much smoothing of contours to do, the contour interval that is most appropriate for each lake, and the best way to smooth the contours between data points. Creating the metadata for this project will be no small task.

Even though GLKN now has a boat at ISRO, coordinating rides around the island and sharing boats with ISRO staff is a crucial aspect of successful monitoring at ISRO. We hope to continue monitoring all nine index lakes in 2009, though a new permanent staff position may not be finalized by the beginning of the season.

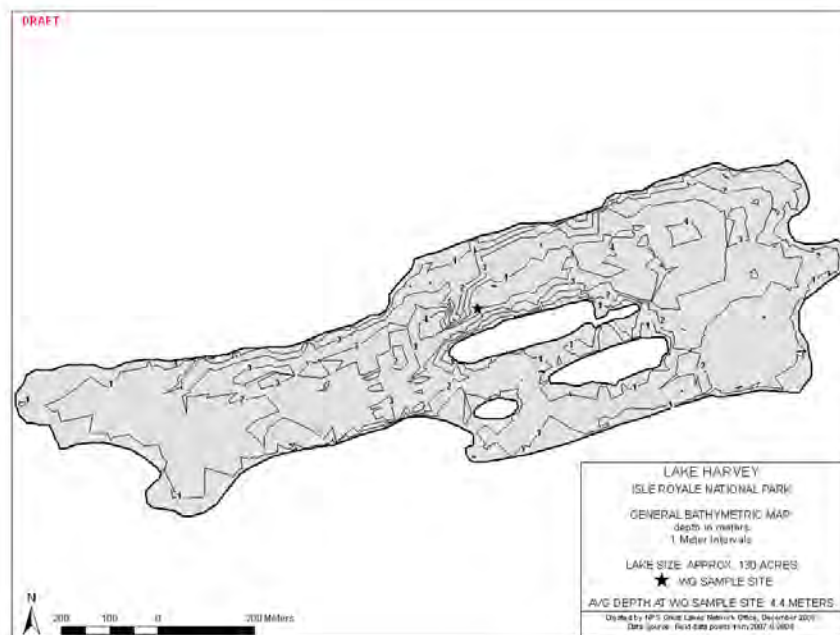


Figure 9. Bathymetric map of Lake Harvey, ISRO, showing no smoothing of contours.



Figure 10. Bathymetric map of Lake Harvey, ISRO, showing a moderate degree of contour smoothing.

Pictured Rocks National Lakeshore

Sampling went well at PIRO in 2008 and all sampling was completed by park staff as planned. In addition to the index lakes, multiprobe measurements were collected at Little Beaver Lake. Remaining benchmarks were installed.

Personnel have been consistent over the last two years; their expertise has been beneficial to the program and has resulted in reliable data. With the assistance of park staff again in 2009, we expect to continue monitoring the five index lakes.

Indiana Dunes National Lakeshore

All sampling at Long Lake, the only index lake at this time, was completed by GLKN staff as planned. In addition, we collected data with the multiprobe at Middle Lagoon and Little Calumet River three times. During the final round of sampling, water samples were collected from Middle Lagoon for laboratory analysis.

We expect to continue monitoring field parameters at Long Lake and Middle Lagoon in 2009. Laboratory parameters will continue to be measured at Long Lake, and as funds permit, at Middle Lagoon. As we finalize a protocol for wadeable streams, the Little Calumet River will become part of that project.

Sleeping Bear Dunes National Lakeshore

All sampling was completed by SLBE and PIRO staff as planned. Four lakes were sampled in addition to the index lakes (North Bar, Otter, Narada, and Tucker). One of those four (Narada)

was sampled only once in September so as not to disturb nesting loons. All lakes with the exception of Narada now have permanent benchmarks installed.

Problems with SLBE's Hydrolab meant some lakes were sampled with a loaner unit until repairs were completed on SLBE's unit. We did not compare the units side-by-side, so we do not know if they differed from each other. However, we recorded which unit was used at each site visit and will take that into account when analyzing data.

The addition of Chris Otto, aquatic specialist, to SLBE's staff will add continuity to the GLKN water quality program that was missing at the park between 2005 and 2007.

We expect to continue monitoring all six index lakes in 2009. We will include the additional four lakes as funding (GLKN and/or SLBE) permits.

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Appendix A

Field and Laboratory Results for Voyageurs National Park

Multiprobe measurements for pH, specific conductance, dissolved oxygen, and temperature are reported from 1.0 m depth. Additional sampling sites (yellow shaded cells) are not included in calculations of means. ND = non-detect, values in parentheses are results of duplicate samples, blank cells indicate that no results are available.

		Locator	Shoepack	Ek	Brown	Peary	Cruiser	Ryan	Little Trout
Alkalinity (mg CaCO ₃ /L)	July	7	ND	8	5	6	7 (6)	6	14
Calcium (mg/L)	July	2.5	3.6	3.0	2.0	2.3	1.9 (2.0)	2.7	3.6
Chloride (mg/L)	July	0.8	1.1	0.7	0.8	0.6	0.4 (0.4)	0.6	0.4
Dissolved Organic Carbon (mg/L)	July	14.6	20.3	15.4	12.2	10.6	4.2 (4.2)	12.0	5.0
Magnesium (mg/L)	July	1.2	1.7	1.4	1.0	1.2	0.8 (0.8)	1.1	1.7
Potassium (mg/L)	July	0.6	0.8	0.7	0.5	0.5	(0.5) 0.5	0.4	0.4
Silica (mg/L)	July	0.9	0.7	0.5	0.9	0.5	0.4 (0.4)	1.2	0.2
Sodium (mg/L)	July	0.9	1.5	1.2	0.9	1	0.5 (0.6)	1	0.7
Sulfate (mg/L)	July	2.7	3.3	2.0	2.3	1.9	2.3 (2.2)	3.7	2.7
Chlorophyll-a (µg/L)	June	2.85	6.00	11.75	1.51	3.92 (3.98)	1.02	1.18	0.67
Chlorophyll-a (µg/L)	July	3.80	12.62	12.36	4.32	8.77	0.87 (0.66)	1.63	2.14
Chlorophyll-a (µg/L)	Sept	4.30	3.92	4.13	3.19 (2.79)	5.46	0.22	4.48	1.23
mean Chlorophyll-a (µg/L)		3.7	7.5	9.4	2.9	6.1	0.7	2.4	1.3
Phaeophytin (µg/L)	June	2.0	4.7	2.4	0.8	1.19 (1.29)	0.3	0.6	0.2
Phaeophytin (µg/L)	July	2.2	5.6	4.5	1.6	4.6	0.33 (0.26)	3.1	0.9
Phaeophytin (µg/L)	Sept	2.4	3.6	1.9	1.62 (1.54)	3.0	0.5	2.2	0.2
mean Phaeophytin (µg/L)		2.2	4.6	2.9	1.3	3.0	0.4	2.0	0.4
Total phosphorus (µg/L)	June	18	19	17	3	6 (5)	1	9	1
Total phosphorus (µg/L)	July	11	23	23	8	18	4 (5)	9	5
Total phosphorus (µg/L)	Sept	9	20	14	9 (10)	20	3	10	5
mean Total phosphorus (µg/L)		13	21	18	7	15	3	9	4
Total nitrogen (µg/L)	June	403	635	566	410	428 (438)	184	496	238
Total nitrogen (µg/L)	July	454	711	687	426	506	186 (192)	438	261
Total nitrogen (µg/L)	Sept	422	688	624	417 (403)	494	153	432	239
mean Total nitrogen (µg/L)		426	678	626	415	478	175	455	246
NH ₄ -N (µg/L)	June	8	12	17	12	24 (26)	0	29	1
NH ₄ -N (µg/L)	July	13	47	18	12	11	5 (4)	9	5
NH ₄ -N (µg/L)	Sept	7	37	32	5 (4)	5	2	7	3
mean NH ₄ -N (µg/L)		9	32	22	10	14	2	15	3

		Locator	Shoepack	Ek	Brown	Peary	Cruiser	Ryan	Little Trout
NO3+NO2-N (µg/L)	June	3	0	7	3	3 (3)	0	60	0
NO3+NO2-N (µg/L)	July	0	3	0	0	0	0 (0)	0	0
NO3+NO2-N (µg/L)	Sept	0	7	3	0 (0)	0	0	0	0
mean NO3+NO2-N (µg/L)		1	3	3	1	1	0	20	0
Total phosphorus - hypolimnion (µg/L)		10	21	21	21	25	8 (12)	14	10
Methyl Hg (ng/L)	June		0.14	0.09	0.09	0.11		0.11	
Methyl Hg (ng/L)	June		0.17						
Methyl Hg (ng/L)	June		0.18						
Methyl Hg (ng/L)	July		0.47	0.20	0.12	0.04		0.06	
Methyl Hg (ng/L)	Sept		0.27	0.16	0.12	0.09		0.17	
mean Methyl Hg (ng/L)			0.29	0.15	0.11	0.08		0.11	
Total Hg (ng/L)	June		3.73	2.55	2.1	1.86		3.54	
Total Hg (ng/L)	June		4.23						
Total Hg (ng/L)	June		4.18						
Total Hg (ng/L)	July		4.23	2.41	2.24	1.74		2.68	
Total Hg (ng/L)	Sept		2.86	1.64	1.72	1.14		1.99	
mean Total Hg (ng/L)			3.61	2.20	2.02	1.58		2.74	
Secchi (m)	June	2.86	1.475	2.55	3.9	3.48	5.98	3.88	7
Secchi (m)	July	1.95	1.225	1.88	2.95	2.73	8.3	3.7	4.93
Secchi (m)	Sept	3.63	1.5	3	3.275	2.325	9.225	3.25	6.325
mean Secchi depth (m)		2.8	1.4	2.5	3.4	2.8	7.8	3.6	6.1
pH	June	6.88	6.71	7.11	6.75	6.92	7.36	6.69	7.62
pH	July	6.93	6.23	7.54	6.82	6.96	7.4	6.81	7.63
pH	Sept	6.86	6.4	7.01	6.91	7.11	7.47	6.76	7.77
mean pH (units)		6.9	6.4	7.2	6.8	7.0	7.4	6.8	7.7
SC25	June	26	25	28	22	25	21	27	36
SC25	July	25	25	28	22	25	21	26	36
SC25	Sept	26	26	31	23	27	21	28	37
mean Specific conductance (µS/cm)		26	25	29	22	26	21	27	36
DO	June	9.67	8.22	9.03	8.69	8.32	9.65	8.49	9.65
DO	July	8.11	7.45	9.11	7.06	7.58	8.92	7.62	8.69
DO	Sept	7.93	7.63	7.68	7.93	7.76	8.67	7.52	8.73
mean Dissolved oxygen (mg/L)		8.6	7.8	8.6	7.9	7.9	9.1	7.9	9.0

		Locator	Shoepack	Ek	Brown	Peary	Cruiser	Ryan	Little Trout
Temp	June	15.21	17.4	16.45	18.09	16.57	14.5	16.87	16.25
Temp	July	20.47	18.63	21.46	21.59	20.53	19.18	21.4	18.95
Temp	Sept	20.17	17.06	16.72	19.7	19.77	18.45	19.45	18.90
mean Temperature (°C)		18.6	17.7	18.2	19.8	19.0	17.4	19.2	18.0
water level (m)	June	-1.008	-1.803	-0.968	-0.685	-1.073	-0.825	-1.003	-1.070
water level (m)	July	-1.008	-1.848	-1.225	-0.645	-1.205	-0.845	-1.035	-1.093
water level (m)	Sept	-1.150	-2.090	-1.140	-0.823	-1.583	-1.080	-1.195	-1.245
total change (m)		-0.14	-0.29	-0.17	-0.14	-0.51	-0.26	-0.19	-0.18
Chla TSI	June	41	48	55	35	44	31	32	27
Chla TSI	July	44	55	55	45	52	29	35	38
Chla TSI	Sept	45	44	45	42	47	16	45	33
mean Chla TSI		43	49	52	41	48	25	38	32
TP TSI	June	46	47	45	20	30	4	36	4
TP TSI	July	39	49	49	34	46	24	36	27
TP TSI	Sept	36	47	42	36	47	20	37	27
mean TP TSI		40	48	46	30	41	16	36	20
Secchi TSI	June	45	54	47	40	42	34	40	32
Secchi TSI	July	50	57	51	44	46	30	41	37
Secchi TSI	Sept	41	54	44	43	48	28	43	33
mean Secchi TSI		46	55	47	43	45	31	42	34
TN:TP	June	22	33	33	137	71	184	55	238
TN:TP	July	41	31	30	53	28	47	49	52
TN:TP	Sept	47	34	45	46	25	51	43	48
mean TN:TP		34	33	35	61	33	62	49	67
additional sites not included in mean									
Secchi visible on bottom included in mean									

Appendix B

Field and Laboratory Results for Apostle Islands National Lakeshore

Multiprobe measurements for pH, specific conductance, dissolved oxygen, and temperature are reported from 0.5 m depth, except for Little Sand Bay in July, which was 1.0 m. Values in parentheses are results of duplicate samples.

		Michigan	Outer	Stockton	Little Sand Bay
Alkalinity (mg CaCO ₃ /L)	July	45	5	5	36 (36)
Calcium (mg/L)	July	13.9	2.5	5.7	11.1 (11.6)
Chloride (mg/L)	July	1.1	1.1	2.4	2.4 (2.3)
Dissolved Organic Carbon (mg/L)	July	11.8	23.1	50.3	27.0 (26.9)
Magnesium (mg/L)	July	3.6	0.9	1.5	3.9 (3.9)
Potassium (mg/L)	July	0.6	1.0	0.6	1.2 (1.2)
Silica (mg/L)	July	6.4	0.084	7.4	2.6 (2.9)
Sodium (mg/L)	July	0.9	0.7	1.4	2.0 (2.0)
Sulfate (mg/L)	July	0.9	3.54	2.3	2.0 (2.0)
Chlorophyll-a (µg/L)	June	1.02 (0.46)	2.21	2.06	4.51
Chlorophyll-a (µg/L)	July	4.41	2.23	2.27	6.41 (5.20)
Chlorophyll-a (µg/L)	Sept	6.97	1.56	5.02	4.98 (3.80)
mean Chlorophyll-a (µg/L)		4.0	2.0	3.1	4.9
Phaeophytin (µg/L)	June	0.32 (0.53)	1.13	1.48	1.61
Phaeophytin (µg/L)	July	0.40	1.02	1.99	2.49 (2.40)
Phaeophytin (µg/L)	Sept	1.63	0.59	2.30	2.55 (1.96)
mean Phaeophytin (µg/L)		0.8	0.9	1.9	2.1
Total phosphorus (µg/L)	June	9 (9)	13	17	43
Total phosphorus (µg/L)	July	13	11	20	40 (41)
Total phosphorus (µg/L)	Sept	12	10	11	24 (25)
mean Total phosphorus (µg/L)		11	11	16	36
Total nitrogen (µg/L)	June	445 (433)	769	920	740
Total nitrogen (µg/L)	July	570	905	1498	947 (957)
Total nitrogen (µg/L)	Sept	483	837	723	948 (942)
mean Total nitrogen (µg/L)		497	837	1047	879
NH ₄ -N (µg/L)	June	16 (16)	55	24	24
NH ₄ -N (µg/L)	July	17	49	57	14 (16)
NH ₄ -N (µg/L)	Sept	11	28	47	33 (35)
mean NH ₄ -N (µg/L)		15	44	43	24
NO ₃ +NO ₂ -N (µg/L)	June	0 (0)	8	0	25
NO ₃ +NO ₂ -N (µg/L)	July	3	14	3	2 (1)
NO ₃ +NO ₂ -N (µg/L)	Sept	0	2	1	0 (0)
mean NO ₃ +NO ₂ -N (µg/L)		1	8	1	9
T-tube	June	>120	>120	74.4	50.9
T-tube	July	>120		61	99.7
T-tube	Sept	104.5	>120	>120	>120
mean Transparency tube					
pH	June	7.47	5.94	5.71	6.73
pH	July	7.37	6.55	5.87	6.31
pH	Sept	7.48	7.02	7.38	6.95
mean pH (units)		7.4	6.5	6.3	6.7

		Michigan	Outer	Stockton	Little Sand Bay
SC25	June	75	23	24	49
SC25	July	96	25	35	99
SC25	Sept	111	28	68	92
mean Specific conductance ($\mu\text{S}/\text{cm}$)		94	25	42	80
DO		8.94	8.66	7.47	8.24
DO		7.99	7.93	6.49	
DO		8.68	9.46	8.73	6.49
mean Dissolved oxygen (mg/L)		8.5	8.7	7.6	7.4
Temp		20.53	18.18	17.92	15.62
Temp		22.68	23.38	22.77	
Temp		16.29	16.46	16.32	15.57
mean Temperature ($^{\circ}\text{C}$)		19.8	19.3	19.0	15.6
water level (m)	June				
water level (m)	July		-1.565	-0.655	-0.64
water level (m)	July			-0.845	
water level (m)	Sept	-1.53	-1.64	-0.92	-0.86
total change (m)			-0.08	-0.27	-0.22
Chla TSI	June	31	38	38	45
Chla TSI	July	45	38	39	49
Chla TSI	Sept	50	35	46	46
mean Chla TSI		42	37	41	47
TP TSI	June	36	41	45	58
TP TSI	July	41	39	47	57
TP TSI	Sept	40	37	39	50
meanTP TSI		39	39	44	55
TN:TP	June	49	59	54	17
TN:TP	July	44	82	75	24
TN:TP	Sept	40	84	66	40
mean TN:TP		44	74	65	24
means not calculated because of values > 120 cm (equipment maximum)					

Appendix C

Field and Laboratory Results for Isle Royale National Park

Multiprobe measurements for pH, specific conductance, dissolved oxygen, and temperature are reported from 1.0 m depth. Additional samples (yellow shaded cells) are not included in calculations of means. Values in parentheses are results of duplicate samples; blank cells indicate that no results are available.

		Ahmik	Sargent	Richie	Beaver	Harvey	George	Siskiwit	Desor	Feldtman
Alkalinity (mg CaCO ₃ /L)	July/Aug	45	37	28 (31)	45	38	55	31	47	22
Calcium (mg/L)	July/Aug	13.2	9.8	9.7 (9.2)	10.8	10.2	20.8	8.71	12.8	10.0
Chloride (mg/L)	July/Aug	1.0	1.0	1.2 (1.2)	0.9	0.7	0.7	0.6	0.9	1.1
Dissolved Organic Carbon (mg/L)	July/Aug	22.4	10.2	(11.2)	15.4	12.0	11.7	5.8	8.3	17.8
Magnesium (mg/L)	July/Aug	5.6	3.9	2.9 (2.8)	5.3	4.0	1.9	2.4	4.0	2.1
Potassium (mg/L)	July/Aug	0.2	0.2	0.3 (0.3)	0.3	0.1	0.1	0.4	0.5	0.4
Silica (mg/L)	July/Aug	7.4	4.6	7.1 (7.0)	8.2	2.5	0.4	2.2	1.3	1.6
Sodium (mg/L)	July/Aug	2.3	2.3	1.6 (1.6)	2.6	2.0	1.0	1.2	1.8	1.3
Sulfate (mg/L)	July/Aug	3.9	5.0	4.1 (4.1)	3.5	4.1	3.0	4.7	3.7	6.8
Chlorophyll-a (µg/L)	June	2.03	2.35	6.56	2.79	1.97	1.30	0.75 (0.74)	2.84	7.48
Chlorophyll-a (µg/L)	July/Aug	2.20	1.66	6.18 (6.44)	2.63	2.46	0.46	0.90	2.23	2.89
Chlorophyll-a (µg/L)	Aug			8.42				0.82		
Chlorophyll-a (µg/L)	Aug	1.71 (1.54)	3.34	5.03	2.38	2.84	2.96	1.45	2.73	3.62
mean Chlorophyll-a (µg/L)		1.9	2.5	6.0	2.6	2.4	1.6	1.0	2.6	4.7
Phaeophytin (µg/L)	June	1.58	0.96	2.88	1.37	0.87	0.44	0.52 (.70)	0.89	2.10
Phaeophytin (µg/L)	July/Aug	1.24	0.59	2.78 (3.44)	1.66	0.53	0.51	0.36	0.71	1.13
Phaeophytin (µg/L)	Aug			3.17				0.25		
Phaeophytin (µg/L)	Aug	0.79 (0.84)	0.99	1.56	1.08	0.52	0.72	0.40	0.54	0.75
mean Phaeophytin (µg/L)		1.2	0.8	2.5	1.4	0.6	0.6	0.5	0.7	1.3
Total phosphorus (µg/L)	June	13	15	22	16	16	9	4 (6)	12	12
Total phosphorus (µg/L)	July/Aug	18	16	29 (26)	14	15	8	4	11	13
Total phosphorus (µg/L)	Aug	16 (17)	10	20	17	13	11	2	13	13
Total phosphorus (µg/L)	Aug			26				3		
mean Total phosphorus (µg/L)		16	14	25	16	15	9	4	12	13
Total nitrogen (µg/L)	June	680	373	512	510	472	359	252 (248)	438	616
Total nitrogen (µg/L)	July/Aug	806	431	585 (600)	522	527	380	210	432	635
Total nitrogen (µg/L)	Aug	812 (814)	408	545	529	549	454	199	455	661
Total nitrogen (µg/L)	Aug			546				201		
mean Total nitrogen (µg/L)		766	404	550	520	516	398	220	442	637

		Ahmik	Sargent	Richie	Beaver	Harvey	George	Siskiwit	Desor	Feldtman
NH4-N (µg/L)	June	11	3	7	12	11	4	6 (5)	4	8
NH4-N (µg/L)	July/Aug	11	4	7 (7)	4	7	3	2	4	9
NH4-N (µg/L)	Aug	11 (9)	5	7	5	5	5	4	5	6
NH4-N (µg/L)	Aug			5				3		
mean NH4-N (µg/L)		11	4	6	7	8	4	4	4	8
NO3+NO2-N (µg/L)	June	0	0	0	0	0	0	44 (45)	0	0
NO3+NO2-N (µg/L)	July/Aug	1	1	0 (0)	0	0	0	7	0	0
NO3+NO2-N (µg/L)	Aug	0 (0)	0	0	0	0	0	0	0	0
NO3+NO2-N (µg/L)	Aug			1				0		
mean NO3+NO2-N (µg/L)		0	0	0	0	0	0	17	0	0
Total phosphorus - hypolimnion (µg/L)			14 (13)	173	38	29		6	22	
Secchi (m)	May			2.35						
Secchi (m)	June	1.96	3.38	2.45	2.53	3.7	3.1	7.5	2.9	2.6
Secchi (m)	July/Aug	2.0	4.23	2.18	2.85	3.38	3.1	6.3	3.4	2.25
Secchi (m)	Aug			2.58				7.45		
Secchi (m)	Aug	2.65	3.63	1.98	2.33	2.85	2.85	7.65	2.95	2.7
Secchi (m)	Sept			1.715						
mean Secchi depth (m)		2.2	3.7	2.2	2.6	3.3	3.0	7.2	3.1	2.5
pH	May			8.01						
pH	June	7.35	7.98	7.75	7.71	8.01	7.92	7.84	8.33	7.77
pH	July/Aug	7.48	8.17	8.41	7.94	8.55	8.36	8.12	8.4	7.72
pH	Aug			8.4				8.09		
pH	Aug	7.80	8.17	7.59	7.66	8.62	8.89	7.94	8.22	7.67
pH	Sept			7.45						
mean pH (units)		7.5	8.1	7.9	7.8	8.4	8.4	8.0	8.3	7.7

		Ahmik	Sargent	Richie	Beaver	Harvey	George	Siskiwit	Desor	Feldtman
SC25	May			73						
SC25	June	85	83	72	96	84	115	68	101	66
SC25	July/Aug	103	86	76	99	89	118	70	103	70
SC25	Aug			77				71		
SC25	Aug	109	88	78	104	90	117	71	105	76
SC25	Sept			79						
mean Specific conductance ($\mu\text{S}/\text{cm}$)		99	86	75	100	88	117	70	103	71
DO	May			11.94						
DO	June	7.42	9.3	10.26	8.3	8.6	8.92	11.29	9.68	10.15
DO	July/Aug	7.67	8.52	9.38	8.22	8.61	8.98	9.18	9.03	8.44
DO	Aug			8.48				8.52		
DO	Aug	7.78	8.41	7.96	7.38	8.26	9.55	8.68	8.24	7.99
DO	Sept			7.95						
mean Dissolved oxygen (mg/L)		7.6	8.7	9.2	8.0	8.5	9.2	9.7	9.0	8.9
Temp	May			12.46						
Temp	June	19.82	18	15.74	20.69	20.53	19.89	11.68	18.38	17.22
Temp	July/Aug	22.09	22.26	22.63	22.94	22.81	20.83	20.68	21.53	21.26
Temp	Aug			23.35				21.95		
Temp	Aug	21.8	22.67	21.15	20.78	22.77	23.31	20.32	21.7	20.39
Temp	Sept			16.81						
mean Temperature ($^{\circ}\text{C}$)		21.2	21.0	19.8	21.5	22.0	21.3	17.6	20.5	19.6
water level (m)	June	-0.340	-1.143	-0.685	-1.050	-0.895	-0.610	-0.500	-0.725	-0.425
water level (m)	July/Aug	-0.435	-1.340	-0.930	-1.110	-1.025	-0.443	-0.663	-0.868	-0.720
water level (m)	Aug			-0.995				-0.733		
water level (m)	Aug	-0.545	-1.430	-1.050	-1.230	-1.110	-0.673	-0.810	-1.005	-0.788
water level (m)	Sept			-1.095	-1.245					-0.820
total change (m)		-0.21	-0.29	-0.37	-0.18	-0.22	-0.06	-0.31	-0.28	-0.36

		Ahmik	Sargent	Richie	Beaver	Harvey	George	Siskiwit	Desor	Feldtman
Chla TSI	June	38	39	49	41	37	33	28	41	50
Chla TSI	July/Aug	38	36	48	40	39	23	30	38	41
Chla TSI	Aug	36	42	52	39	41	41	29	40	43
mean Chla TSI		37	39	50	40	39	32	29	40	45
TP TSI	June	41	43	49	44	44	36	24	40	40
TP TSI	July/Aug	46	44	53	42	43	34	24	39	41
TP TSI	Aug	44	37	47	45	41	39	14	41	41
meanTP TSI		44	42	50	44	43	36	21	40	41
Secchi TSI	June	50	42	47	47	41	44	31	45	46
Secchi TSI	July/Aug	50	39	49	45	42	44	33	42	48
Secchi TSI	Aug	46	41	46	48	45	45	31	44	46
mean Secchi TSI		49	41	47	46	43	44	32	44	47
TN:TP	June	52	25	23	32	30	40	63	37	51
TN:TP	July/Aug	45	27	20	37	35	48	53	39	49
TN:TP	Aug	51	30	22	33	35	43	55	37	50
mean TN:TP		49	30	22	33	35	43	55	37	50
additional samples not used in means										
Secchi visible on bottom included in mean										

Appendix D

Field and Laboratory Results for Pictured Rocks National Lakeshore

Multiprobe measurements for pH, specific conductance, dissolved oxygen, and temperature are reported from 1.0 m depth. Values in parentheses are results of duplicate samples; blank cells indicate that no results are available.

		Grand Sable	Legion	Beaver	Chapel	Miners	Little Beaver
Alkalinity (mg CaCO ₃ /L)	July/Aug	49 (54)	ND	70	92	149	
Calcium (mg/L)	July/Aug	14.8 (14.3)	0.5	25.2	23.5	35.4	
Chloride (mg/L)	July/Aug	0.9 (0.8)	0.6	0.9	1.1	2.3	
Dissolved Organic Carbon (mg/L)	July/Aug	7.9 (7.6)	4.6	5.0	11.9	9.7	
Magnesium (mg/L)	July/Aug	5.3 (5.1)	0.2	5.5	10.6	17.6	
Potassium (mg/L)	July/Aug	1.0 (1.0)	0.3	0.7	0.7	0.8	
Silica (mg/L)	July/Aug	3.4 (3.8)	0.1	6.6	3.4	6.2	
Sodium (mg/L)	July/Aug	0.9 (0.9)	0.1	1.0	0.7	1.4	
Sulfate (mg/L)	July/Aug	6.0 (5.6)	2	7.0	9.3	7.1	
Chlorophyll-a (µg/L)	June	1.81	0.60 (0.89)	1.13	1.38	0.58	
Chlorophyll-a (µg/L)	July/Aug	4.70 (3.62)	1.04	5.45	2.82	2.60	
Chlorophyll-a (µg/L)	Sept	3.60	0.88	5.61	2.14	13.02 (14.12)	
mean Chlorophyll-a (µg/L)		3.2	0.9	4.1	2.1	5.6	
Phaeophytin (µg/L)	June	0.73	1.29 (0.91)	0.67	0.63	0.39	
Phaeophytin (µg/L)	July/Aug	1.08 (0.92)	0.41	1.54	0.61	0.77	
Phaeophytin (µg/L)	Sept	1.59	0.46	1.27	0.43	2.63 (2.96)	
mean Phaeophytin (µg/L)		1.1	0.7	1.2	0.6	1.3	
Total phosphorus (µg/L)	June	9	6 (7)	10	10	7	
Total phosphorus (µg/L)	July/Aug	8 (10)	10	9	15	12	
Total phosphorus (µg/L)	Sept	8	11	14	8	25 (25)	
mean Total phosphorus (µg/L)		9	9	11	11	15	
Total nitrogen (µg/L)	June	307	270 (272)	229	368	473	
Total nitrogen (µg/L)	July/Aug	253 (250)	261	269	365	478	
Total nitrogen (µg/L)	Sept	256	278	299	343	385 (380)	
mean Total nitrogen (µg/L)		272	270	266	359	445	

		Grand Sable	Legion	Beaver	Chapel	Miners	Little Beaver
NH ₄ -N (µg/L)	June	10	14 (16)	11	17	20	
NH ₄ -N (µg/L)	July/Aug	4 (4)	5	5	7	10	
NH ₄ -N (µg/L)	Sept	3	6	4	5	3 (4)	
mean NH ₄ -N (µg/L)		6	9	7	10	11	
NO ₃ +NO ₂ -N (µg/L)	June	45	50 (50)	0	28	226	
NO ₃ +NO ₂ -N (µg/L)	July/Aug	0 (0)	3	1	2	213	
NO ₃ +NO ₂ -N (µg/L)	Sept	2	0	0	0	95 (93)	
mean NO ₃ +NO ₂ -N (µg/L)		16	18	0	10	178	
Total phosphorus - hypolimnion (µg/L)		15 (25)	24	13	9		
Secchi	June	2.42	5.83	3.51	2.37	1.97	1.85
Secchi	July/Aug	3.38	5.95	3.3	2.98	2.15	
Secchi	Sept	2.90	7.53	2.28	2.95	2.23	1.53
mean Secchi depth (m)		2.9	6.4	3.0	2.8	2.1	1.7
pH	June	8.01	5.16	8.20	7.91	8.43	8.08
pH	July/Aug	8.36	5.26	8.59	8.13	8.06	
pH	Sept	8.04	5.25	8.23	8.29	8.46	8.38
mean pH (units)		8.1	5.2	8.3	8.1	8.3	8.2
SC25	June	114	6	169	169	295	137
SC25	July/Aug	115	8	172	198	295	
SC25	Sept	116	8	178	222	325	170
mean Specific conductance (µS/cm)		115	7	173	196	305	154
DO	June	10.04	9.25	8.70	8.81	9.86	9.10
DO	July/Aug	9.15	8.10	8.94	9.27	8.98	
DO	Sept	9.07	8.16	6.88	8.60	11.62	6.87
mean Dissolved oxygen (mg/L)		9.4	8.5	8.2	8.9	10.2	8.0
Temp	June	15.88	18.29	15.93	16.07	12.48	15.95
Temp	July/Aug	21.71	22.45	21.49	20.99	16.60	
Temp	Sept	19.04	21.52	20.09	21.81	15.71	19.91
mean Temperature (°C)		18.9	20.8	19.2	19.6	14.9	17.9

		Grand Sable	Legion	Beaver	Chapel	Miners	Little Beaver
water level (m)	June	0.53	-1.01	-1.04	-1.32	-1.011	
water level (m)	July/Aug	0.48	-1.09	-1.03	-1.46	-1.12	
water level (m)	Sept	0.329	-1.235	-1.04	-1.745	-1.17	
total change (m)		0.20	-0.23	0.00	-0.43	-0.16	
Chla TSI	June	36	26	32	34	25	
Chla TSI	July/Aug	46	31	47	41	40	
Chla TSI	Sept	43	29	48	38	56	
mean Chla TSI		42	29	42	38	40	
TP TSI	June	36	30	37	37	32	
TP TSI	July/Aug	34	37	36	43	40	
TP TSI	Sept	34	39	42	34	51	
mean TP TSI		35	35	38	38	41	
Secchi TSI	June	47	35	42	48	50	
Secchi TSI	July/Aug	42	34	43	44	49	
Secchi TSI	Sept	45	31	48	44	48	
mean Secchi TSI		45	33	44	45	49	
TN:TP	June	34	45	23	37	68	
TN:TP	July/Aug	32	26	30	24	40	
TN:TP	Sept	32	25	21	43	15	
mean TN:TP		31	29	24	33	30	

Appendix E

Field and Laboratory Results for Indiana Dunes National Lakeshore

Multiprobe measurements for pH, specific conductance, dissolved oxygen, and temperature are reported from 0.5 m depth. Values in parentheses are results of duplicate samples; blank cells indicate that no results are available.

		Long (July)	Middle Lagoon (Sept)
Alkalinity (mg CaCO ₃ /L)	July/Sept	88 (89)	75
Calcium (mg/L)	July/Sept	27.1 (27.3)	14.3
Chloride (mg/L)	July/Sept	24.9 (24.9)	93.0
Dissolved Organic Carbon (mg/L)	July/Sept	10.2 (9.4)	7.4
Magnesium (mg/L)	July/Sept	8.6 (8.2)	14.7
Potassium (mg/L)	July/Sept	0.5 (0.5)	1.6
Silica (mg/L)	July/Sept	1.2 (1.2)	7.0
Sodium (mg/L)	July/Sept	12.1 (12.1)	63.4
Sulfate (mg/L)	July/Sept	5.4 (5.0)	17.5
Chlorophyll-a (µg/L)	May	0.79	
Chlorophyll-a (µg/L)	July	1.09 (1.24)	
Chlorophyll-a (µg/L)	Sept	3.06	4.22
mean Chlorophyll-a (µg/L)		1.7	4.2
Phaeophytin (µg/L)	May	0.79	
Phaeophytin (µg/L)	July	0.69 (0.79)	
Phaeophytin (µg/L)	Sept	1.14	0.52
mean Phaeophytin (µg/L)		0.9	0.5
Total phosphorus (µg/L)	May	5	
Total phosphorus (µg/L)	July	16 (21)	
Total phosphorus (µg/L)	Sept	32	25
mean Total phosphorus (µg/L)		19	25
Total nitrogen (µg/L)	May	419	
Total nitrogen (µg/L)	July	480 (457)	
Total nitrogen (µg/L)	Sept	680	580
mean Total nitrogen (µg/L)		523	580
NH ₄ -N (µg/L)	May	11	
NH ₄ -N (µg/L)	July	9 (12)	
NH ₄ -N (µg/L)	Sept	14	7
mean NH ₄ -N (µg/L)		12	7
NO ₃ +NO ₂ -N (µg/L)	May	1	
NO ₃ +NO ₂ -N (µg/L)	July	0 (0)	
NO ₃ +NO ₂ -N (µg/L)	Sept	5	0
mean NO ₃ +NO ₂ -N (µg/L)		2	0
T-tube	May	>120	>120
T-tube	July	82.25	>120
T-tube	Sept	46.05	>120
mean Transparency tube			
pH	May	7.63	8.02
pH	July	7.32	9.41
pH	Sept	6.74	9.55
mean pH (units)		7.2	9.0

		Long (July)	Middle Lagoon (Sept)
SC25	May	245	825
SC25	July	256	600
SC25	Sept	270	546
mean Specific conductance ($\mu\text{S}/\text{cm}$)		257	657
DO	May	7.76	9.48
DO	July	2.14	11.69
DO	Sept	0.61	11.46
mean Dissolved oxygen (mg/L)		3.5	10.9
Temp	May	13.31	14.3
Temp	July	20.19	24.03
Temp	Sept	21.5	25.67
mean Temperature ($^{\circ}\text{C}$)		18.3	21.3
water level (m)	May	-0.359	-5.9
water level (m)	July	-0.58	-5.745
water level (m)	Sept	-0.73	-5.705
total change (m)		-0.37	0.17
Chla TSI	May	28	
Chla TSI	July	31	
Chla TSI	Sept	42	45
mean Chla TSI		34	45
TP TSI	May	27	
TP TSI	July	44	
TP TSI	Sept	54	51
mean TP TSI		42	51
TN:TP	May	84	
TN:TP	July	30	
TN:TP	Sept	21	23
mean TN:TP		28	23
means not calculated because of values >120 cm (equipment maximum)			

Appendix F

Field and Laboratory Results for Sleeping Bear Dunes National Lakeshore

Multiprobe measurements for pH, specific conductance, dissolved oxygen, and temperature are reported from 1.0 m depth. Values in parentheses are results of duplicate samples; blank cells indicate that no results are available.

		Narada									
		Manitou	Florence	(Sept)	Shell	Bass (North)	Otter	Tucker	North Bar	Loon	Round
Alkalinity (mg CaCO ₃ /L)	July	129	49	138	89	86	124	127	147	132	126 (123)
Calcium (mg/L)	July	31.7	12.4	39.5	25.1	26.6	33.3	36.8	40.8	39.4	28.7 (28.7)
Chloride (mg/L)	July	1.0	0.9	9.1	1.2	7.0	7.7	1.2	4.5	8.9	23.9 (24.2)
Dissolved Organic Carbon (mg/L)	July	7.7	9.9	8	12.4	11.3	5.6	14.3	4.8	5.5	9.7 (9.8)
Magnesium (mg/L)	July	16.9	6.3	14	16.2	10.4	14.0	12.6	15.4	13.2	17.6 (16.9)
Potassium (mg/L)	July	0.6	0.4	0.41	0.4	1.0	0.8	0.2	0.7	0.8	0.7 (0.7)
Silica (mg/L)	July	1.6	0.3	7.2	5.1	1.5	6.7	6.7	7.1	5.5	6.0 (4.9)
Sodium (mg/L)	July	1.2	0.3	5.66	1.6	3.1	3.9	0.8	1.5	6.5	15.5 (15.3)
Sulfate (mg/L)	July	11.0	5.6	4.06	35.2	10.8	9.1	5.9	11.2	10.8	9.6 (9.7)
Chlorophyll-a (µg/L)	June	4.00	2.45		0.79	1.86	0.87	4.69	1.2	0.85 (0.80)	1.82
Chlorophyll-a (µg/L)	July	3.70	1.22		0.36	1.68	0.30	4.56	1.15	4.77	4.65 (4.69)
Chlorophyll-a (µg/L)	Sept	2.82	7.01	1.56	1.53	2.78	2.46	1.05	3.32	2.24 (2.31)	4.44
mean Chlorophyll-a (µg/L)		3.5	3.6	1.6	0.9	2.1	1.2	3.4	1.9	2.6	3.6
Phaeophytin (µg/L)	June	3.81	0.68		0.33	1.09	0.22	0.98	0.22	0.28 (0.46)	0.78
Phaeophytin (µg/L)	July	0.90	0.41		0.26	0.55	0.14	1.20	0.28	0.69	1.19 (1.08)
Phaeophytin (µg/L)	Sept	0.42	1.18	0.65	0.24	0.41	0.5	0.47	0.95	0.41 (0.58)	0.96
mean Phaeophytin (µg/L)		1.7	0.8	0.7	0.3	0.7	0.3	0.9	0.5	0.5	1.0
Total phosphorus (µg/L)	June	15	19		7	10	16	16	13	8 (8)	9
Total phosphorus (µg/L)	July	12	19		9	12	9	16	7	9	9 (8)
Total phosphorus (µg/L)	Sept	12	20	9	9	9	7	13	8	7 (7)	11
mean Total phosphorus (µg/L)		13	19	9	8	10	11	15	9	8	9
Total nitrogen (µg/L)	June	531	723		720	618	582	631	628	378 (370)	631
Total nitrogen (µg/L)	July	513	833		822	659	471	708	522	301	676 (668)
Total nitrogen (µg/L)	Sept	477	844	509	949	702	377	779	521	221 (224)	652
mean Total nitrogen (µg/L)		507	800	509	830	660	477	706	557	299	652
NH ₄ -N (µg/L)	June	11	19		28	18	79	12	36	31 (29)	87
NH ₄ -N (µg/L)	July	7	35		18	7	14	8	18	7	30 (32)
NH ₄ -N (µg/L)	Sept	13	44	27	83	20	31	30	95	10 (9)	52
mean NH ₄ -N (µg/L)		10	33	27	43	15	41	17	50	16	57

		Narada									
		Manitou	Florence	(Sept)	Shell	Bass (North)	Otter	Tucker	North Bar	Loon	Round
NO3+NO2-N (µg/L)	June	2	13		0	17	2	0	379	169 (172)	22
NO3+NO2-N (µg/L)	July	6	21		15	14	216	95	257	44	183 (104)
NO3+NO2-N (µg/L)	Sept	6	21	7	7	5	39	5	158	10 (7)	8
mean NO3+NO2-N (µg/L)		5	18	7	7	12	86	33	265	74	58
Total phosphorus - hypolimnion (µg/L)		46	20		7	11	5	13	28	10	13 (17)
Secchi	June	2.34	3.24		3.89	3.1	4.04	2.44	3.79	4.74	3.49
Secchi	July	2.00	2.0		3.21	2.93	3.28	2.38	2.62	3.73	2.76
Secchi	Sept	3.54	2.26	4.59	3.23	3.77	2.94	2.44	3.13	4.17	3.54
mean Secchi depth (m)		2.6	2.5	4.6	3.4	3.3	3.4	2.4	3.2	4.2	3.3
pH	June	8.33	7.78		8.48	8.5	8.29	8.46	8.39	8.17	8.14
pH	July	8.32	8.61		8.44	8.51	8.25	8.09	8.06	8.29	8.38
pH	Sept	8.74	8.10	7.81	8.61	8.85	8.51	8.05	8.32	8.42	8.48
mean pH (units)		8.5	8.2	7.8	8.5	8.6	8.4	8.2	8.3	8.3	8.3
SC25	June	275	106		272	220	304	258	328	320	345
SC25	July	264	109		240	213	274	256	311	302	325
SC25	Sept	257	115	307	259	208	266	263	311	296	323
mean Specific conductance		265	110	307	257	214	281	259	317	306	331
DO	June	11.24	10.58		11.99	10.97	10.62	11.96	9.79	9.72	10.09
DO	July	9.51	9.71		10.47	9.93	10.64	10.19	9.29	9.69	9.01
DO	Sept	9.07	9.07	6.47	8.59	9.52	12.77	7	10.47	12.35	12.3
mean Dissolved oxygen (mg/L)		9.9	9.8	6.5	10.4	10.1	11.3	9.7	9.9	10.6	10.5
Temp	June	18.21	18.14		20.37	19.13	19.44	20.83	19.96	18.87	19.47
Temp	July	23.9	24.04		25.33	24.04	24.19	24.75	23.49	24.28	24.26
Temp	Sept	20.46	19.53	20.6	20.97	21.66	21.28	20.24	19.55	20.69	20.63
mean Temperature (°C)		20.9	20.6	20.6	22.2	21.6	21.6	21.9	21.0	21.3	21.5
water level (m)	June	-0.66	-0.70		-0.53	-0.50	-0.64	-0.518	-0.675	-0.50	-1.095
water level (m)	July	-0.7125	-0.73		-0.62	-0.765	-0.695	-0.625	-0.805	-0.64	-1.06
water level (m)	Sept	-0.9025	-0.885		-0.885	-1.2875	-0.725	-0.78	-0.895	-0.66	-1.11
total change (m)		-0.24	-0.19		-0.36	-0.79	-0.09	-0.26	-0.22	-0.16	-0.02

		Narada									
		Manitou	Florence	(Sept)	Shell	Bass (North)	Otter	Tucker	North Bar	Loon	Round
Chla TSI	June	44	39		28	37	29	46	32	29	36
Chla TSI	July	43	33		21	36	19	45	32	46	46
Chla TSI	Sept	41	50	35	35	41	39	31	42	39	45
mean Chla TSI		43	41	35	28	38	29	41	36	38	42
TP TSI	June	43	47		32	37	44	44	41	34	36
TP TSI	July	40	47		36	40	36	44	32	36	36
TP TSI	Sept	40	47	36	36	36	32	41	34	32	39
mean TP TSI		41	47	36	35	38	37	43	36	34	37
Secchi TSI	June	48	43		41	44	40	48	41	38	42
Secchi TSI	July	50	50		43	45	43	48	46	41	46
Secchi TSI	Sept	42	48	38	43	41	44	47	44	39	42
mean Secchi TSI		47	47	38	42	43	43	48	44	39	43
TN:TP	June	35	38		103	62	36	39	48	47	70
TN:TP	July	43	44		91	55	52	44	75	33	75
TN:TP	Sept	40	42	57	105	78	54	60	65	32	59
mean TN:TP		39	41	57	100	64	45	47	60	37	70

National Park Service
U.S. Department of the Interior



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