EPA/600/R-19/097

A Special Report for the Great Lakes

2015 National Coastal Condition Assessment (NCCA) and 2014 – 2018 Connecting River System Pilot Assessments

September 2019

U.S. Environmental Protection Agency Office of Research and Development (USEPA)
Center for Computational Toxicology and Exposure
Great Lakes Toxicology and Ecology Division

Cover images:
Top left, Round goby *(Neogobius melanostomus)* and dreissenid mussels from underwater video collected in the Huron-Erie Corridor; top right, Ohio Environmental Protection Agency scientist measuring weight of fish collected; bottom left, sediment sample collection; bottom right, Wisconsin Department of Natural Resources scientist filtering a chlorophyll sample.

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Acknowledgments:
This report supplements the 2015 National Coastal Condition Assessment report that had many authors and contributors. We thank Elizabeth Hinchey Malloy, Todd Nettesheim, Sarah Lehmann, Hugh Sullivan, Alexandra Bijak, John Kiddon, Will Bartsch, Meredith Brackett, Margaret Corcoran, Tim Corry, Anne Cotter, Rose Ellison, Mary Beth Giancarlo, Paul Horvatin, Russ Kreis, Julie Lietz, Sam Miller, Megan O'Brien, James Pauer, Mark Pearson, Jill Scharold, Nicole Singleton, Linda Harwell, Peg Pelletier, Garrett Stillings, the captain and crew of the R/V Lake Guardian, and the captain and crew of the R/V Mudpuppy II.

Scott Parker and Chris Filstrup served as external peer-viewers for the report.

Data availability:
National Coastal Condition Assessment data are available at https://www.epa.gov/national-aquatic-resource-surveys/ncca

Suggested citation:
Pawlowski, M., Wick, M., Bolgrien, D., Nord, M., Launspach, J., and Angradi, T. 2019. 2015 National Coastal Condition Assessment (NCCA) and 2014-2018 Connecting River System Pilot Assessments. A Special Report for the Great Lakes. U.S. Environmental Protection Agency, Duluth, MN, EPA/600/R-19/097

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Introduction

The NCCA is one of four National Aquatic Resource Surveys (NARS) administered by the US EPA's Office of Water in partnership with states and tribes (USEPA, 2015b, 2016d). The NCCA is designed to yield unbiased estimates of the ecological condition of the nearshore waters of the US based on a quinquennial survey. The survey produces both area-weighted means of parameters, and categorical condition estimates based on relevant thresholds. This report describes the methods and major findings of the NCCA survey of the Laurentian Great Lakes' (Fig. 1) nearshore waters, connecting river systems, and selected additional resources ("spatial enhancements") conducted by the USEPA, collaborating US states, and other partners, during 2014-2016. This report complements the findings of the 2015 National Coastal Condition Assessment (NCCA) survey implemented by the USEPA's Office of Water, which can be referenced for additional background and results for the complete national assessment (USEPA, 2021a, b). In 2010, the Great Lakes was fully incorporated into the NCCA; this report presents finding for the second implementation (2015) of the Great Lakes component of the NCCA survey. Repeated implementation of the survey can be used to assess change in the ecological condition of the Great Lakes nearshore over time.

Figure 1. The Laurentian Great Lakes, Lake Erie basins, Saginaw Bay, and connecting river systems.

Design of the Great Lakes component of the National Coastal Condition Assessment

The Great Lakes NCCA design included a base design developed for the USEPA's Office of Water by the EPA's Office of Research and Development, as well as enhanced designs to assess additional resources (described in more detail below). The probability-based approach used for the base design and enhancements allowed determination of statistically-valid estimates of the condition of the nearshore waters of the Great Lakes (Diaz-Ramos et al., 1996; Stevens, 1997; Stevens et al., 1999; Stevens et al., 2003; Stevens et al., 2004). NCCA survey sites were selected using a generalized random tessellation stratified (GRTS) survey design. Sample locations were selected, and weights were assigned using the *spsurvey* package in the statistical software environment R (Kincaid et al., 2019). Each selected site represented a known percentage (weight) of the area in each system. Weighted means and condition class estimates were based on site results weighted by the area each site represents.

Sites that could not be sampled due to safety or logistic issues were replaced with sites from an overdraw sample. Overdraw sample sites were selected using the methods described above for the base design and the weights adjusted using *spsurvey*. Sites were relocated but not replaced when the "X-site" (design survey site location defined by a latitude and longitude) was not sampleable, but a nearby location was sampleable. This relocation was permitted if the new site was within a 37 m radius of the X-site. To improve the chances of successfully collecting benthic (lake bottom) samples, which have a high failure rate, crews could sample anywhere within a 500 m radius of the X-site for sediment or benthic invertebrates. To improve the chances of to successfully collecting a fish sample, crews could sample anywhere within 1000 m of the X-site. A site was not rejected if some samples or parameters could not be collected. For example, the failure of fish or sediment collection was not used as a determining factor for rendering a site unsampleable for other sampling.

Base sample design

The assessed resource for the Great Lakes component of the NCCA was the nearshore US waters of the Great Lakes defined as waters within 5 km of shore and ≤30 m deep. The Great Lakes nearshore sample "frame" was first developed for the 2010 NCCA from existing standard GIS vector shoreline coverage from NOAA (USEPA, 2014d; Kelly et al., 2015). That coverage was modified to include a coverage extension 500 m upstream into river mouths and to add embayment areas missing from the existing shoreline coverage.

The 2015 Great Lakes NCCA nearshore sample frame was developed by the USEPA's Office of Research and Development (ORD) Great Lakes Toxicology and Ecology Division (GLTED). The nearshore includes river mouths and estuaries, embayments, and open waters adjacent to the US shoreline. It does not include the connecting river systems of the Great Lakes (water bodies between lakes plus the upper St. Lawrence River), for which a separate frame was developed (described below).

The base sample design assigned 45 sites to the United States portion of nearshore of each of the five Great Lakes for a total of 225 sites (Table 1). Samples in each lake were allocated among bordering states' waters proportionally by shoreline length.

Spatial Enhancements

Within the Great Lakes nearshore, additional sites were added in embayments and in sub-basins of Lake Erie as spatial enhancements to increase the scope and precision of assessment estimates. Embayments were included in the 2010 survey; the Lake Erie Basin enhancement was added in 2015.

The objective of the embayment enhancement was to increase the representation of shallower and more sheltered embayment areas hypothesized to have a disproportionate influence on overall nearshore condition due to their closer connections to tributaries and watershed stressors (Kelly et al., 2015; Yurista et al., 2016). Embayments were defined as indentations of the shoreline for which the width from a line across the opening of the indentation to the furthest inland point is greater than the width of the opening and having an area at least as large as that of a semicircle with a diameter equivalent to the width of the opening (Kelly et al., 2015). Some embayments have tributaries, and all have an open water connection or channel to the adjacent Great Lake. The embayments ranged in size from <0.01 to 93 km^2 (mean, 6.6 km^2) and comprised approximately 5% of the total nearshore area.

For the Great Lakes assessment summarized in this report, 361 sites (225 base sites plus 136 embayment sites) were used for the combined nearshore and embayment condition assessment. This assessment represents 18,438 km^2 of nearshore and embayment area. The nearshore subpopulation and the embayments subpopulation of the Great Lakes were also assessed as mutually exclusive resource areas. The nearshore-only subpopulation was represented by 218 of the 225 base sites that were not in embayments. The embayment-only subpopulation was represented by 136 embayment sites plus seven base sites located within embayments. Hereafter, the three Great Lakes subpopulations are referred to as the combined nearshore and embayments, the nearshore, and embayments.

The objective of the Lake Erie basin spatial enhancement was to increase the precision of water quality assessments in each basin. Thirty-three enhancement sites were added in Lake Erie (western, central, and eastern basins, Fig. 1, Table 1) to bring the total to 30 sites in each basin. These extra sites were sampled for water quality only.

Table 1. Number of sites in the design, number of sites visited, and number successfully sampled for each subpopulation and indicator. OTI is the Oligochaete Trophic Index. The PONAR is a type of bottom sampler. Number of OTI samples means the number of samples for which the OTI could be calculated. Number of videos collected refers to videos of adequate quality for assessment.

Subpopulation		Number of design sites	Number of sites visited	Water samples	Sediment samples	Fish tissue samples	Fish mercury samples	Benthic samples		Round goby presence	Dreissenid presence
				Number of samples collected					Number of OTI samples	Number videos collected	Number of samples collected (video or PONAR)
Lake Superior	Nearshore	45	42	42	36	37	37	34	22	28	36
	Embayments	36	36	36	36	35	35	36	33	18	31
Lake Huron	Nearshore	45	44	44	40	37	37	32	26	44	44
	Embayments	23	23	23	54	47	46	20	14	53	54
Lake Michigan	Nearshore	45	45	45	32	32	32	43	36	36	41
	Embayments	55	55	54	20	22	22	54	44	19	23
Lake Erie*	Nearshore	45	44	44	34	42	41	32	31	20	40
	Embayments	13	13	13	13	13	13	13	13	8	13
Lake Ontario	Nearshore	45	43	43	17	28	14	16	12	41	37
	Embayments	16	16	16	12	15	14	13	11	11	16
Great Lakes		368	361	360	294	308	291	293	242	242	335
St. Marys River		100	94	94	92	35	35	92	80	80	93
Huron-Erie Corridor	All sites	100	95	95	88	31	31	90	86	84	93
	St. Clair River	19	18	18	13	7	7	18	17	15	18
	Lake St. Clair	50	48	48	48	8	8	46	45	45	48
	Detroit River	31	29	29	27	16	16	26	24	24	27
Niagara River		60	59	59	28	0	0	37	36	57	57

* Water-only sampling was also done at an additional 33 nearshore sites in Lake Erie such that 30 sites were sampled in each basin. This allowed for statistically robust estimates of water-related conditions to be estimated in each basin of Lake Erie for the Lake Erie basin enhancement study (see Spatial Enhancements section). In the Lake Erie nearshore, a total of 27, 26, and 24 sites were sampled in the western, central, and eastern basins, respectively. In Lake Erie embayments, 3, 4, and 6 sites were sampled in the western, central, and eastern basins, respectively.

Connecting River system Pilot Study

The Great Lakes connecting river systems are part of the Great Lakes ecosystem, but these resources had not previously been assessed as a part of any previous NARS. Two Great Lakes connecting river systems, the St. Marys River and the Huron-Erie Corridor (HEC), which includes the St. Clair River, Lake St. Clair, and the Detroit River, were assessed as part of NCCA in 2014 - 2016 as a connecting channel pilot study (Wick et al., 2019). The Niagara River was assessed in 2018. Because the existing NCCA sample design did not include the connecting river systems, separate connecting-channel design frames were created. The design frames included the area of each channel from the outlet of the upriver Great Lake to the downriver Great Lake including Canadian waters. In some areas, the connecting channel frame overlapped slightly with the Great Lake design frame, but no Great Lakes sites were in this overlapping area. The extent of the Niagara River frame was defined to align with Buffalo River Area of Concern boundaries to help fulfill local assessment needs.

Ninety-four probability sites were sampled in the St. Marys River, 95 probability sites were sampled in the HEC, and 59 probability sites were sampled in the Niagara River. In addition, 16 hand-picked sites were sampled in the St. Marys River and the HEC, and 12 hand-picked sites were sampled in the Niagara River in coordination with state and local managers. Hand-picked sites were in areas of interest based on Total Maximum Daily Loads, sediment remediation, or other local environmental priorities. Data from these sites were not used in condition estimates but can provide contextual information about a resource.

Sample Collection

Great Lakes sites were sampled from June – September in 2015. The HEC was sampled in September of 2014 and 2015, the St. Marys River was sampled in July and August of 2015 and 2016, and the Niagara River was sampled in July of 2018. Due to logistic constraints, the connecting river systems were sampled during a shorter interval than the lakes. Seasonal variation generally cannot be addressed in GRTS designs (Messer et al., 1991); the sample or “index” period is assumed to be representative for annual assessment purposes.

NCCA sampling protocols were designed so that at least one site could be sampled in a day by a 4-person crew (USEPA, 2015c). During a site visit, crews collected water, sediment, fish, and underwater video. Water samples were collected 0.5 m below the surface using a Kemmerer bottle. Standard PONAR grab samples were collected for sediment toxicity, sediment contamination, and benthic invertebrates. The top 2 cm of one PONAR sample was analyzed for concentrations of chemical constituents, total organic carbon (TOC), grain size, and sediment toxicity. A separate intact PONAR sample was elutriated (organisms separated from sediment) for analysis of macroinvertebrates. Water samples were filtered with a Whatman GF/F 47-mm 0.7-micron filter for chlorophyll *a* and the filtered water was used to measure dissolved nutrients. A water sample was collected in a sterile container for enterococci analysis. Fish were collected using various gears for whole fish tissue samples. Dissolved oxygen, pH, temperature, and conductivity profile data were collected using a multiprobe instrument. Water clarity was measured using a weighted 20-cm black and white Secchi disk and with a Photosynthetically Active Radiation (PAR) meter. For sites where the Secchi disk was visible on the bottom, Secchi depth was estimated using light attenuation determined from PAR data as described in Appendix A.

Underwater videos were collected in the Great Lakes, St. Marys River, and HEC as described in Lietz et al. (2015), with either a SeaViewer SeaDrop color camera or a GoPro4 camera. The camera was lowered on a weighted line to the bottom and 1-2 minutes of video recorded. In the Niagara River, a down-looking camera and an oblique-looking GoPro Hero5 camera (1080p resolution) and LED lights were mounted on an open video carriage made of stainless steel The carriage was lowered to the riverbed to collect approximately one minute of video (Wick et al., 2020).

Samples were analyzed by multiple laboratories using methods specified in the NCCA laboratory manual (USEPA, 2016a, b) and applicable quality assurance project plan (USEPA, 2014c). Standardized field and laboratory protocols were followed to ensure comparability of results.

Table 1 shows the number of sites visited for each lake and river system and the total number of water, sediment, fish, benthos, and video samples collected for each Great Lake and connecting river system. A few sites in the base design were not sampleable due to shallow water, rapids, ship traffic, or lack of safe access, therefore the number of sites visited was smaller than the number of base design sites for some subpopulations. The sampling methods allowed benthos, sediment, and fish samples to be collected up to 500 m (1,000 m for fish) from the designated X-site. Even with this allowance, not all samples could be obtained at all sites (missing data are discussed in more detail below). About 10% of sites were revisited within a season for quality assurance purposes, but these analyses are not discussed in this report. If too few fish were caught during the first site visit, data from the second were used for condition estimates.

Indicators for Assessing the Condition of the Great Lakes

The NCCA indicators (Table 2) were selected to provide a broad assessment of the ecological condition of coastal waters and the stressors impacting them. Most of the indicators were included in the original National Coastal Assessment (NCA) of marine waters (USEPA, 2011) and could be applied to the Great Lakes with minor modifications. Four derived indicators were used to assess the condition of the Great Lakes: eutrophication, a benthic index, sediment quality, and ecological fish tissue contamination. Additional indicators added to augment the assessment in the Great Lakes including cyanobacteria, microcystin, invasive species, and fish tissue mercury.

Underwater video for assessing conditions in coastal waters was piloted in the 2010 Great Lakes assessment and was repeated in 2015. In this report invasive species presence was based on underwater video. Underwater video can provide other useful data about the lake bottom including habitat characteristics including substrate type and vegetation, the presence of litter, and other anthropogenic Impacts. Methods for video analysis are still under development (Wick et al., 2020). All videos collected in the 2010 and 2015 Great Lakes NCCA are available to the public at https://gispub.epa.gov/NCCA/.

For multi-metric indicators (e.g., eutrophication, sediment quality) the assessment for that indicator was based on the available metrics. For example, if only sediment contamination was available and sediment toxicity was not, then the sediment quality indicator was based on sediment contamination alone.

Eutrophication Status Indicator

Water quality was assessed using a eutrophication status indicator which integrates four water quality indicators: total phosphorus concentration, chlorophyll *a* concentration, near-bottom dissolved oxygen concentration, and water clarity (as Secchi depth). Total nitrogen was also collected but was not used for the eutrophication indicator because there are currently no published thresholds for nitrogen impairment in the Great Lakes. The eutrophication status was derived as follows: If no component indicators were assessed as poor and only one was assessed as fair, then the eutrophication status was assessed as good for that lake. If one component indicator was poor and two or more were fair, then the status was assessed as fair. If two or more components were poor, then the lake was assessed as having poor water quality.

The International Joint Commission (IJC) Phosphorus Management Strategies Task Force (PMSTF, 1980) developed total phosphorus, chlorophyll *a*, and Secchi depth thresholds for each Great Lake and each basin of Lake Erie based on the expected trophic status for the lake or basin (Table 2a). The thresholds were developed for “open waters”, but data used to generate the thresholds included nearshore samples (Gregor and Rast, 1979), so they were considered relevant to the nearshore and embayment sites for the Great Lakes assessment. The PMSTF only identified a single threshold based on the trophic status for each lake (fair to good), so the lower threshold (fair to poor) was defined for the NCCA report as the value indicative of crossing into the next more nutrient-enriched trophic status. The NCCA analysts and partners used IJC study results (Gregor and Rast, 1979) to identify trophic status thresholds for selected basins (i.e., Saginaw Bay in Lake Huron and western, central, and eastern basins of Lake Erie), that were not specified in the 1980 PMSTF report. Thresholds were not previously specified for the Great Lakes connecting river systems. Connecting river systems were therefore assessed against the most protective downriver thresholds after Wick et al. (2019).

Thresholds for bottom dissolved oxygen are consistent with marine water quality thresholds (Diaz and Rosenberg, 1995; USEPA, 2011). Studies in the Great Lakes (Costantini et al., 2011; Krieger and Bur, 2009) corroborate 2 mg/L as a threshold for hypoxic condition (threshold between fair and poor condition).

Cyanobacteria

In 2010 and 2015, phytoplankton samples were collected for taxonomic analysis. The 2010 assessment included a pilot assessment of potential risks to human health through recreational exposure based on cyanobacteria cell counts. Methods for using phytoplankton taxonomy for assessment of condition are in development.

Cyanobacteria (also known as blue-green algae) are a group of phytoplankton that have characteristics of both algae and bacteria. Some can produce algal toxins that present a health risk to humans and animals. Normally cyanobacteria are present in low numbers, but occasionally conditions (high nutrient levels combined with other water quality and hydrodynamic conditions) cause blooms that form visible green scums and can produce algal toxins that pose a human health risk. These events are called harmful algal blooms, or HABs.

Cyanobacteria cell counts were compared to the World Health Organization (WHO, 2003a) guidelines for potential human health risks (Table 2b). The thresholds for good conditions (<20,000 cells/mL) are based on the WHO threshold for least concern for adverse health effects. Fair conditions are based on the threshold for low probabilities of adverse health effects (20,000 to 100,000 cells/mL), primarily skin irritation and short-term gastrointestinal illness. Poor conditions are based on the threshold for moderate probabilities of adverse health effects (>100,000 cells/mL), including long-term illness in addition to skin irritation and gastrointestinal illness).

Table 2a. Indicators and associated thresholds used to assess condition of the Great Lakes and connecting river systems.

<table>
<tr><th colspan="2" rowspan="3">Stratum</th><th colspan="11">Water quality (values equal to the threshold are assessed as the better condition class)</th></tr>
<tr><th colspan="2">Chlorophyll *a* (µg/L)</th><th colspan="2">Total phosphorus (µg/L)</th><th colspan="2">Dissolved oxygen (mg/L)</th><th colspan="2">Secchi depth (m)</th><th colspan="3">Eutrophication status</th></tr>
<tr><th>Good/ Fair</th><th>Fair/ Poor</th><th>Good/ Fair</th><th>Fair/ Poor</th><th>Good/ Fair</th><th>Fair/ Poor</th><th>Good/ Fair</th><th>Fair/ Poor</th><th>Good</th><th>Fair</th><th>Poor</th></tr>
<tr><td colspan="2">Lake Superior</td><td>1.3</td><td>2.6</td><td>5</td><td>10</td><td>5</td><td>2</td><td>8</td><td>5.3</td><td rowspan="14">No component indicators are rated poor, and a maximum of one is rated fair.</td><td rowspan="14">One component indicator is rated poor, or two or more indicators are rated fair.</td><td rowspan="14">Two or more component indicators are rated poor.</td></tr>
<tr><td colspan="2">St. Marys River</td><td>1.3</td><td>2.6</td><td>5</td><td>10</td><td>5</td><td>2</td><td>8</td><td>5.3</td></tr>
<tr><td colspan="2">Lake Michigan</td><td>1.8</td><td>2.6</td><td>7</td><td>10</td><td>5</td><td>2</td><td>6.7</td><td>5.3</td></tr>
<tr><td rowspan="2">Lake Huron</td><td>Lake Huron</td><td>1.3</td><td>2.6</td><td>5</td><td>10</td><td>5</td><td>2</td><td>8</td><td>5.3</td></tr>
<tr><td>Saginaw Bay</td><td>3.6</td><td>6</td><td>15</td><td>32</td><td>5</td><td>2</td><td>3.9</td><td>2.1</td></tr>
<tr><td rowspan="3">Huron-Erie Corridor</td><td>St. Clair River</td><td>2.6</td><td>3.6</td><td>10</td><td>15</td><td>5</td><td>2</td><td>5.3</td><td>3.9</td></tr>
<tr><td>Lake St. Clair</td><td>2.6</td><td>3.6</td><td>10</td><td>15</td><td>5</td><td>2</td><td>5.3</td><td>3.9</td></tr>
<tr><td>Detroit River</td><td>2.6</td><td>3.6</td><td>10</td><td>15</td><td>5</td><td>2</td><td>5.3</td><td>3.9</td></tr>
<tr><td rowspan="3">Lake Erie</td><td>Western Basin</td><td>3.6</td><td>6</td><td>15</td><td>32</td><td>5</td><td>2</td><td>3.9</td><td>2.1</td></tr>
<tr><td>Central Basin</td><td>2.6</td><td>3.6</td><td>10</td><td>15</td><td>5</td><td>2</td><td>5.3</td><td>3.9</td></tr>
<tr><td>Eastern Basin</td><td>2.6</td><td>3.6</td><td>10</td><td>15</td><td>5</td><td>2</td><td>5.3</td><td>3.9</td></tr>
<tr><td colspan="2">Lake Ontario</td><td>2.6</td><td>3.6</td><td>10</td><td>15</td><td>5</td><td>2</td><td>5.3</td><td>3.9</td></tr>
<tr><td colspan="2">Niagara River</td><td>2.6</td><td>3.6</td><td>10</td><td>15</td><td>5</td><td>2</td><td>5.3</td><td>3.9</td></tr>
<tr><td colspan="13">Sources: Total phosphorus, chlorophyll a, and Secchi depth thresholds for Great Lakes adapted from PMSTF, 1980 and IJC, 1979. Dissolved oxygen thresholds from Diaz and Rosenberg, 1995; USEPA, 2011, Costantini et al., 2011, Krieger and Bur, 2009. See Wick et al., 2019 for detail on connecting river system thresholds.</td></tr>
</table>

Table 2b. Indicators and associated thresholds used to assess condition of the Great Lakes-continued.

Strata	Cyanobacteria		
All strata	Good: Least probability of adverse health effects	Fair: Low probability of adverse health effects	Poor: moderate probability of adverse health effects
	<20,000 cyanobacteria cells/mL	20,000 - 100,000 cyanobacteria cells/mL	>100,000 cyanobacteria cells/mL
Source: World Health Organization published guidelines for potential human health risks (WHO, 2003a).			

	Microcystin	
All strata	Good	Poor
	≤8 µg/L	>8 µg/L
Source: Adopted from USEPA recommendations for microcystin concentration thresholds, based on relative probability of acute health effects from recreational exposure (USEPA, 2019b).		

	Enterococci	
All strata	Good	Poor
	≤1,280 CCE/100mL	>1,280 CCE/100mL
Source: Adopted from USEPA's recreational water quality threshold for enterococci (USEPA, 2012).		

	Sediment quality								
	Sediment contamination			Sediment toxicity			Sediment quality		
	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
All strata	Mean PECQ is ≤0.1	Mean PECQ is >0.1 and <0.6	Mean PECQ is ≥0.6	Control-corrected survival is ≥90%	Control-corrected survival is ≥75% and <90%	Control-corrected survival is <75%	Both indicators rated good	At least one indicator rated fair, and none are rated poor	At least one indicator rated poor
Sources: Thresholds for mean Probable Effects Concentration Quotients (PECQ) were adopted from MacDonald et al., 2000 and Crane and Hennes, 2007. Sediment toxicity thresholds were adopted from USEPA's National Sediment Quality Survey methods (USEPA, 2004).									

Table 2c. Indicators and associated thresholds used to assess condition of the Great Lakes-continued.

Strata	Benthic index - Oligochaete Trophic Index (OTI)		
All strata	Good	Fair	Poor
	OTI is <0.6	OTI is ≥0.6 and ≤1.0	OTI is >1.0
Sources: Thresholds for the OTI were adopted from methods developed for the State of the Great Lakes reporting (SOLEC, 2007, ECCC and USEPA, 2017).			

	Fish tissue contamination		
All strata	Good	Fair	Poor
	None of the measured contaminant concentrations exceed the screening value for any receptor group	At least one measured contaminant concentration exceeds the screening value for one receptor group.	At least one measured contaminant concentration exceeds the screening value for two or more receptor groups.
Sources: Thresholds (screening values) were calculated using toxicity reference values (TRVs) for each receptor (piscivorous fish, birds, and mammals) and contaminant. TRVs were based on no observed adverse effect levels (NOAEL) (Sample and Arenal, 1999). See Appendix D for screening values for each contaminant and receptor.			

Strata	Fish tissue mercury	
All strata	Good/Low	Poor/High
	≤300 ppb Hg	>300 ppb Hg
Source: Adopted from USEPA's water quality criterion for Methylmercury (USEPA, 2001).		

	Invasive mussels (*Dreissena* spp.)		Round gobies (*Neogobius melanostomus*)		
All strata	Present	Not observed	Present	Suspected presence	Not observed
	Invasive mussels were observed in video or collected in PONAR sample	Invasive mussels not observed in video or collected in PONAR sample	Round goby observed in video	Possible round goby observed (not applicable for Niagara River)	Round goby not observed in video

Microcystin

Microcystins are the most common algal toxins observed in the Great Lakes (e.g., Dyble et al., 2008; Murphy et al., 2003). The microcystin concentration was determined using the ELISA method (USEPA, 2016a) which measures the total of all microcystins without distinguishing the many individual types of microcystins.

Thresholds for microcystin were applied based on USEPA recommendations for concentration thresholds based on the relative probability of acute health effects from recreational exposure to microcystins (USEPA, 2019b). The threshold of ≤8 µg/L was adopted for microcystin, below which the risk of health concerns from recreational exposure to microcystin is low and condition was assessed as good. Areas where this threshold was exceeded were assessed as being in poor condition. (Table 2b). Most samples were below the detection limits of 1 µg/L, which is the WHO drinking water limit guideline (WHO, 2003b).

Enterococci

Enterococcus is a large genus of lactic acid bacteria that is found in the intestines of mammals and birds. Enterococci can be pathogenic, posing health risks of infection for humans and animals. NCCA measures enterococci because it is an indicator of possible sewage contamination of surface waters. The USEPA has established a recreational water quality threshold for enterococci of ≤1,280 calibrator cell equivalents (CCE) per 100 mL (USEPA, 2012), below which the risk of health concerns from recreational exposure is low and condition was assessed as good. Condition of areas where this threshold was exceeded were assessed as poor.

Sediment Quality

Sediment quality was based on sediment contamination and sediment toxicity indicators. For the Great Lakes, sediment contaminants were assessed using the mean Probable Effect Concentration Quotient (PECQ, Ingersoll et al., 2001; USEPA, 2002). The PECQ, a unitless value, is the measured concentration of that contaminant divided by an established PEC, or concentration at which effects on organisms were observed in laboratory tests. Only contaminants with reliable PECs were included: arsenic, cadmium, chromium, copper, lead, nickel, zinc, total PCB congeners, and total PAHs (see Appendix B for included PCB congeners and PAHs). The mean PECQ is the average of the mean PECQ for metals, the PECQ for total PAHs and the PECQ for total PCBs. See Appendix B for more detail on how the mean PECQ was calculated. The mean PECQ was then compared to published thresholds of ≤0.1 for good condition, 0.1 – 0.6 for fair condition, or ≥0.6 for poor condition (Table 2b, MacDonald et al., 2000; Crane and Hennes, 2007).

Sediment toxicity was assessed by measuring the survival rate of the freshwater amphipod, *Hyalella azteca* after a 10-day exposure to the sediments under laboratory conditions (USEPA, 2000; USEPA, 2014c). The thresholds for sediment toxicity are based on published values. A control-corrected survival rate of ≥90% was considered good condition, survival between 75% and 90% was considered fair condition, and a survival rate of <75% was considered poor condition (USEPA, 2004).

Sediment quality at a site was assessed as poor (i.e., high potential for exposure effects on biota) if either one of the component indicators, contamination or toxicity, was categorized as poor; condition was assessed as fair if either indicator was rated fair; and condition was assessed as good if both component indicators were assessed as good.

Benthic Index

The benthic community was assessed using the Oligochaete Trophic Index (OTI), which is the method used by the State of the Great Lakes Ecosystem Conference (SOLEC, 2007; ECCC and USEPA, 2017). The OTI is based on the index of Howmiller and Scott (1977) with subsequent modifications by Milbrink (1983) and Lauritsen et al. (1985). The OTI is a weighted index based on the tolerance of oligochaete species to organic enrichment (ECCC and USEPA, 2017). The OTI ranges from 0 to 3; scores <0.6 indicate oligotrophic/good conditions; scores between 0.6 and 1.0 indicate mesotrophic/fair conditions; and scores >1.0 indicate eutrophic/poor conditions (Table 2c). See Appendix C for further details on how OTI was calculated.

Ecological Fish Tissue Contamination

Fish were collected by crews using various methods (USEPA, 2015c). If fish from the target list were not available, alternative fish species could be submitted. Whole-body fish tissues were assessed based on USEPA guidance (USEPA, 1997). This approach evaluates whether concentrations of contaminants in fish tissue pose a potential risk to fish and wildlife (receptors of concern) that consume fish.

Screening values (thresholds) for each receptor group (piscivorous fish, birds, and mammals) and contaminant were calculated using established toxicity reference values (TRVs) for each receptor (Sample and Arenal, 1999; USEPA, 2021b). The screening values for each contaminant and receptor are in Appendix D. Condition for the fish tissue contaminant indicator was based on the number of receptor groups with at least one screening value exceedance. Table 2c summarizes the protocol for assigning good, fair, or poor condition to Great Lakes and connecting river systems for potential risk of contaminant exposure to fish and wildlife.

The screening values that are used to assess fish tissue contaminant conditions differ in two important ways compared to the those used 2010 NCCA reports. In 2010, screening values were based on the lowest observed adverse effect levels (LOAELs) for each contaminant and receptor group. In the present report, screening values were recalculated based on the no observed adverse effects levels (NOAEL) which more closely align with protective endpoints used in EPA's Water Quality Criteria recommendations (USEPA, 2016e). Using NOAEL values rather than LOAEL values results in more protective thresholds than were used in 2010. The second change to the screening values made during the 2015 assessment involved those for selenium. In the 2010 assessment, no sites in the Great Lakes had good conditions for fish tissue contaminants due to screening value exceedances of selenium in the bird receptor group at all sites (USEPA 2016d). The screening values for selenium were updated for this report using EPA's national aquatic life criterion recommendations for selenium in freshwater which are less protective but more accurately reflect selenium concentrations that could cause ecologically relevant adverse effects to wildlife populations (USEPA, 2016e). Together, these changes cause the results in this report to appear dramatically different than those in the 2010 report. In reality, fish tissue contaminant concentrations in the Great Lakes did not change appreciably between 2010 and 2015 (USEPA, 2021a). A full description of the methods used to calculate the screening values used in this report is available in the NCCA 2015 Technical Support Document (USEPA, 2021b).

In the connecting river systems, fish were only collected during the 2015 sampling season, with sampling primarily in US waters of the St. Marys River and the HEC. Fish were not collected in the Niagara River. Population estimates for the fish tissue contamination in the connecting river systems represent only the resource area accounted for by the sites at which fish sampling was attempted.

Fish Tissue Mercury

Mercury is among the most common toxic pollutants in fish tissue and is the basis of many fish consumption advisories in the Great Lakes (USEPA, 2009). The USEPA has identified a human consumption criterion of 0.3 mg methylmercury per kg (300 ppb) (USEPA, 2001). Sites with fish tissue meeting or exceeding this value were assessed as poor; sites with fish tissue below this threshold were in good condition (Table 2c). Like the ecological fish tissue contaminant indicator, fish tissue mercury samples in the connecting river systems were only collected in 2015 and primarily at US sites. Population estimates for fish tissue in the connecting river systems represent only the area represented by the sites at which fish sampling was attempted.

Invasive Species

Round gobies (*Neogobius melanostomus*) and dreissenid mussels (*Dreissena* spp.) can cause water quality, habitat, and food web changes that affect coastal condition. Lietz et al. (2015) showed that the presence of these species could be determined from underwater video footage. Estimates of percent of the resource area where round gobies were present are based on underwater video. Estimates for dreissenids were based on video and PONAR samples together. Analysts viewed videos to identify invasive mussels or round gobies. Analysts were trained using an EPA-supplied dataset, and a quality assurance assessment check was completed following the analysis. Analysts identified round gobies based on their characteristic black dorsal spot, body morphology, and demersal orientation. They identified dreissenid mussels based on their morphology, size, and attachment to surfaces (see image on cover page of a round goby and dreissenid mussels from video taken in the HEC). Due to cryptic coloration, prolific algae or leafy vegetation, turbidity, or other factors that resulted in poor video quality, mussels and gobies could be missed in videos. The estimates presented in this report are therefore considered underestimates of invasive species presence.

Round gobies could be identified with confidence if they were near the camera or if they displayed their black dorsal spot. However, in many cases, they were challenging to identify. Analysts reported both confident and possible detections of round gobies. In the condition plots (described below), presence/absence are indicated with black (confident of presence) or dark gray (suspected/possible presence), not detected is indicated with white bars, and unassessed with light gray bars.

Dreissenid mussels were collected in the standard PONAR samples. However, a standard PONAR sample represents only about 0.05 m^2 of bottom and may not detect dreissenid mussels if they are present at low densities or in patches, or if the benthic substrate is too coarse for effective PONAR sampling. Because neither PONAR sampling nor underwater video methods can always detect dreissenid mussels at a site when they are present, using video and PONAR samples together provides a more reliable indicator for dreissenid presence (Lietz et al., 2015). In this report, dreissenid presence is reported based on detections in both videos and in PONAR samples. The percent of area where mussels were estimated to be present was based on positive detection in either the PONAR sample or video (shown as black bars in the summary assessment figures, described below). Percent area where mussels were not observed in either PONAR samples or video was denoted by white bars in the summary assessment figures. Unassessed area due to poor quality video and no PONAR sample was denoted by light gray bars.

Videos were collected at 534 of 550 sites in the Great Lakes and connecting river systems in 2014–2016. Video could not be collected at 16 sites, which represent unassessed area. Due to poor video quality, 19% of the videos collected could not be analyzed, and the resource area represented by these sites was unassessed. Video technology and analysis methods have improved since the 2016 assessments. Improved methods were used for the Niagara River in 2018. In these higher quality videos, analysts could confidently detect round gobies, so the category of “suspected round goby” was not included in the assessment of the Niagara River. Positive round goby and dreissenid mussel presence at a site were based on detection in at least one of the two videos collected at each site (down looking or oblique video).

Assessment Reporting

Assessment results are presented in horizontal bar plots (e.g., Fig. 2). The lengths of the bars represent the estimated percent of area within a resource (nearshore area or connecting river system area) in each condition class. For the Great Lakes, conditions based on each indicator are reported as a percent of the area of the nearshore and embayments combined (left column of bars), the percent area of nearshore (center column of bars), and the percent area of embayments (right column of bars). Error bars are 95% confidence intervals for the condition estimate.

Condition of the St. Marys River is reported as a percentage of the entire area of the St. Marys River. Condition of the HEC is reported for the entire area of the HEC and for individual waterbodies within the HEC: the St. Clair River, Lake St. Clair, and the Detroit River. Condition of the Niagara River is reported for the Upper River (above the falls), the Lower River, and the entire river. The assessed Upper River includes the Buffalo Harbor area (Lake Ontario) of the Niagara River AOC.

The connecting river systems were assessed as areas distinct from the Great Lakes (the small amount of overlap in the design frames was ignored). Assessed resources (i.e., subpopulations) should have at least 30 sites for estimates to be statistically robust (Herlihy et al., 2000). Some subpopulations did not meet this criterium but are reported here for completeness. Examples include the embayment-only areas of some lakes (e.g., Lake Erie, Lake Ontario), and individual waterbodies within the HEC (e.g., St. Clair River, Table 1).

Field data were collected at 361 Great Lake sites (218 nearshore and 143 embayment sites), 94 sites in the St. Marys River, 95 sites in the HEC, and 59 sites in the Niagara River (Table 1). Sites at which any subset of the full complement of indicator data was collected (excluding fish tissue assessments) were included in condition estimates. Sites where no data were collected for any indicators were excluded from the determination of condition estimates. Therefore, condition estimates represent the area assessed rather than the area identified in the original design. If an indicator was missing for any sites, the condition based on that indicator/index is shown as “unassessed” in the bar plots for some percentage of the original design. An individual indicator or index could be unassessed because site conditions prevented collection of a sample or field measurement, or if the sample or data collected did not meet quality assurance requirements.

Missing data were common for the benthic index, ecological fish tissue, and fish tissue mercury. For the benthic index, there were two reasons for this: 1) PONAR sampling is difficult on hard substrates or areas with dense mussel beds, and 2) the OTI calculations (see Appendix C) require that tolerance-classified oligochaete species are present in the sample. Sites where either no PONAR sample was collected (19% of Great Lakes nearshore samples) or classified oligochaetes were not present preventing calculation of the OTI (14% of Great Lakes nearshore samples, Table 1) were unassessed. Lake Ontario was the most difficult lake in which to collect benthos samples (and sediment samples) due to rocky substrates and abundant dreissenid mussels.

The ecological fish tissue contaminant and fish tissue mercury indicators have requirements for the species, lengths, and weights of fish used, and collecting enough fish meeting these parameters was challenging in 2015. To increase the number of fish samples collected in 2015, the allowable fish collection area was extended to 1000 m from the X-site, compared to 500 m in 2010. In the connecting river systems, sampling was attempted at only a subset of sites, so the fish tissue condition estimate represents a smaller portion of the system than other indicators (Table 1). In the Great Lakes, the fish tissue indicator represents the same area as other indicators but does have a significant portion of unassessed area where fish were not caught (15% of samples missing for fish tissue contamination, and 19% of samples missing for fish tissue mercury).

Several parameters were collected in the NCCA 2015 and connecting river systems that were not included in the assessment. These include total nitrogen, chloride, conductivity, sulfate, pH, silica, total algal toxin concentration, metals in sediment, PAHs in sediment, PCBs in sediment, diatom and non-diatom phytoplankton taxa richness, and macroinvertebrate taxa richness. Spatial variation in measured values for these parameters is illustrated in Appendix E.

Summary of Assessment Results – Great Lakes

Water Quality

Based on four water quality indicators (total phosphorus, chlorophyll *a*, Secchi depth, and dissolved oxygen), more of the Great Lakes combined nearshore and embayment area was in good condition than in fair or poor condition (Fig. 2). Based on total phosphorus, condition of 44% of the combined nearshore and embayment area was assessed as good, 29% as fair, 23% as poor, and 4% was not assessed. Based on chlorophyll *a*, 73% of nearshore and embayment area was in good condition, 10% was fair, and 17% was poor. Based on water clarity (Secchi depth), 46% of nearshore and embayment area was in good condition, 13% was fair, 37% was poor, and 4% was not assessed. Based on dissolved oxygen, about 98% of nearshore and embayment area was in good condition, <1% was in fair condition, <1% was in poor condition, and <1% was not assessed. Based on the eutrophication indicator derived from the four water quality indicators, 54% of the combined nearshore and embayment area was in good condition, 22% was fair, 24% was poor, and less than 1% was unassessed.

Embayments in the Great Lakes had a higher percentage of area assessed as poor for total phosphorus (50% poor), chlorophyll *a* (39% poor), and water clarity (53% poor) than the nearshore excluding embayments (22%, 16%, and 36% poor, respectively). This was reflected in condition estimates based on the eutrophication indicator: 45% of embayment area was in poor condition and only 23% of the nearshore area was in poor condition. Based on dissolved oxygen, assessed conditions were mostly good in both the nearshore (98% good) and in embayments (96% good).

Cyanobacteria and Microcystin

Based on cyanobacteria concentrations, 64% of the Great Lakes combined nearshore and embayment area was in good condition, 25% was in fair condition, and 10% was in poor condition. Conditions in the nearshore were good in 65% of the area, fair in 25%, and poor in 10%. In embayments, 57% of the area was in good condition, 31% of area was fair, and 12% of area was poor.

Microcystin concentrations at all but one site in the Great Lakes combined nearshore and embayments were below the threshold of 8 µg/L for low risk to recreational users. The one site where microcystin concentrations exceeded the threshold was in Lake Erie and accounted for less than 0.1% of the combined nearshore and embayment area. Microcystin was detected at 71 of the 361 sites in the Great Lakes nearshore and embayments, and concentrations ranged from 0.1 - 8.4 µg/L.

Enterococci

Conditions in the combined nearshore and embayments were assessed as good for enterococci in more than 98% of the area (Fig. 2). The rest of the area was in poor condition (<1%) or was not assessed (<1%). Conditions in the nearshore were similar to the combined nearshore and embayments because the nearshore comprises most of the combined area. In the embayments, 98% of the area was in good condition with the remaining 2% in poor condition (Fig. 2).

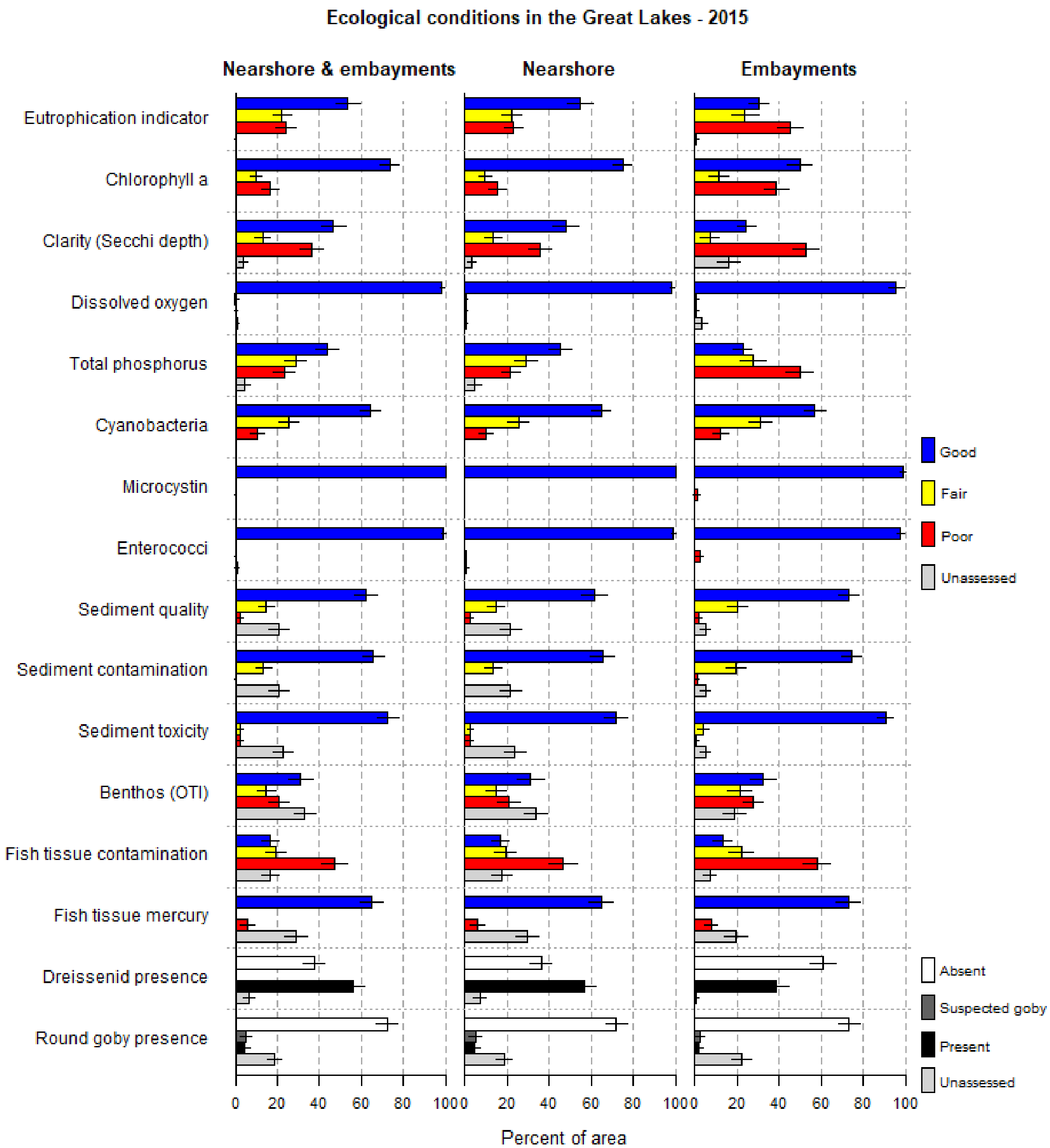

Figure 2. Ecological conditions of the Great Lakes based on the 2015 NCCA.

Sediment Quality

Sediment quality in the Great Lakes was in good condition in 62% of the of the combined nearshore and embayment area with most of the remainder in fair condition (15%) or unassessed (21%) due to hard bottom and other factors (Fig. 2). The percent of the area in good condition was higher for the embayments (73%) than the nearshore (62%), but the nearshore had four times more unassessed area than embayments which tended to have more readily sampled substrate. Poor sediment quality conditions were found in about 2% of the area in both the nearshore and embayments.

Sediment quality is based on sediment contamination and sediment toxicity. Sediment quality conditions were driven primarily by sediment contamination which generally had less area assessed as good than sediment toxicity. Conditions based on sediment contamination were good in about 65% of the nearshore and in the combined nearshore and embayments. Sediment toxicity was in good condition in over 70% of the nearshore and combined nearshore and embayments. Most of the rest (>20%) of the nearshore and the combined nearshore and embayments was unassessed for sediment toxicity due sampling problems.

Conditions based on sediment contamination were assessed as good and fair condition in 74% and 20% of the embayments, respectively, with about 1% of the area in poor condition, and 5% unassessed. Ninety-one percent of embayment area was in good condition for sediment toxicity, and most of the rest in fair and unassessed conditions.

Benthic Index

In the combined nearshore and embayments resource area of the Great Lakes, the condition of 31% of the area was assessed as good condition, 15% was in fair condition, and 21% was in poor condition based on the Oligochaete Trophic Index (OTI). The remaining 33% of the area in the combined resource could not be assessed with the OTI; 19% was due to PONAR samples not collected at the site, and 14% was due to collected PONAR samples not containing the enough tolerance-classified oligochaetes to allow calculation of the OTI.

A higher percentage of embayment area was assessed as poor (32% good, 21% fair, and 28% poor) than the nearshore (31% good, 15% fair, and 20% poor), although a higher percentage of the nearshore was unassessed (34%) than embayments (9%). The higher percentage of unassessed area in the nearshore compared is because embayments were more likely to have soft sediments where PONAR sampling attempts are more often successful.

Ecological Fish Tissue Contamination

Ecological fish tissue contaminant conditions were assessed as good in 17%, fair in 19%, and poor in 47% of the combined nearshore and embayments area of the Great Lakes (Fig. 2). The remaining 17% of this combined area could not be assessed due to lack of sufficient numbers of fish caught. In the Great Lakes as a whole, fish tissue contaminant conditions did not differ greatly between the nearshore and the embayments areas. Embayments had slightly larger areas that were in fair and poor condition than the nearshore, but also had less unassessed area than the nearshore (Fig. 2).

For the ecological fish tissue contaminant indicator, a screening value exceedance in any single receptor group (piscivorous mammal, fish, or bird) causes the condition to go from good to fair; a screening value exceedance in additional receptor groups causes the index to go from fair to poor (Table 2c). The relatively low amounts area with good ecological fish tissue contaminant conditions in this survey was largely due to screening value exceedances for selenium, mercury, and PCBs in piscivorous birds and mammals.

The method for assessing ecological fish tissue contaminant conditions changed between the 2010 NCCA report and the 2015 report (see Indicator section above). In the 2010 report, none of the Great Lakes area was assessed as good for this indicator due to very conservative (i.e., protective) screening values for selenium. Comparisons of the 2010 results with the 2015 results using the updated method suggested that significantly more of the Great Lakes nearshore had good and fair conditions for this indicator in 2015 (USEPA, 2021a). However, the amount of unassessed area decreased substantially in 2015, so it is unclear whether fish tissue contamination conditions have actually improved.

Fish Tissue Mercury

Fish tissue mercury conditions were good in 73% of embayment area but only about 65% of the nearshore and the combined nearshore and embayments areas. Only 19% of the area of the embayments could not be assessed whereas nearly 30% of the area of the nearshore and combined nearshore and embayments could not be assessed. The remaining area (<10%) in each subpopulation had fish tissue mercury concentrations above the mercury threshold of 300 ppb and were assessed as poor condition (Fig. 2). Fair condition for fish tissue mercury is not defined (Table 2c).

Invasive Species

Dreissenid mussels were estimated to be present in 56% of the Great Lakes combined nearshore and embayments area, with 7% of the area unassessed either because a PONAR sample or a video of high enough quality were not available. Both methods detected dreissenid mussels in 13% of the nearshore, and PONAR samples detected an additional 24% of area where videos were poor quality or did not detect mussels, and videos detected mussels in 18% of the area where they were not collected in PONAR samples.

Based on underwater video, round gobies were present in 4% of the Great Lakes combined nearshore and embayments area, with an additional 5% of area with suspected round gobies. Round gobies were more common in the nearshore (10% of area) than in embayments (4% of area). Nineteen percent of the area was unassessed for round goby, mostly due to poor video quality.

Lake Superior

Seventy-eight sites were sampled to assess 3,202 km^2 of nearshore area, of which 42 were nearshore sites and 36 were embayment sites. The embayments represent 211 km^2 of the nearshore area. Lake Superior sample locations are shown in Fig. 3.

Water Quality

Conditions in the combined nearshore and embayment area of Lake Superior were assessed as mostly in good condition based on chlorophyll *a* (86% of the area), water clarity (54%), and dissolved oxygen (100%). Based on total phosphorus, more of the combined nearshore and embayment area was in fair condition (62%) than good condition (9%). Based on the eutrophication indicator, 62% of the combined nearshore and embayments area of Lake Superior was in good condition (Fig. 4).

A higher percent of the embayment area was in poor condition based on total phosphorus (41% poor), chlorophyll *a* (23% poor), and water clarity (46% poor) than the nearshore (8%, 0%, and 23% poor, respectively). These conditions were reflected in condition estimates based on the eutrophication indicator: 35% of embayment area was in poor condition, and only 6% of nearshore was in poor condition.

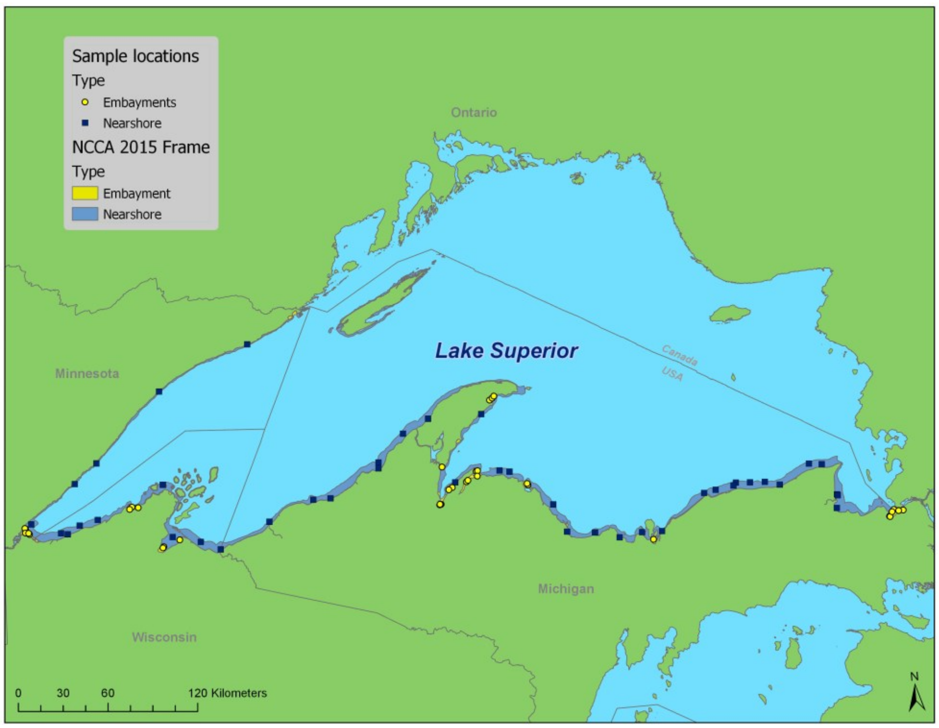

Figure 3. Sample locations in Lake Superior for the 2015 NCCA.

Cyanobacteria and Microcystin

Cyanobacteria conditions in Lake Superior were assessed as good in 85% of the combined nearshore and embayments area and fair in the remaining 15% (Fig. 4). Conditions in the nearshore were similar to the combined nearshore and embayments. Condition based on cyanobacteria was better in the nearshore (86% of the area in good condition) than in embayments (67% good).

Microcystin concentrations at all sites site in Lake Superior were below the threshold of 8 µg/L so 100% of the combined nearshore and embayments area in Lake Superior was assessed as being in good condition. Microcystin was detected at only 7 sites Lake Superior, and each had a concentration of 0.1 µg/L, the detection limit for the microcystin assay.

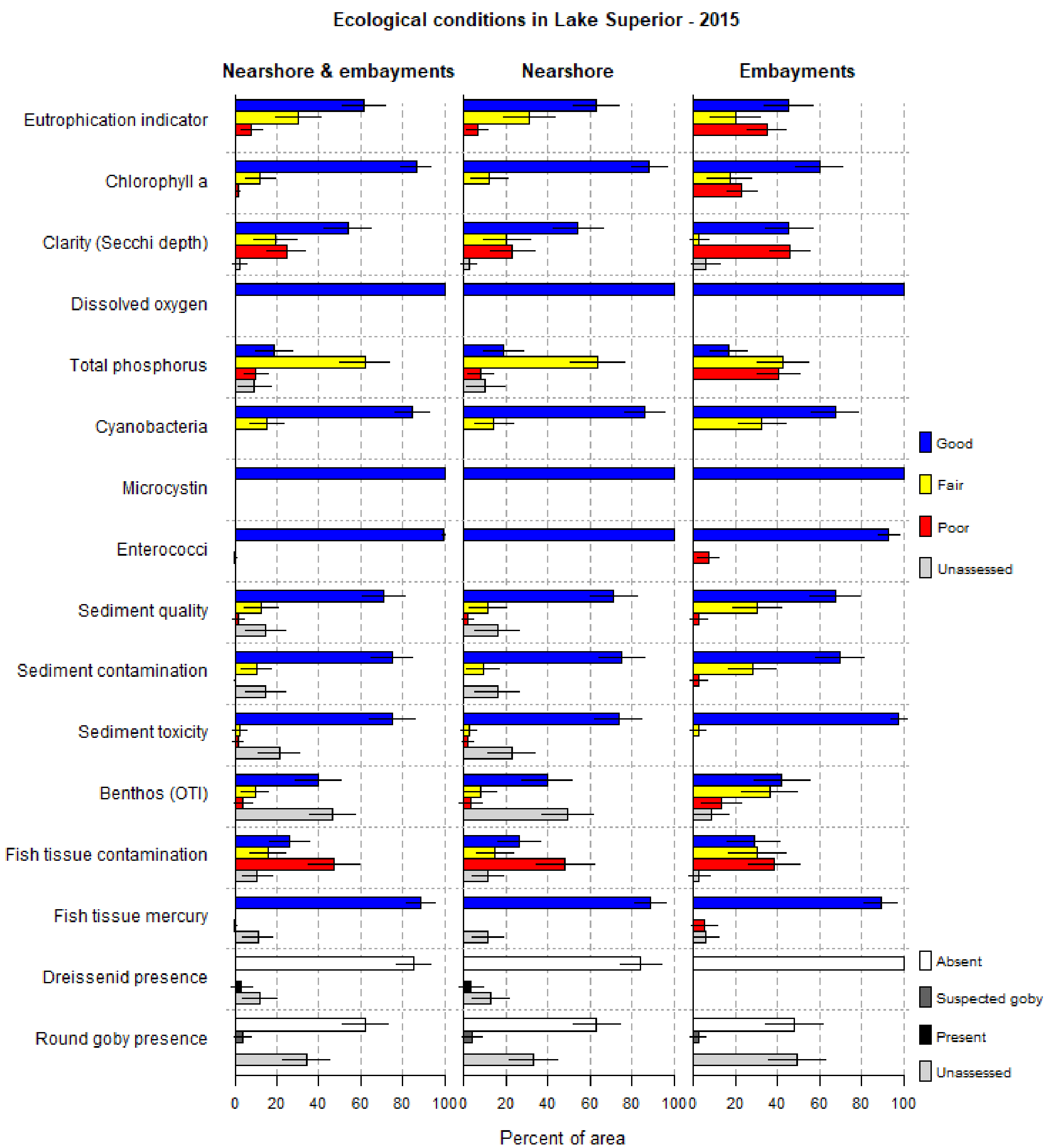

Figure 4. Ecological conditions of Lake Superior based on the 2015 NCCA.

Enterococci

Enterococci cell concentrations were below the threshold value of 1,280 CCE/100ml at nearly all the sites in Lake Superior; 99% of the area in the combined nearshore and embayment area was assessed as being in good condition. All exceedances of the enterococci thresholds were in the embayments, where 7% of the area was in poor condition (Fig. 4).

Sediment Quality

Sediment quality in Lake Superior was in good condition for greater than 70% of the area of the combined nearshore and embayments and the nearshore (Fig. 4). Within embayments, conditions were good across 67% of the area. The lower percent of good sediment quality conditions in the embayments was due to a slightly lower percentage of area with good conditions for sediment contamination (both sediment contamination and sediment toxicity must be rated good for the site to be in good condition).

Benthic Index

In Lake Superior's combined nearshore and embayments, 46% of the area could not be assessed using the OTI. Twenty-one percent of the area was unassessed because PONAR samples could not be collected; 25% was unassessed because collected samples did not contain enough tolerance-classified oligochaetes to calculate the OTI. In the remaining area, the condition of 40% of the area was assessed as in good condition, 10% was fair, and 4% was poor. A higher percentage of the embayment area was in poor condition (42% good, 36% fair, and 14% poor) than the nearshore (40% good, 8% fair, and 3% poor).

Ecological Fish Tissue Contaminant

Of Lake Superior's combined nearshore and embayments area, 26% was in good condition for fish tissue contaminants, 16% in fair condition, 47% in poor condition, and the remaining 11% of area not assessed due to lack of fish caught (Fig. 4). The nearshore of Lake Superior had a greater percentage of area in poor condition or that was unassessed than the embayments area.

Fish Tissue Mercury

Fish tissue mercury conditions in Lake Superior were assessed as good in about 89% of the combined nearshore and embayments and in both the embayments and nearshore individually (Fig. 4). In the combined nearshore and embayments, conditions were poor in less than one percent of the area. All sites where poor fish tissue mercury conditions were detected were in embayments, where about 6% of the area was in poor condition. The unassessed area was due to lack of fish caught.

Invasive Species

Based on a single site in the nearshore near Port Wing, Wisconsin, dreissenid mussels were estimated to be present across 3% of Lake Superior's combined nearshore and embayments area. Dreissenids are common in the Duluth-Superior Harbor, which is about 40 km southwest from this site, but dreissenids are otherwise been rare in the open waters of Lake Superior (Trebitz et al., 2019). It has been hypothesized that dreissenids are uncommon in Lake Superior because water temperatures, food availability, and the concentrations of Ca^{2+} (or some combination of these factors) may be limiting mussel abundance (Ramcharan et al., 1992; Trebitz et al., 2019). However, the observation of dreissenids in this survey and other recent surveys (Trebitz et al., 2019) in Lake Superior suggest that Lake Superior may be (or may be becoming) more suitable habitat for dreissenids. Video and PONAR data from future NCCA surveys will help to determine whether dreissenids are becoming more widespread in Lake Superior's nearshore.

Based on underwater video, round gobies were suspected for an estimated 4% of the combined nearshore and embayments area in Lake Superior, with no positive goby observations and with 34% of the area unassessed due to poor video quality.

Lake Michigan

One hundred sites were sampled to assess 7,869 km^2 of Lake Michigan's nearshore area, of which 45 were nearshore base sites and 55 were embayment sites. The embayments represent 402 km^2 of the nearshore area. Lake Michigan sample locations are shown in Fig. 5.

Water Quality

Most of the combined nearshore and embayment area of Lake Michigan was assessed as being in good condition based on the four components of the eutrophication indicator (Fig. 6). Based on the eutrophication indicator, 62% of the combined nearshore and embayment area of Lake Michigan was in good condition, 15% was in fair condition, 23% was in poor condition, and less than one percent was unassessed.

More of the area of embayments was in poor condition for total phosphorus (46%), chlorophyll *a* (30%), and water clarity (45% poor), than the nearshore (24%, 10%, and 34% poor, respectively). Based on the eutrophication indicator, 35% of embayment area was in poor condition, and 22% of nearshore area was in poor condition.

Cyanobacteria and Microcystin

Condition based on cyanobacteria cell counts was good in 78% of the Lake Michigan combined nearshore and embayment area, was fair in 16%, and poor in 6% of the area (Fig. 6). In the embayments, 71% of the area was in good condition and 22% and 7% of the area was in fair and poor condition, respectively (Fig. 6).

Microcystin concentrations at all sites in Lake Michigan were below the threshold of 8 µg/L for low risk to recreational users so 100% of the combined nearshore and embayment area was in good condition. Microcystin was detected at only 16 of the 100 sites in Lake Michigan and concentrations ranged from of 0.1-1.16 µg/L.

Enterococci

In Lake Michigan, only one embayment site exceeded the USEPA recreational threshold of 1,280 CCE/100 mL for enterococci. Condition based on enterococci was assessed as good in 99% of the embayment area and 100% of the nearshore.

Figure 5. Sample locations in Lake Michigan for the 2015 NCCA.

Sediment Quality

Sediment quality conditions in Lake Michigan were assessed as good in more than 70% of the nearshore and in the combined nearshore and embayments. In the embayments, more than 90% of the area was in good condition (Fig. 6). Though sediment contaminant conditions were similar in the nearshore and embayments, the nearshore had a small amount of area in poor condition based on sediment toxicity, whereas none of the area in the embayments was assessed as poor based on sediment toxicity.

Benthic Index

Benthos conditions could not be assessed in 19% of the combined Lake Michigan nearshore and embayment area. Of the unassessed area, 5% was due to PONARs not being collected and 14% was due to PONAR samples not containing enough the tolerance-classified oligochaetes to calculate the OTI (see Appendix C). A slightly higher percentage of the Lake Michigan embayments was assessed as poor condition (41% good, 15% fair, and 25% poor) than the nearshore (45% good, 17% fair, and 19% poor).

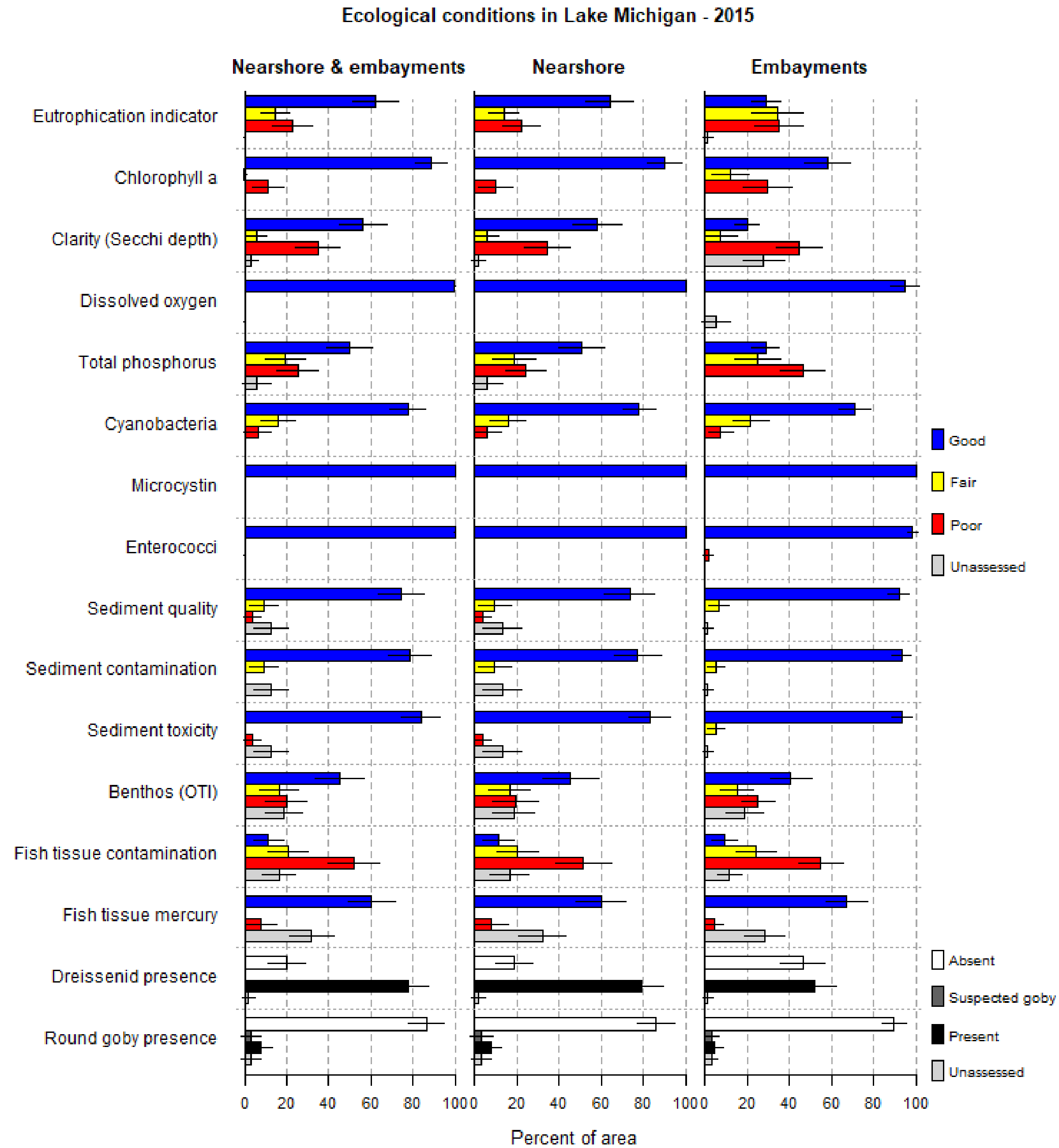

Figure 6. Ecological conditions of Lake Michigan based on the 2015 NCCA.

Ecological Fish Tissue Contamination

Fish tissue contaminant conditions in Lake Michigan were good in 11%, fair in 21%, and poor in 52% of the combined nearshore and embayment area with the remaining area unassessed due to lack of sufficient fish caught (Fig. 6). The percent of area in good, fair, and poor condition did not differ greatly between the nearshore and embayments.

Fish Tissue Mercury

Fish tissue mercury conditions in Lake Michigan were assessed as good in 67% of the embayment area and about 60% of the nearshore and the combined nearshore and embayment area (Fig. 6). Conditions were poor in about 8% of the nearshore and the combined nearshore and embayment, with the remaining 32% unassessed. In embayments, conditions were poor in 5% and unassessed in 28% of the area.

Invasive Species

Dreissenid mussels were estimated to be present in 78% of Lake Michigan's combined nearshore and embayment area, with just 2% of area unassessed. Dreissenids were detected using both video and PONAR at 20% of the combined nearshore and embayment area. PONAR samples alone detected dreissenids at an additional 40% of area where videos were of poor quality or did not record mussels. Videos detected mussels in 18% of the area where PONAR samples were not collected. Mussels were observed across 52% of the embayment area and 80% of the nearshore area.

Round gobies were estimated to be present across 8% of the combined Lake Michigan nearshore and embayment area, with an additional 3% of the area suspected of having round gobies. Three percent of the area was unassessed for round goby due to poor quality video. Round gobies were less common in embayments (7% of area) than in the nearshore (11% of area).

Lake Huron

Sixty-seven sites were sampled to assess 3,289 km^2 of Lake Huron's nearshore, including 44 base sites and 23 embayment sites. The embayments represent 119 km^2 of the area. Lake Huron sample locations are shown in Fig. 7.

Water Quality

Most of the combined nearshore and embayment area of Lake Huron was in good conditions based on chlorophyll *a* (59% good), water clarity (43% good), and dissolved oxygen (100% good; Fig. 8). Based on total phosphorus, 43% of combined nearshore and embayment area was in good condition, 43% was in fair condition, and 14% was in poor condition. Based on the eutrophication indicator, 47% of the combined nearshore and embayment area was in good condition, with 36% fair, and 17% poor.

Based on total phosphorus, 30% of embayment area and 43% of the nearshore area was in good condition. Based on chlorophyll *a*, 61% of embayment area and 59% of the nearshore area was in good conditions. For water clarity, 30% of embayment area had good conditions; 43% of nearshore area had good conditions. All assessed area in both the nearshore and embayments had good conditions based on dissolved oxygen. Based on the eutrophication indicator, more of the embayment area was in poor condition (35% poor) than the nearshore (16% poor).

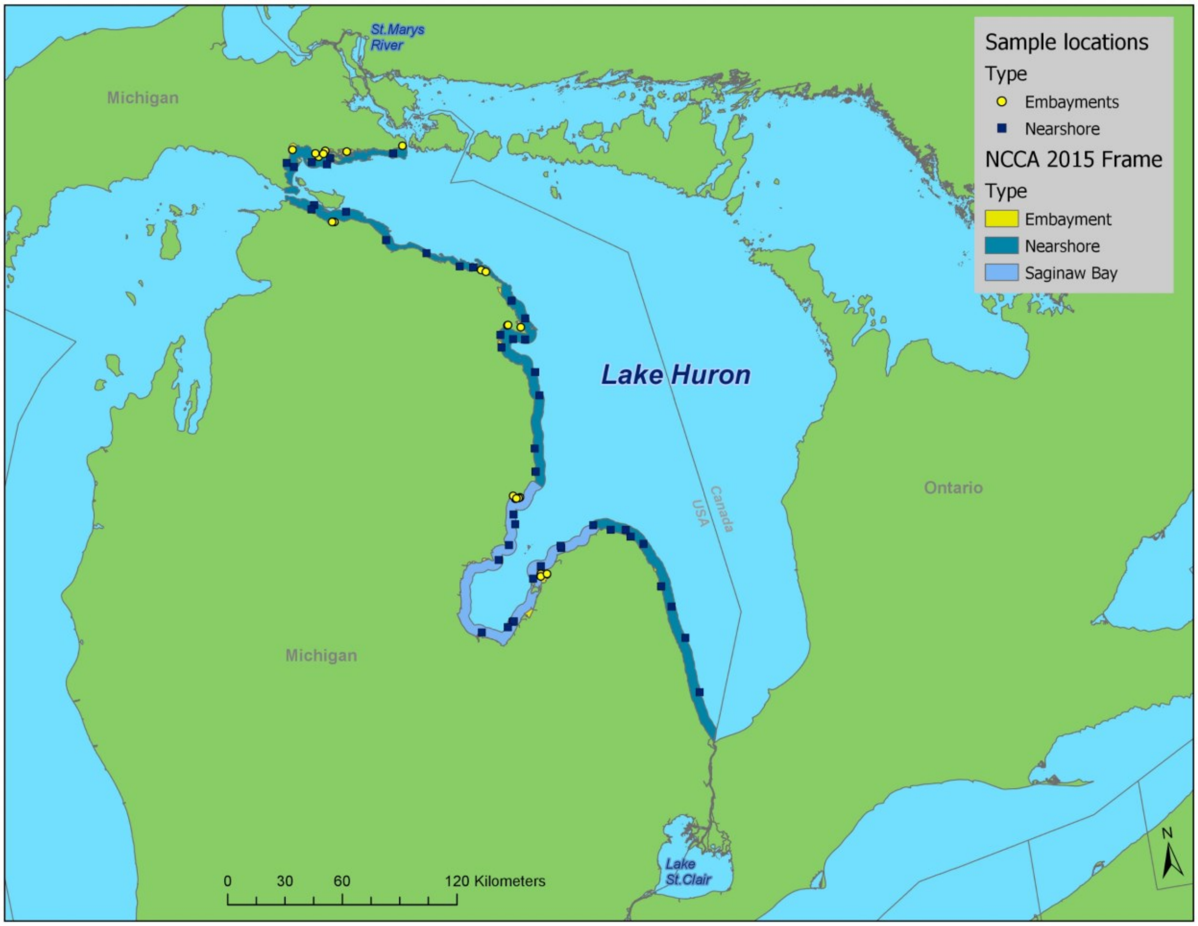

Figure 7. Sample locations in Lake Huron for the 2015 NCCA.

Cyanobacteria and Microcystin

Conditions based on cyanobacteria cell counts were assessed as good in 34%, fair in 43%, and poor in 23% of the Lake Huron combined nearshore and embayment area (Fig. 8). Conditions in the nearshore were the same as the combined nearshore and embayments. In the embayments, 43% of the area had good conditions, 39% of the area was in fair condition, and 17% of the area was in poor condition based on cyanobacteria.

Microcystin concentrations at all sites in Lake Huron were below the threshold of 8 µg/L for low risk to recreational users so 100% of the combined nearshore and embayment area was assessed as good. Microcystin was detected at only 18 of the 67 sites in Lake Huron and concentrations ranged from of 0.11–4.23 µg/L.

Enterococci

No sites in the Lake Huron exceeded the recreational threshold of 1,280 CCE/100mL for enterococci, so conditions were assessed as good in 100% of the Lake Huron combined nearshore and embayment area. Detected concentrations of enterococci ranged from 130 –1,159 CCE/100mL.

Sediment Quality

Sediment quality conditions in Lake Huron were good in 64% of the nearshore area and in the combined nearshore and embayments. Sediment quality conditions were in good condition in 87% of embayment area (Fig. 8). The smaller amount of area in the nearshore in good condition was because of the slightly smaller percentage of area in the nearshore with good sediment contamination and sediment toxicity conditions. There were no poor sediment quality conditions in either the embayments or nearshore, but sediment conditions could not be assessed because of hard bottom at about 27% of the area in the nearshore and 13% of the area in the embayments (Fig. 8).

Benthic Index

Benthos conditions could not be assessed in 41% of the combined nearshore and embayment area in Lake Huron. Of this, 27% was unassessed because PONAR samples could not be collected and 14% was unassessed because PONAR samples did not contain enough tolerance-classified oligochaetes to calculate the OTI. In the assessed area, 13% of the combined nearshore and embayment area was in good condition, 19% was fair, and 27% was poor. For Lake Huron embayments, 9% of the area was in good condition, 35% was in fair condition, and 17% was in poor condition. For the nearshore, 14% of the area was in good condition, 18% was in fair condition, and 27% was in poor condition.

Ecological Fish Tissue Contamination

In the combined nearshore and embayments area of Lake Huron, 7% was in good condition, 14% was fair, 53% was poor, and the remaining area could not be assessed due to lack of fish caught. More embayment area was in poor condition (73%) than the nearshore (52%).

Fish Tissue Mercury

Fish tissue mercury conditions in Lake Huron were assessed as good in 69% of the area of the embayments, 52% of the nearshore, and 53% of the combined nearshore and embayments (Fig. 8). Condition based on fish tissue mercury conditions could not be assessed in 41% of the nearshore and 22% of the area of embayments. Conditions were assessed as poor in about 7% of the area of the nearshore and the combined nearshore and embayments and were poor in about 9% of the embayment area.

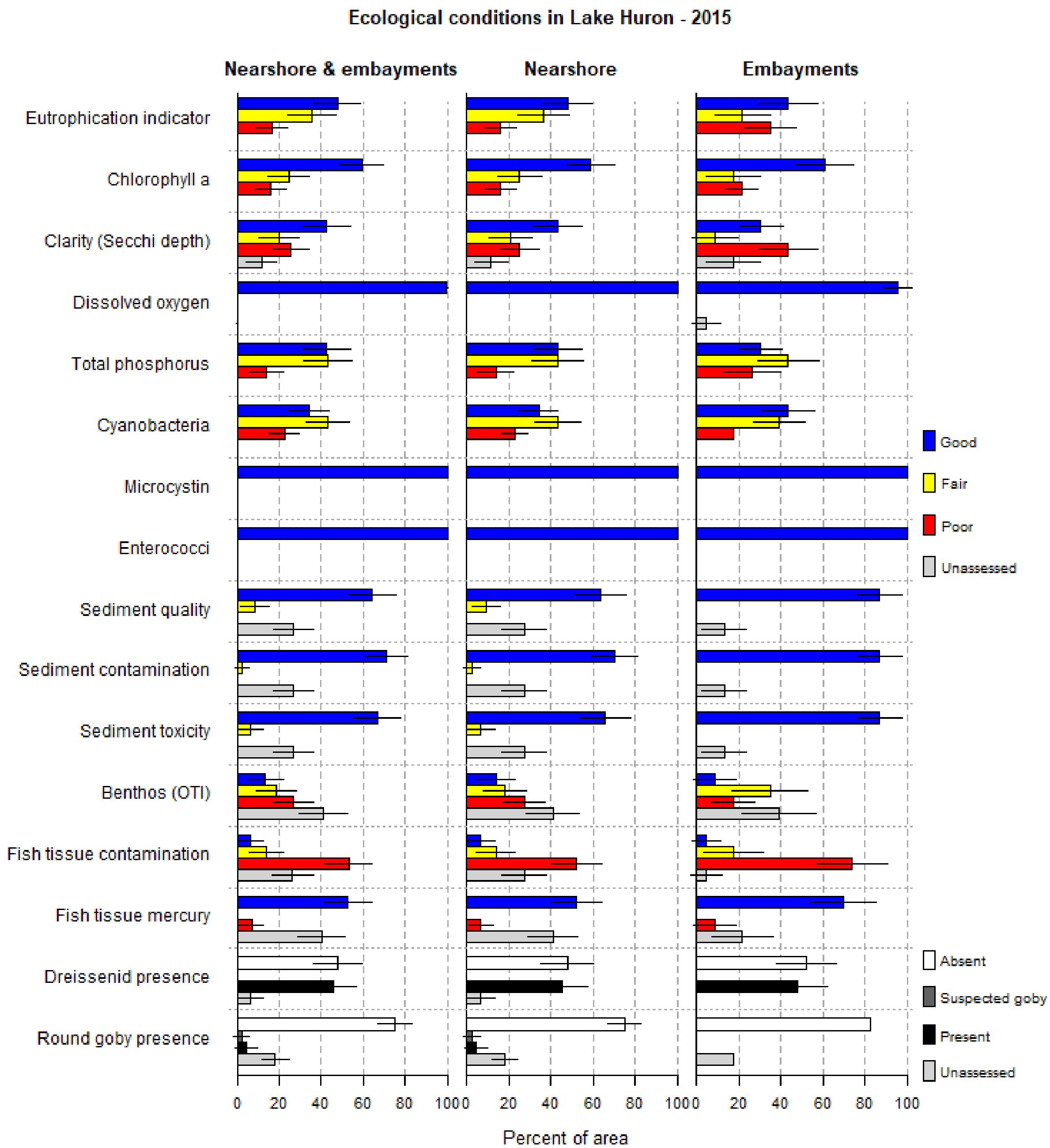

Figure 8. Ecological conditions of Lake Huron based on the 2015 NCCA.

Invasive Species

Dreissenid mussels were estimated to be present across 46% of Lake Huron's combined nearshore and embayment area, with 7% of the area unassessed because a PONAR sample was not collected or a good quality video was not available. Dreissenid mussels were detected using both PONAR and video in 9% of Lake Huron's combined area, and PONAR samples alone detected dreissenids in an additional 17% of area where videos were of poor quality or did not detect mussels. Videos detected mussels in 20% of area where they were not observed in PONAR samples. Dreissenid mussels were similarly frequent in the nearshore (45% of area) and embayments (48% of area).

Round gobies were estimated to be present in 4% of Lake Huron combined nearshore and embayment area, with an additional 2% of the area having suspected round gobies. Eighteen percent of the area was unassessed for round goby because of poor quality videos. Round gobies were not observed at any embayment sites in Lake Huron.

Lake Erie

Ninety sites were sampled in Lake Erie, of which 44 were base sites and 13 were embayments (Fig. 9). An additional 33 sites were sampled for water quality parameters, microcystin, and cyanobacteria to increase the precision of condition estimates for each basin of the lake (western, central, and eastern). These sites represent an area of 2,700 km^2 of the US nearshore coastal area. The embayments represent 80 km^2 of the area. Condition assessment results for Lake Erie, which are based on base sites and the embayment enhancement (57 sites). Condition assessment results for Lake Erie basins are based on all 90 sites (see Table 1 footnote).

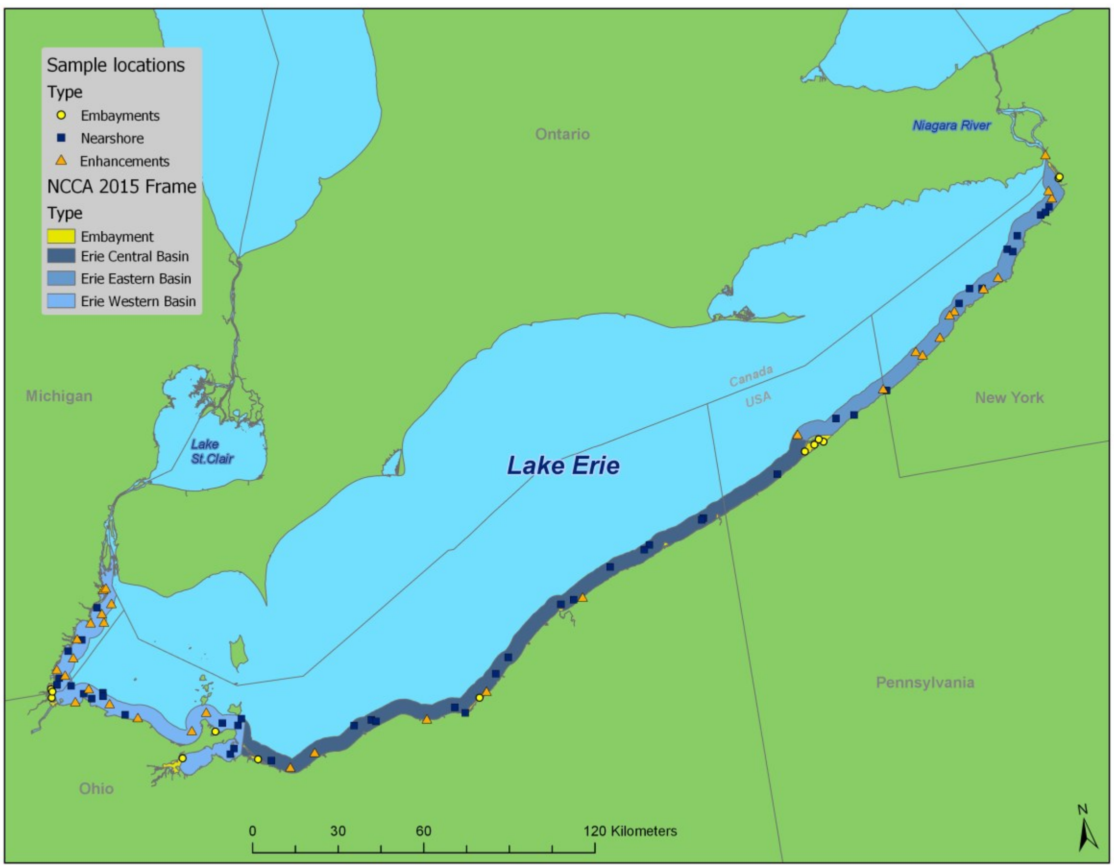

Figure 9. Sample locations in Lake Erie for the 2015 NCCA.

Water Quality

Based on water quality, Lake Erie had the highest percentage of combined nearshore and embayment area assessed in poor condition (Fig. 10). Forty-three percent of the combined nearshore and embayment area of Lake Erie was in poor condition based on total phosphorus; 54% was in poor condition based on chlorophyll *a*, and 70% was in poor condition based on water clarity. Based on dissolved oxygen, 92% of Lake Erie combined nearshore and embayment area was in good condition. Based on the eutrophication indicator, 60% of Lake Erie's combined nearshore and embayment area was in poor condition, 17% was in fair condition, and 23% was in good condition.

Embayments in Lake Erie had a higher percentage of area in poor condition for total phosphorus (81% poor), chlorophyll *a* (92% poor), and water clarity (88% poor) than the nearshore alone (47%, 53%, and 70% poor, respectively). Based on the eutrophication indicator, 92% of Lake Erie embayment area was in poor condition, compared to 60% of Lake Erie nearshore area. It should be noted that embayments are fewer in Lake Erie than in other the Great Lakes, and the embayment-only assessment was based on just 13 sites (Table 1).

Water quality in the combined nearshore and embayments in Lake Erie basins improved from west to east (Fig. 11). Based on total phosphorus, the western basin had no area in good condition, the central basin had 27% in good condition, and the eastern basin had 83% in good condition. For chlorophyll *a*, 9% of the combined nearshore and embayment area was in good condition in the western basin, 23% in the central basin, and 40% in the eastern basin. Based on water clarity, the western basin had no nearshore area in good condition, the central basin had 7% in good condition, and the eastern basin had 33% of combined nearshore and embayment area in good condition. For the eutrophication indicator, 82% of the combined area was in poor condition for the western basin, 77% was in poor condition for the central basin, and 21% was in poor condition for the eastern basin.

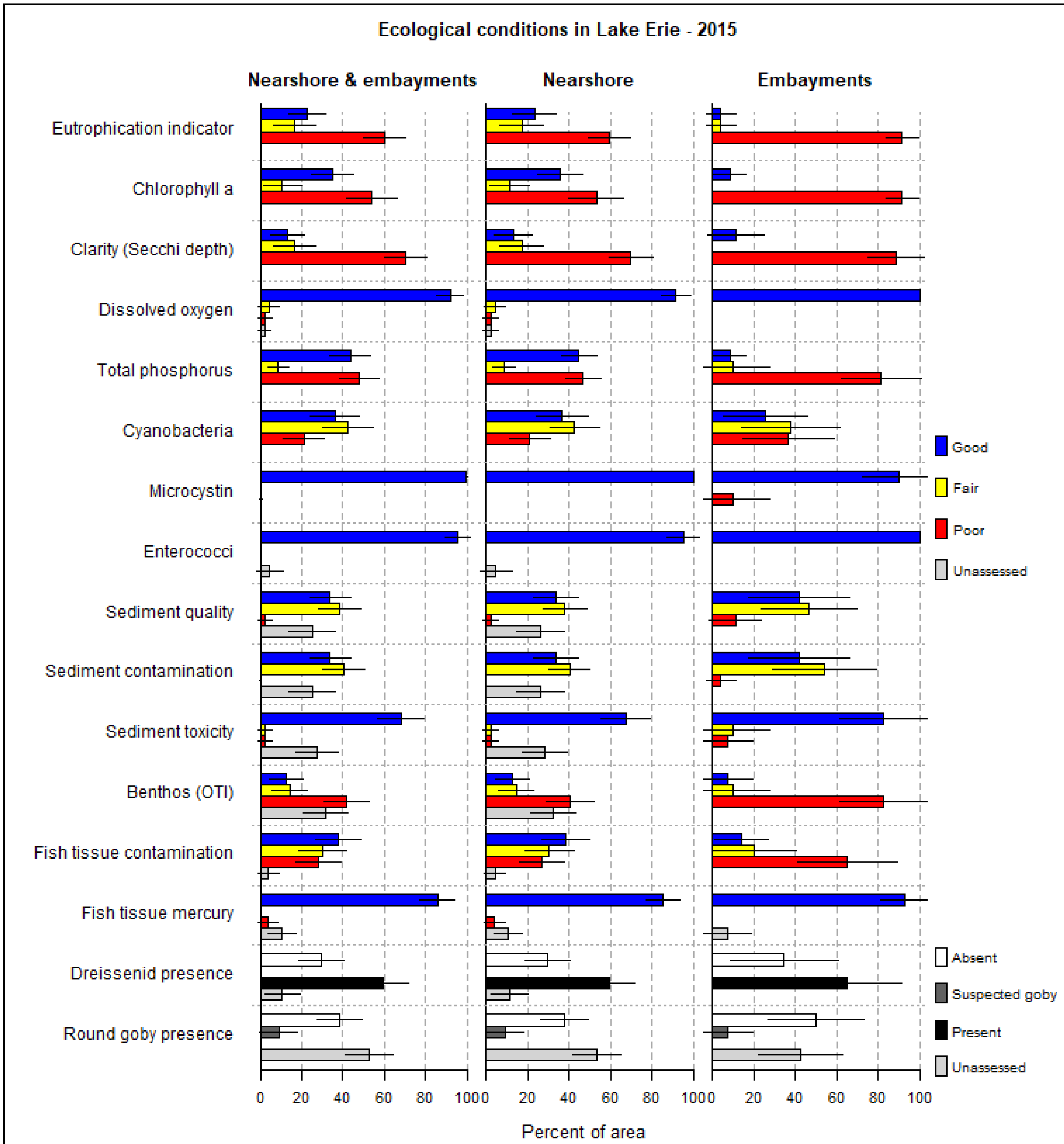

Figure 10. Ecological conditions of Lake Erie based on the 2015 NCCA.

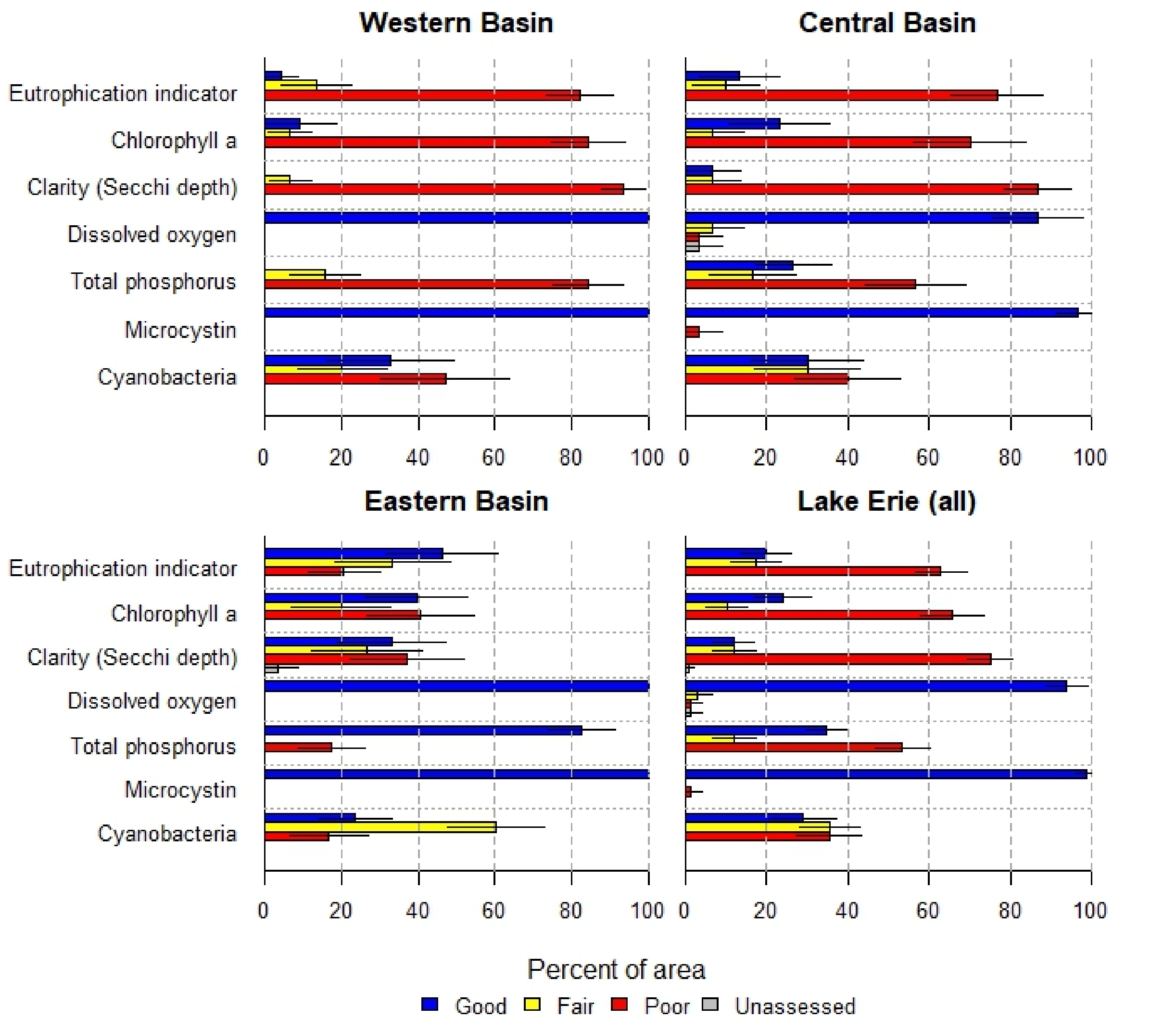

Figure 11. Water quality conditions summarized by basin from the Lake Erie enhancement of the 2015 NCCA. The lower right panel combines data from each of the three basins.

Cyanobacteria and Microcystin

Cyanobacteria conditions were assessed as good in 36% of the combined nearshore and embayment area of Lake Erie, fair in 43% of the area, and poor in 21% of the area (Fig. 10). Conditions in the nearshore were the same as the combined nearshore and embayments. In the embayments, cyanobacteria conditions were good in 26% of the area, fair in 38%, and poor in 37%.

Microcystin concentrations at all but one embayment site in Lake Erie were below the threshold of 8 μg/L for low risk to recreational users. This site accounted for less than 1% of the combined nearshore and embayment area assessed in Lake Erie, so more than 99% of the nearshore area of Lake Erie was in good condition based on microcystin. Because of the low number of embayment sites in Lake Erie, this one site accounted for 10% of the area of Lake Erie embayments. Microcystin was detected at 21 of the 57 sites in Lake Erie and concentrations ranged from of 0.11-8.37 µg/L.

Cyanobacteria and microcystin were both collected at the additional 33 Lake Erie basin enhancement sites. The western basin had the highest percentage of the combined nearshore and embayment area in poor condition based on cyanobacteria (47%, Fig. 11). Forty percent of the central basin was in poor condition, and 17% of the eastern basin was in poor condition. None 33 basin enhancement sites had microcystin concentrations that exceeded the microcystin threshold of 8 µg/L. One embayments site in the central basin exceeded the threshold.

Enterococci

No sites in Lake Erie exceeded the recreational threshold of 1,280 CCE/100mL. One site was unassessed.

Sediment Quality

Sediment quality conditions in the combined nearshore and embayment areas of Lake Erie were assessed as good and fair in 34% and 38%, respectively. Sediment quality conditions could not be assessed in 25% of this combined area. Because a high percent of the nearshore was unassessed, more of the embayments were assessed as being in good, fair, and poor condition than the nearshore. Poor sediment quality conditions in the embayments were due to both sediment contamination and toxicity, whereas poor sediment quality conditions in the nearshore resulted from poor sediment toxicity conditions alone (Fig. 10).

Benthic Index

Based on the OTI, 13% of the combined nearshore and embayment area was in good conditions; 14% of the area was in fair conditions, and 42% was in poor condition. Benthic conditions could not be assessed in 31% of the area in the combined nearshore and embayment in Lake Erie. Of that, 29% of the area was unassessed because PONARs could not be collected, and 2% was unassessed because OTI could not be calculated for the PONAR samples that were collected. All the area that could not be assessed was in the nearshore. In the Lake Erie nearshore, 13% of the area was in good condition, 14% was in fair condition, and 41% was in poor condition. In Lake Erie embayments, 7% of the area was in good condition, 10% was in fair condition, and 83% was in poor condition.

Ecological Fish Tissue Contamination

Fish tissue contaminant conditions were good in 38%, fair in 30%, and poor in 28% of the combined nearshore and embayment area of Lake Erie. Only 4% of this area could not be assessed (Fig. 10). All of the sites that were unassessed were in the nearshore, and fish tissue contaminant conditions in the nearshore of Lake Erie were very similar to the combined nearshore and embayment area (Fig. 10). Conditions were good in 14%, fair in 21%, and poor in 65% of the embayments area.

Fish Tissue Mercury

Fish tissue mercury conditions in Lake Erie were assessed as good in 93% of the area in the embayments and could not be assessed in the remaining 7% (Fig. 10). Nearshore conditions were good in about 86% of the area and were poor in 4% of the area. Fish tissue mercury conditions could not be assessed in the remaining 10% of the nearshore. Conditions in the combined nearshore and embayment area were nearly equivalent to the conditions in the nearshore because embayments represent a small area of Lake Erie.

Invasive Species

Dreissenid mussels were estimated to be present in 60% of Lake Erie's combined nearshore and embayment area, with 11% of area unassessed because a PONAR sample could not be collected or because of poor video quality. Dreissenid mussels were detected in 13% of the combined nearshore and embayment area using both PONAR sampling and underwater video. Dreissenid mussels were collected in PONAR samples at an additional 30% of area where videos did not detect them. Mussels were detected by videos but not collected in PONAR samples for 17% of combined nearshore and embayment area. Dreissenid mussels were similarly frequent in the embayments (65% of area) and the nearshore (59% of area).

Round gobies were suspected to be present in 9% of Lake Erie's combined nearshore and embayment area, but there were no confident detections of gobies in Lake Erie. However, over half of the combined area (53%) was unassessed for round goby, mostly because of poor video quality.

Lake Ontario

In Lake Ontario, 59 total sites that were sampled to assess 1,378 km^2 of nearshore area. There were 43 NCCA base sites and 16 embayment sites sampled (Fig. 12). The embayments represent a 96 km^2 of the area.

Water Quality

Based on the four water quality indicators, most of the combined nearshore and embayment area of Lake Ontario was in good condition (Fig. 13). Based on the eutrophication indicator, 61% of the combined nearshore and embayment area was in good condition, with 24% in fair condition, and 15% in poor condition.

Lake Ontario embayments had high percentages of area in poor condition based on total phosphorus (87% poor), chlorophyll *a* (87% poor), and water clarity (81% poor) compared to the nearshore (9%, 7%, and 28% poor, respectively). Based on the eutrophication indicator, 87% of embayment area was in poor condition, but only 9% of nearshore area was in poor condition. Like Lake Erie, embayments are few in the US waters of Lake Ontario. There were just 16 sites sampled in embayments, and 43 sites sampled in the nearshore for water quality.

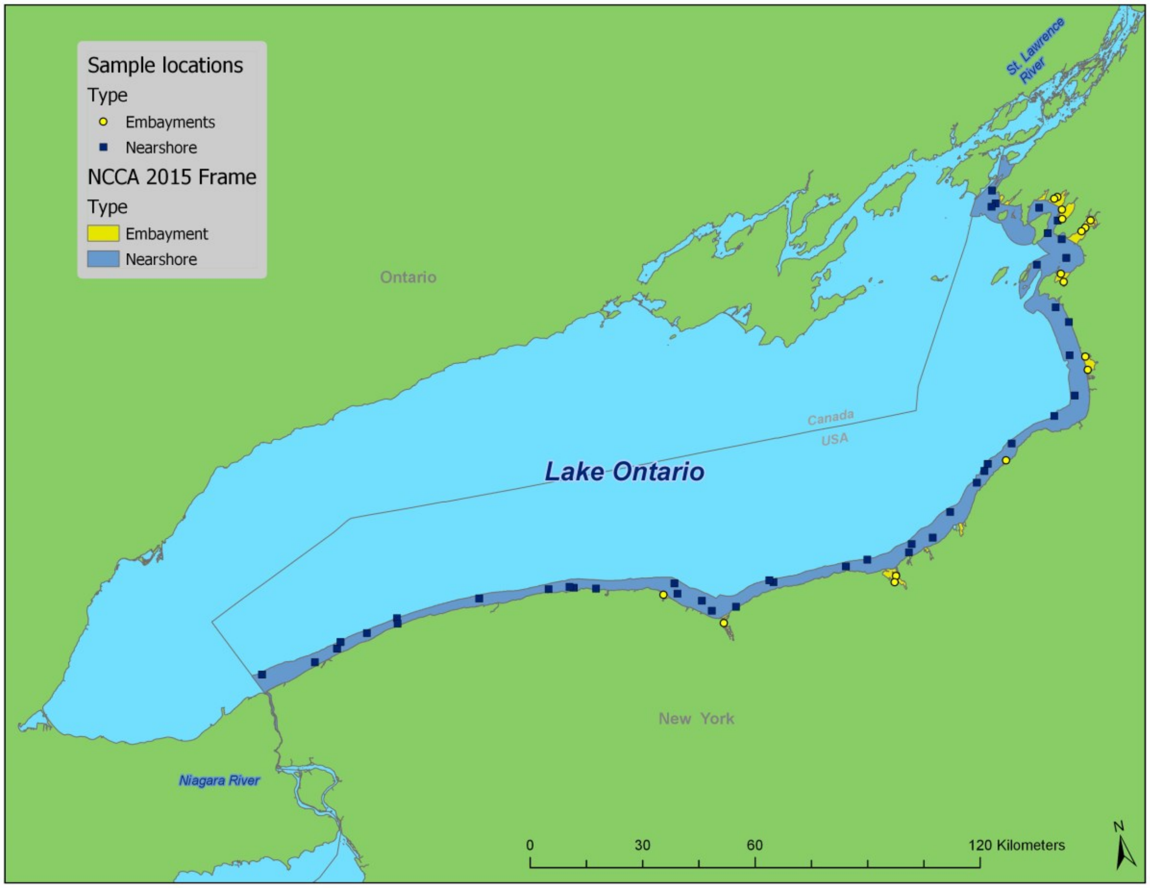

Figure 12. Sample locations in Lake Ontario for the 2015 NCCA.

Cyanobacteria and Microcystin

Conditions based on cyanobacteria were assessed as good in 66% of the combined nearshore and embayment area of Lake Ontario, fair in 27% of the area, and poor in 7% of the area (Fig. 13). Conditions were good in 70% of nearshore area, with 26% in fair condition, and 5% in poor condition. In the embayments, 19% of area was in good condition, 50% was in fair condition, and 31% was in poor condition.

Microcystin concentrations at all sites in Lake Ontario were below the threshold of 8 µg/L for low risk to recreational so that 100% of the combined nearshore and embayment area assessed in Lake Ontario had good microcystin conditions. Microcystin was detected at only 9 of the 59 sites in Lake Ontario and concentrations ranged from of 0.108-1.625 µg/L.

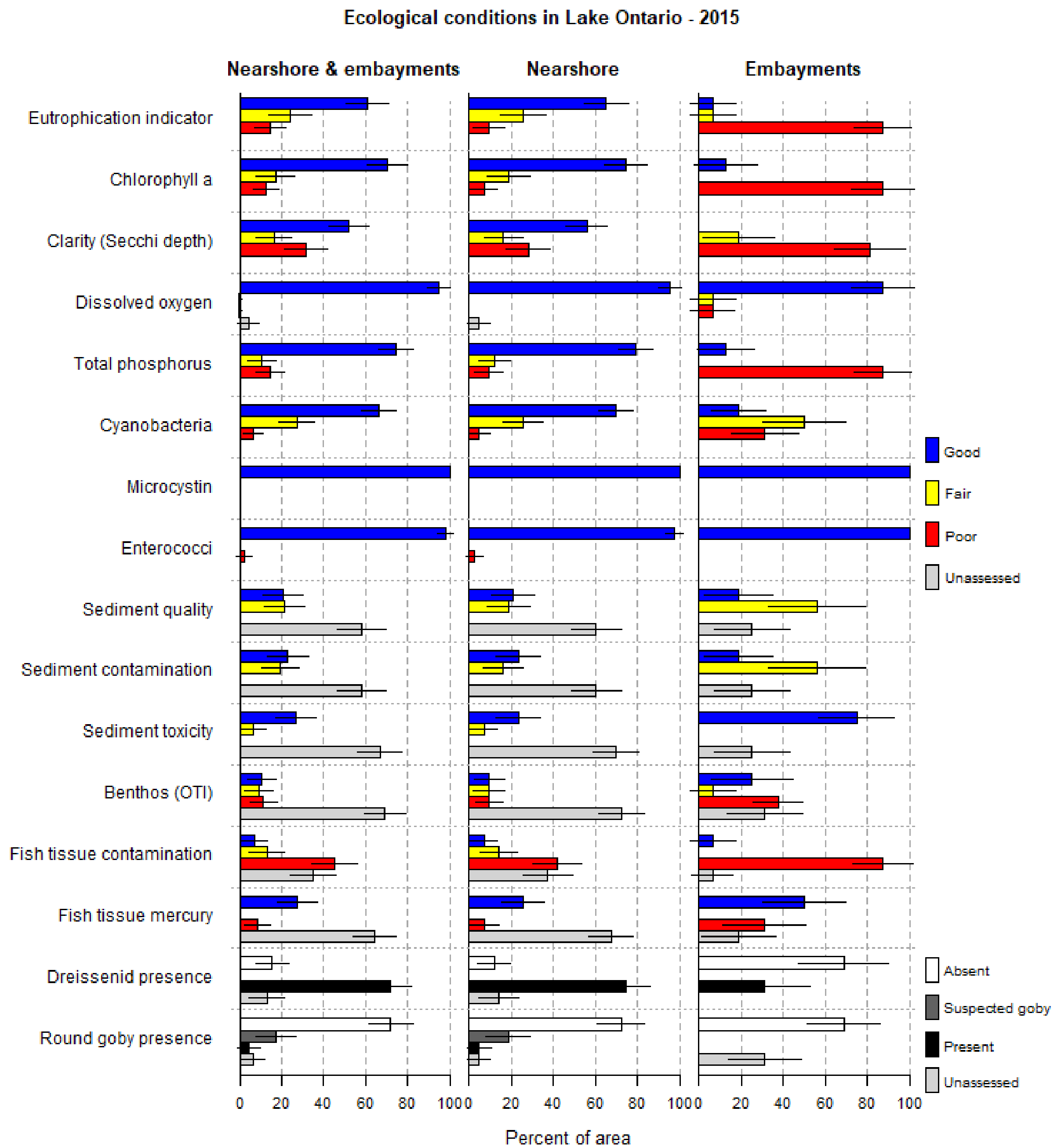

Figure 13. Ecological conditions of Lake Ontario based on the 2015 NCCA.

Sediment Quality

Sediment quality conditions were assessed as 21% good and 21% fair in the combined nearshore and embayment areas with the remaining 58% of area unassessed for sediment quality because of hard substrates (Fig. 13). The amount of area with good sediment quality condition was similar in the nearshore and embayments, which reflected similar amounts of area in each with good conditions for the sediment contamination component. However, the percent of area in the nearshore that could not be assessed was more than double that of embayments. Condition based on sediment toxicity was assessed as good in 75% of the area of the embayments compared to only 23% of the nearshore, much of which was unassessed.

Benthic Index

Sixty-nine percent of the Lake Ontario combined nearshore and embayment area could not be assessed with the OTI. Of the assessed area, 10% was in good condition, 9% was fair, and 12% was poor (Fig. 13). Fifty-nine percent of the area was unassessed because PONAR samples could not be collected and 10% was unassessed because the OTI could not be calculated. Of the nearshore area that could be assessed using the OTI, 9% was in good condition, 9% was fair, and 9% was poor. For the embayments, 25% of area was in good condition, 6% was fair, and 38% was poor.

Ecological Fish Tissue Contamination

Based on fish tissue contaminants, 7% of the combined nearshore and embayment area of Lake Ontario was in good condition, 13% was fair, 35% was poor, and the remaining 45% of area could not be assessed due to lack of fish caught (Fig. 13). Conditions in the nearshore area were similar to the combined nearshore and embayment area while conditions in the embayments alone were in poor condition in more than 80% of the area.

Fish Tissue Mercury

Fish tissue mercury conditions in Lake Ontario embayments were assessed as good in 50% of the area and poor in 31% of the area. Conditions were assessed as good and poor in 26% and 7%, respectively, of the area of the nearshore (Fig. 13). The remaining area in each could not be assessed due to lack of fishing success.

Invasive Species

Dreissenid mussels were estimated to be present in 71% of Lake Ontario’s combined nearshore and embayment area, with 13% of the area not assessed because a PONAR sample could not be collected or due to poor video quality. Dreissenid mussels were detected in 19% of Ontario’s combined nearshore and embayment area using both PONAR and video. They were observed in an additional 6% of area based on PONAR samples. Mussels were detected from videos for an additional 46% of area where they were not collected in PONAR samples. Videos were especially helpful in Lake Ontario because much of the bottom was hard and PONAR sampling was often not successful. Dreissenid mussels were more common in the nearshore, where they were estimated to be present in 74% of area, compared to 31% of embayment area.

Round gobies were estimated to be present in 4% of the Lake Ontario combined nearshore and embayment area, with an additional 17% of area with possible round gobies. Six percent of the area could not be assessed for round goby because of poor video quality. Round gobies were observed only in the nearshore.

The St. Marys River

In 2015, 50 sites were sampled; and in 2016, 44 sites were sampled in the St. Marys River. The two years of data (94 sites) were pooled to assess the 470 km^2 of the St. Marys River (Fig. 14).

Water Quality

Conditions in the St. Marys River (Fig. 15) were mostly assessed as good based on chlorophyll *a* and dissolved oxygen (61% and 93% good, respectively), mostly fair based on total phosphorus (55% of area in fair condition), and mostly poor based on water clarity (90% poor). Based on the eutrophication indicator, 58% of the system was assessed as fair, 37% was poor, and only 5% was good. St. Marys River was assessed with Lake Huron water quality thresholds, which are protective of Lake Huron's oligotrophic status (see Wick et al., 2019, for a discussion of threshold selection).

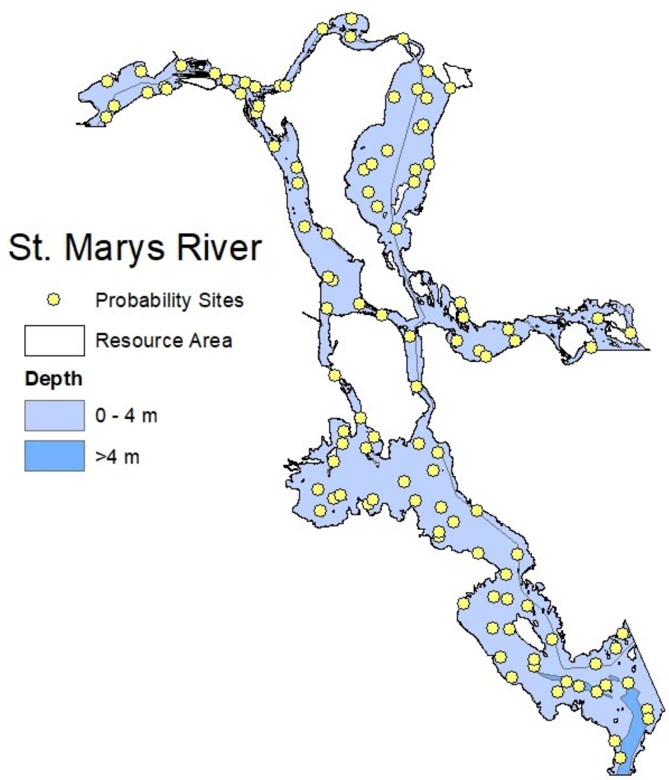

Figure 14. St. Marys River sample locations for the 2015-2016 NCCA.

Cyanobacteria and Microcystin

Based on cyanobacteria concentration, 60% of the area in the St. Marys River was in good condition and 40% of the river was in fair condition. No microcystins were detected in any St. Marys River water samples, so condition of 100% of the area in the St. Marys River was assessed as good for microcystins (Fig. 15).

Enterococci
No sites in the St. Marys River exceeded the recreational threshold of 1,280 CCE/100 mL for enterococci.

Sediment Quality
Sediment quality conditions were assessed as good in 57% of the area in the St. Marys River (Fig. 15). About 40% of the area was in fair condition and about 1% in poor condition. Conditions for sediment contamination and sediment toxicity were both mostly good (63% and 86%, respectively). Poor conditions for sediment contamination were detected at only one site in the St. Marys River, accounting for about 1% of the area.

Benthic Index
Based on the OTI, 51% of area of the St. Marys River was in good condition, 21% was fair, and 13% was in poor condition. The remaining 15% could not be assessed because no PONAR sample could be collected (2%) or the OTI could not be calculated (13%).

Ecological Fish Tissue Contamination
Fish were sampled for fish tissue contaminants at 40 sites in the St. Marys River in 2015 (primarily in US waters) and no sites were sampled in 2016. Enough fish of target species were caught at 35 sites. Condition estimates represent conditions in the sample areas, not the entire resource. Contaminant conditions were estimated to be good in 10%, fair in 30%, and poor in 48% of the sampled area with the remaining area unassessed. The same contaminants (selenium and mercury) that contributed to the mostly fair and poor fish tissue conditions in the Great Lakes contributed to the mostly fair and poor conditions in the St. Marys River.

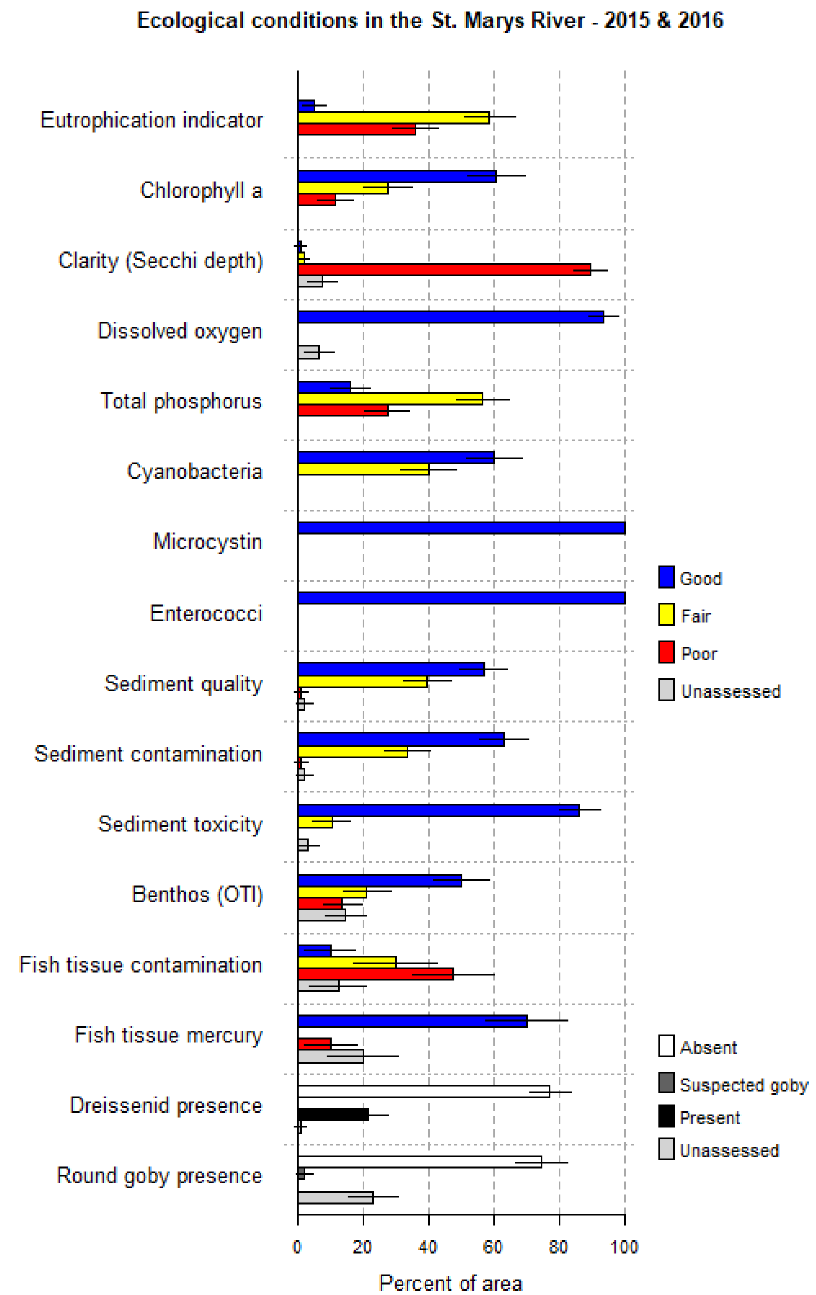

Figure 15. Ecological conditions of the St. Marys River based on the 2015-2016 NCCA.

Fish Tissue Mercury

Fish tissue mercury conditions were good in 70% of the sampled area in the St. Marys River, and poor in 10% of the sampled area. The remaining area was unassessed due to lack of fish caught.

Invasive Species

Dreissenid mussels were estimated to be present in 21% of the area of the St. Marys River. Dreissenids were detected in both PONAR samples and videos in 4% of the area. PONAR samples alone detected dreissenids in 5% of the area. Videos detected mussels in an additional 12% of area where they were not collected in PONAR samples.

Round gobies were suspected to be present in 2% of the St. Marys River. Twenty-three percent of the area was unassessed for round goby mostly because of poor video quality.

Huron-Erie Corridor (HEC)

Fifty-seven sites were sampled in 2014 and 48 sites were sampled in 2015 to assess the condition of the 1,287 km^2 of the HEC (Fig. 16). For the assessment, ninety-five first site visits were combined from the two years of sampling. In 2014, two of the sites were revisited in the same year. In 2015, seven different sites sampled in 2014 were revisited. Revisited sites were not used in the condition estimates. Subpopulation assessments of the St. Clair River, Lake St. Clair, and the Detroit River were based on 18, 48, and 29 sites, respectively.

Water Quality

Condition of most of the area of the HEC was assessed as good based on total phosphorus, chlorophyll *a*, and dissolved oxygen (81%, 86%, and 100%, respectively). Only 24% of HEC area was in good condition based on water clarity, with 21% fair and 54% in poor condition. Based on the eutrophication indicator, 45% of the area of the HEC was in good condition, 39% was fair, and 15% was poor. The HEC was assessed using water quality thresholds for the central/eastern basin of Lake Erie which are more protective of water quality than the thresholds for western Lake Erie (see Wick et al., 2019, for a discussion of threshold selection).

Water quality decreased down-river within the HEC, with more of the area of the Detroit River in poor condition than the St. Clair River or Lake St. Clair. For example, based on total phosphorus, 95% of the St. Clair River was area in good condition, 84% of Lake St. Clair was area in good condition, and 47% of the Detroit River was in good condition. Likewise, based on chlorophyll *a*, 100% of area in the St. Clair River, 86% of Lake St. Clair, and 76% of the Detroit River was in good condition. Lake St. Clair had the highest percentage area (27%) in good condition based on water clarity compared to the St. Clair River (10%) and the Detroit River (4%).

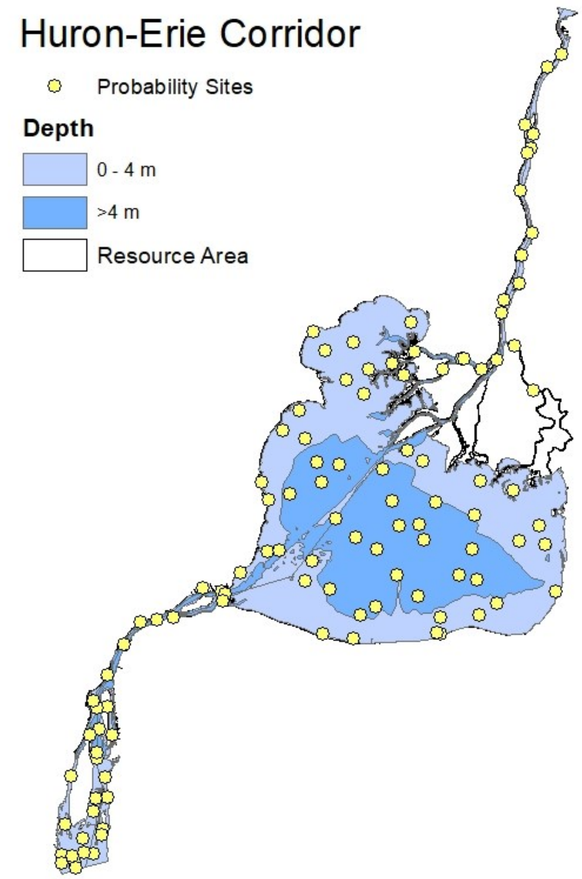

Figure 16. Huron-Erie Corridor sample locations for the 2014-2015 NCCA.

Cyanobacteria and Microcystin

Cyanobacteria conditions in the HEC were good in 28% of the area, fair in 60%, and poor in 11% of the area (Fig. 17). Condition based on cyanobacteria declined downriver from the St. Clair River (37% good) to Lake St. Clair (28% good) and the Detroit River (23% good).

Microcystin concentrations were below the threshold of 8 µg/L for low risk to recreational users at all sites in the HEC so 100% of the area was assessed as good. Microcystin was not detected in the St. Clair River. Microcystin was detected at 9 of 49 sites in Lake St. Clair with concentrations ranging from 0.12 - 1.66 µg/L. In the Detroit River, microcystin was detected at 8 of 31 sites, with concentrations ranging from of 0.16 - 0.99 µg/L.

Enterococci

Enterococci cell concentrations were below the threshold of 1,280 CCE/100mL for low risk to recreational users at all but one site in the Detroit River. Conditions based on enterococci were good in 100% of the St. Clair River and Lake St. Clair.

Sediment Quality

Sediment quality conditions were good and fair in 83% and 14% of the area, respectively (Fig. 17). Lake St. Clair had the highest percent of area in good condition (90%) followed by the St. Clair River (44%) and the Detroit River (30%). Poor sediment quality conditions were detected in 12% of the Detroit River area resulting from both sediment contamination and sediment toxicity. No poor sediment quality conditions were detected in the St. Clair River or Lake St. Clair.

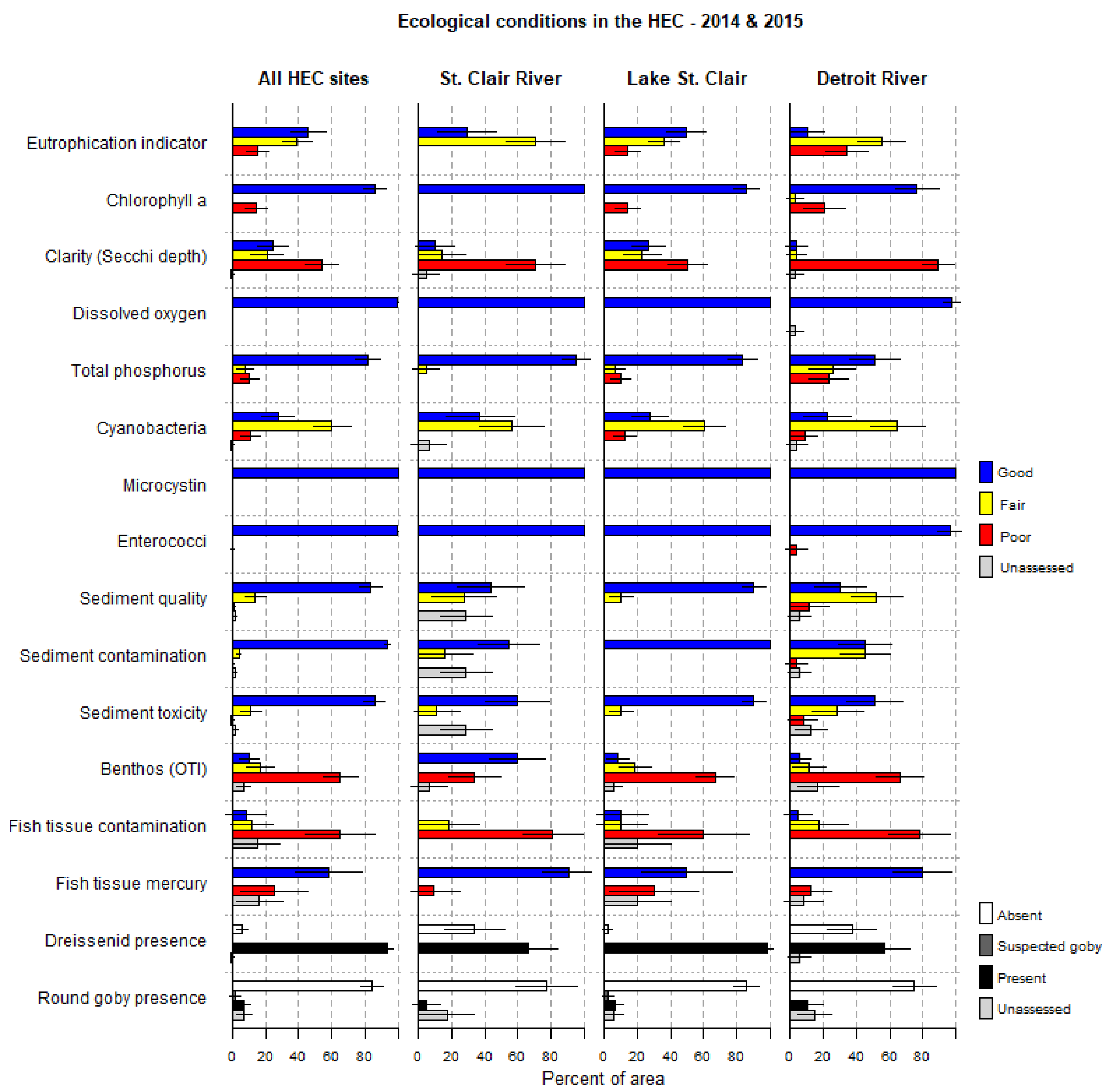

Figure 17. Ecological conditions of the HEC based on the 2014-2015 NCCA.

Benthic Index
Benthos conditions could not be assessed 6%of the St. Clair River, 6% of Lake St. Clair, and 16% of the Detroit River. In the Detroit River and Lake St. Clair, unassessed areas were more often the result of PONAR failures (hard bottom) than from sites where the OTI could not be calculated. In the St. Clair River, all the sites that could not be assessed were because the OTI could not be calculated.

Based on the OTI, conditions were good in 10% of the entire HEC area, in 60% of the St. Clair River, 8% of Lake St. Clair, and 6% of the Detroit River. In the St. Clair River, none of the area was in fair condition and 34% was in poor condition. Fair and poor conditions were present in 21% and 65% of Lake St. Clair, respectively, and in 6% and 72% of the Detroit River, respectively.

Ecological Fish Tissue Contamination
Fish tissue was sampled at 33 sites in the HEC in 2015; no sites were sampled in 2014. Most of the sampling occurred in US waters. Of the sampled sites, enough fish were collected at 31 sites. Conditions reported are for the area where sampling was attempted. Conditions based on fish tissue contaminants were good in 8%, fair in 12%, and poor in 65% of the HEC area with the remaining 15% of area not assessed due to lack of fish caught (Fig. 17).

Of the HEC subpopulations, fish tissue contaminant conditions were good in 10% of Lake St. Clair and 5% of the Detroit River; no good conditions were found in the St. Clair River. Conditions were fair in 19%, 10%, and 17% of the sampled area in the St. Clair River, Lake St. Clair, and Detroit River, respectively (Fig. 17). The remaining areas in the St. Clair River and Detroit River were in poor condition. In Lake St. Clair, 20% of area could not be assessed and the remaining area was in poor condition. Sample sizes for waterbody-specific (i.e., subpopulation) condition estimates for fish tissue contaminants in the HEC were below the recommended sample size of 30 for reliable condition estimates.

Fish Tissue Mercury
Of the sampled HEC area, 58% was in good condition for fish tissue mercury, 25% was in poor condition, and 17% could not be assessed. Conditions were good in 91% of the area in the St. Clair River and 80% of the Detroit River, but only 50% of Lake St. Clair was in good condition (Fig. 17).

Invasive Species
Dreissenid mussels were estimated to be present in 93% of the HEC, with less than a percent of area unassessed. Dreissenids were detected using both PONAR and video in 28% of the area of the HEC. Mussels were collected in PONAR samples in an additional 60% of the area, and in videos alone in an additional 5% of the area. Dreissenid mussels were estimated to be present in 98% of Lake St. Clair. Round gobies were estimated to be present in 7% of the HEC and were suspected in an additional 2% of area. Seven percent of the area was unassessed for round gobies due to videos not being collected or being poor video quality.

The Niagara River

In 2018, 59 sites were sampled (29 sites in the upper river and 30 sites in the lower river) to assess 67.3 km^2 of the Niagara River (Fig. 18).

Water Quality

Conditions in the Niagara River (Fig. 19) were mostly good for total phosphorus, chlorophyll *a,* and DO (>99%, 97%, and 97% of area in good condition, respectively). Fifty-four percent of the area was in good condition for clarity while 19% of the area was unassessed for clarity due to swift currents which prevented accurate Secchi depth or PAR readings. Based on the eutrophication indicator, 84% of the system was in good condition, 16% was in fair condition, and none of the area was in poor condition. The Niagara River was assessed with Lake Ontario water quality thresholds, which are protective of Lake Ontario's oligo-mesotrophic status.

Water quality was similar in the upper and lower Niagara Rivers. Total phosphorus, chlorophyll *a*, and DO were nearly all in good condition in both the upper and lower river. Based on water clarity, 55% of area was in good condition in the upper river, and 47% of area was in good condition in the lower river. However, the upper river had a larger area with poor (17%) and unassessed (21%) conditions for water clarity than the lower river (7% and 3%, respectively). Based on the eutrophication indicator, 83% of the upper river area was in good condition and 93% of the lower river was in good condition.

Cyanobacteria and Microcystin

Cyanobacteria conditions in the Niagara River were assessed as good in 87% of the area and fair in 13% of the area, with no area in poor condition (Fig. 19). Conditions were slightly better in the lower river, where 97% of area was in good condition, than in the upper river where 86% of area was in good condition.

Microcystin concentrations were below the threshold of 8 µg/L for low risk to recreational users at all sites in the Niagara River, however about 15% of the area of the Upper and Lower River were unassessed due to missing samples (Fig. 19). All microcystin concentrations at sampled locations were below method detection limits and it is likely that microcystin conditions were good throughout the river (including the unassessed sites).

Enterococci

Enterococci cell concentrations were below the threshold of 1,280 CCE/100mL for low risk to recreational users at all sites in the Niagara River (Fig. 19).

Sediment Quality

Sediment quality conditions in the Niagara River were 11% good, 14% fair, and 7% poor, with 68% of area unassessed. The large unassessed area was due to the prevalence of rocky substrates where sediment samples could not be collected. Rock substrates were less common in the lower Niagara River, leading to more assessed area there (Fig. 19). The lower Niagara also had larger percents of area with good sediment contaminant and sediment toxicity conditions than the upper Niagara River. As a result, the lower Niagara River had a higher proportion of area with good and fair sediment quality conditions (40% and 20%, respectively) and had less unassessed area (33%) than the Upper River, which had 7% of area with good conditions, 14% of area with fair conditions, and 72% of area unassessed. Both the upper and lower river had about 7% of the area assessed as poor for sediment quality.

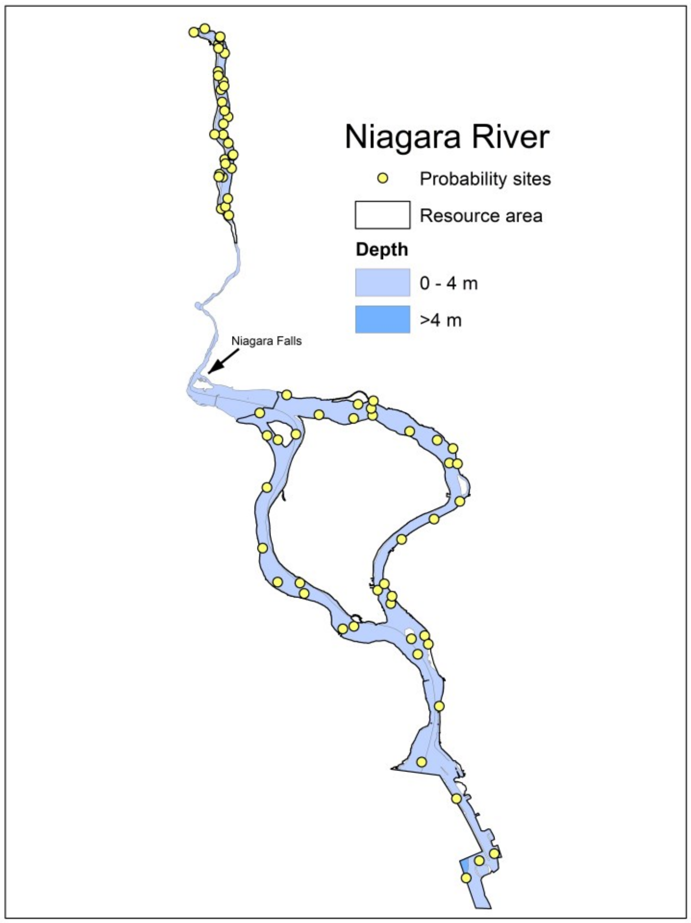

Figure 18. Niagara River sample locations during 2018. The section directly above and below Niagara Falls could not be sampled due to fast currents and rapids.

Benthic Index

Benthic conditions in the Niagara River were assessed as good in 21% of the area, fair in 5%, and poor in 23%; the remaining 51% could not be assessed due to hard bottom or a lack of tolerance-classified oligochaetes (Fig. 19). Benthic conditions were similar in the Upper Niagara River because it accounts for more than half of the assessed area in the whole river. However, more of the Lower Niagara River was assessed as fair (17%) or poor (40%), and less was unassessed (23%) than the upper River (3%, 21%, and 54%, respectively).

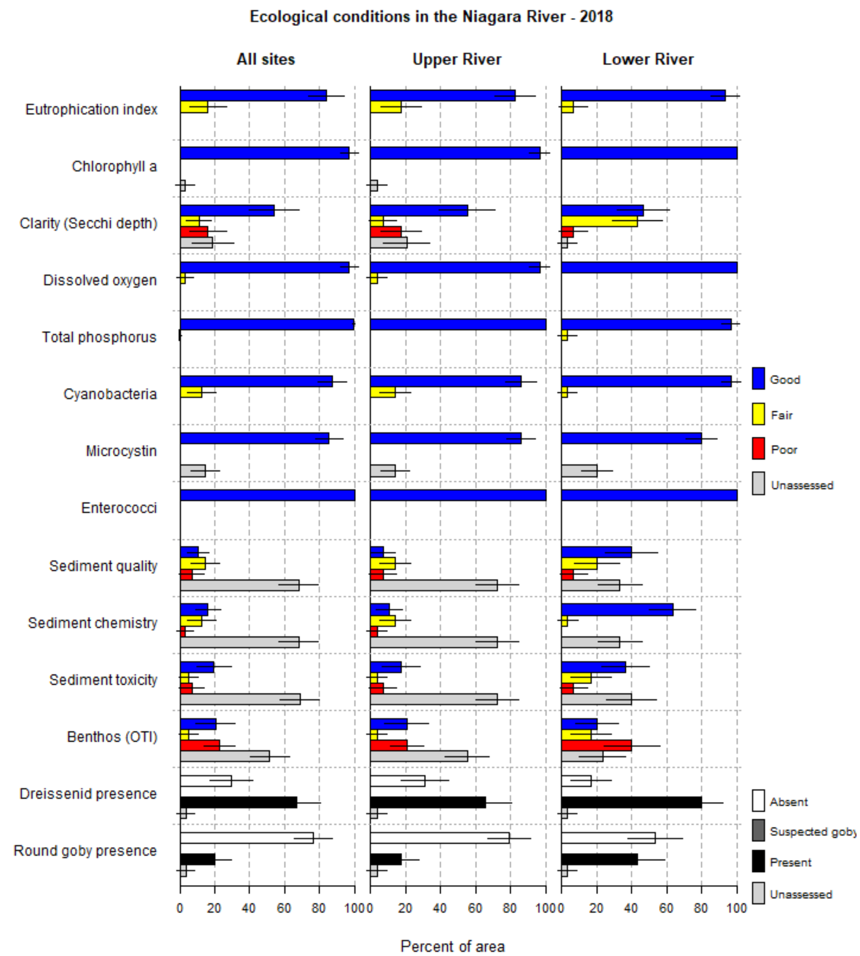

Figure 19. Ecological conditions of Niagara River, 2018.

Invasive Species

Based on PONAR samples and video combined, mussels were present in 67% of the total river area. Dreissenid mussels were present in 80% of the lower river and 66% of the upper river area. Based on PONAR alone, mussels were estimated to be present in 35% of the area, and based on video alone, the estimate was 50% of area. This demonstrates the importance of using both methods together for the best estimate of mussel presence. Due to fast currents, 3% of the area was unassessed for dreissenid mussels because neither video nor PONAR could be collected (percent PONAR failure was much higher than video due to current and hard substrate, Fig. 19).

Round gobies were estimated to be present in 20% of the Niagara River area based on underwater video. Videography was often difficult because of the swift currents. Seventy-four percent of videos had less than 50 seconds at the bottom. Round gobies were present in 43% of area in the lower river, and 17% of the upper river. Three percent of the area was unassessed for round gobies because video could not be collected due to currents.

Temporal and Spatial Comparisons Among Great Lakes

Comparisons Between 2010 and 2015 Findings

The weighted means of measured continuous variables used for assessing the ecological condition in 2010 and 2015 were compared using Z-tests (α=0.05). With only two surveys completed so far, trend analysis is not reliable, and it is unknown if differences observed between 2010 and 2015 are due to normal interannual variability, a temporal trend, or some combination of the two.

In Lake Superior, average concentrations of total phosphorus, total nitrogen, and cyanobacteria cell counts were significantly higher in 2015 than in 2010 (Fig. 18a, b). In Lake Huron, total phosphorus, chlorophyll *a*, cyanobacteria, and PAH PECQ (for sediment) were all significantly higher in 2015 than in 2010 (Fig. 18a, b). Bottom dissolved oxygen concentration was lower and Secchi depth was shallower in Lake Huron in 2015 than in 2010. In Lake Erie, total phosphorus, total nitrogen, bottom dissolved oxygen, cyanobacteria, and PAH PECQ were all significantly higher in 2015 than in 2010 while sediment toxicity was significantly lower in 2015 (Fig. 18a-c). None of the variables differed between 2015 and 2010 in Lake Michigan, except for weighted mean site depth due to random variation in site locations (Fig. 18d). In Lake Ontario, total nitrogen, cyanobacteria, and OTI were all significantly higher in 2015 than in 2010, and sediment toxicity was significantly lower in 2015 than in 2010 (Fig. 18a, b, d).

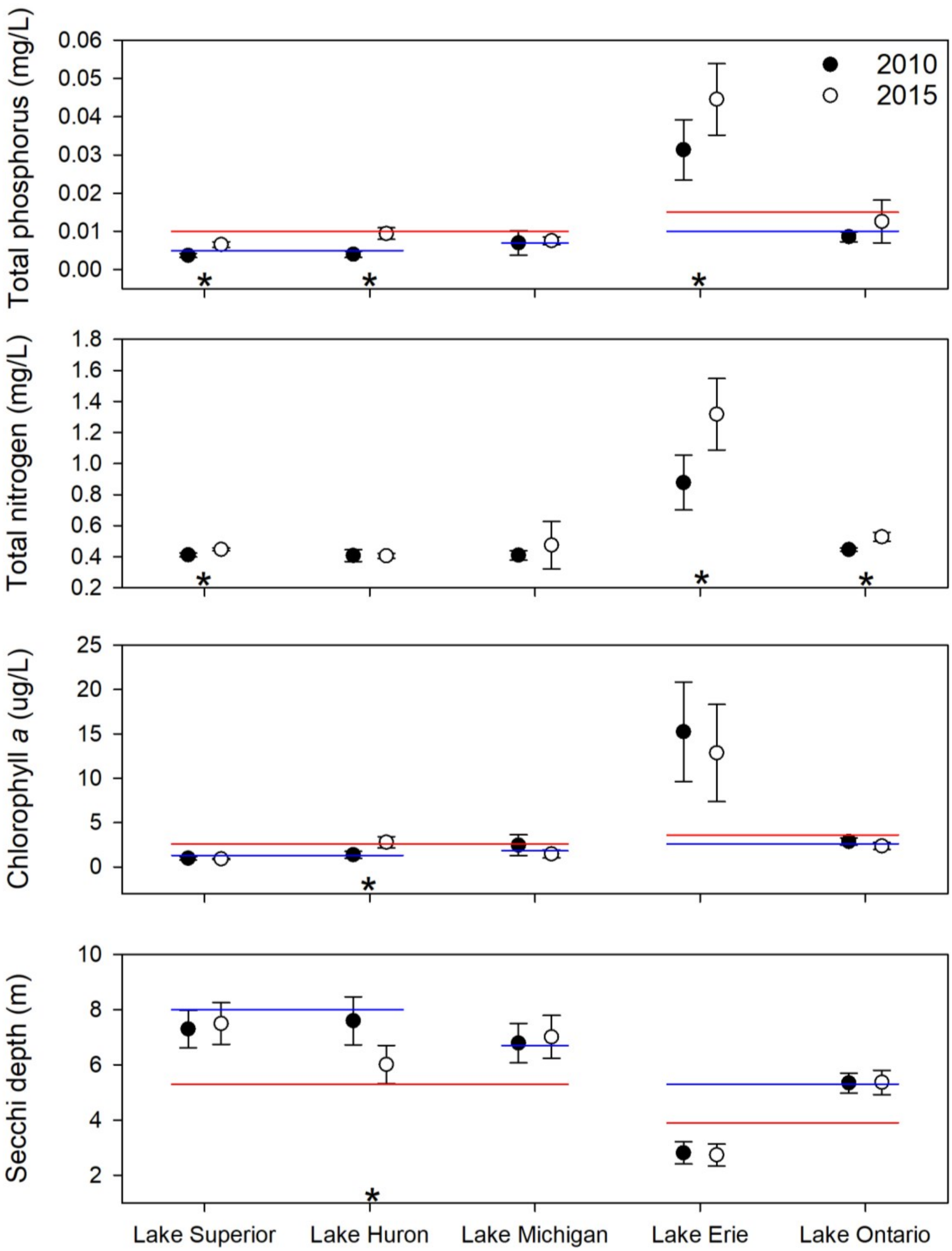

Figure 18a. Comparison of conditions among lakes and between 2010 to 2015. Plots show weighted mean concentrations of continuous assessment variables for 2010 and 2015 surveys and ±95% confidence intervals. Stars indicate where there was a significant difference between 2010 and 2015 based on a *Z*-test (α=0.05). For reference, NCCA thresholds are shown with blue (good/fair) and red (fair/poor) lines. For water quality, thresholds are lake specific. There is no applicable Great Lakes threshold for total nitrogen.

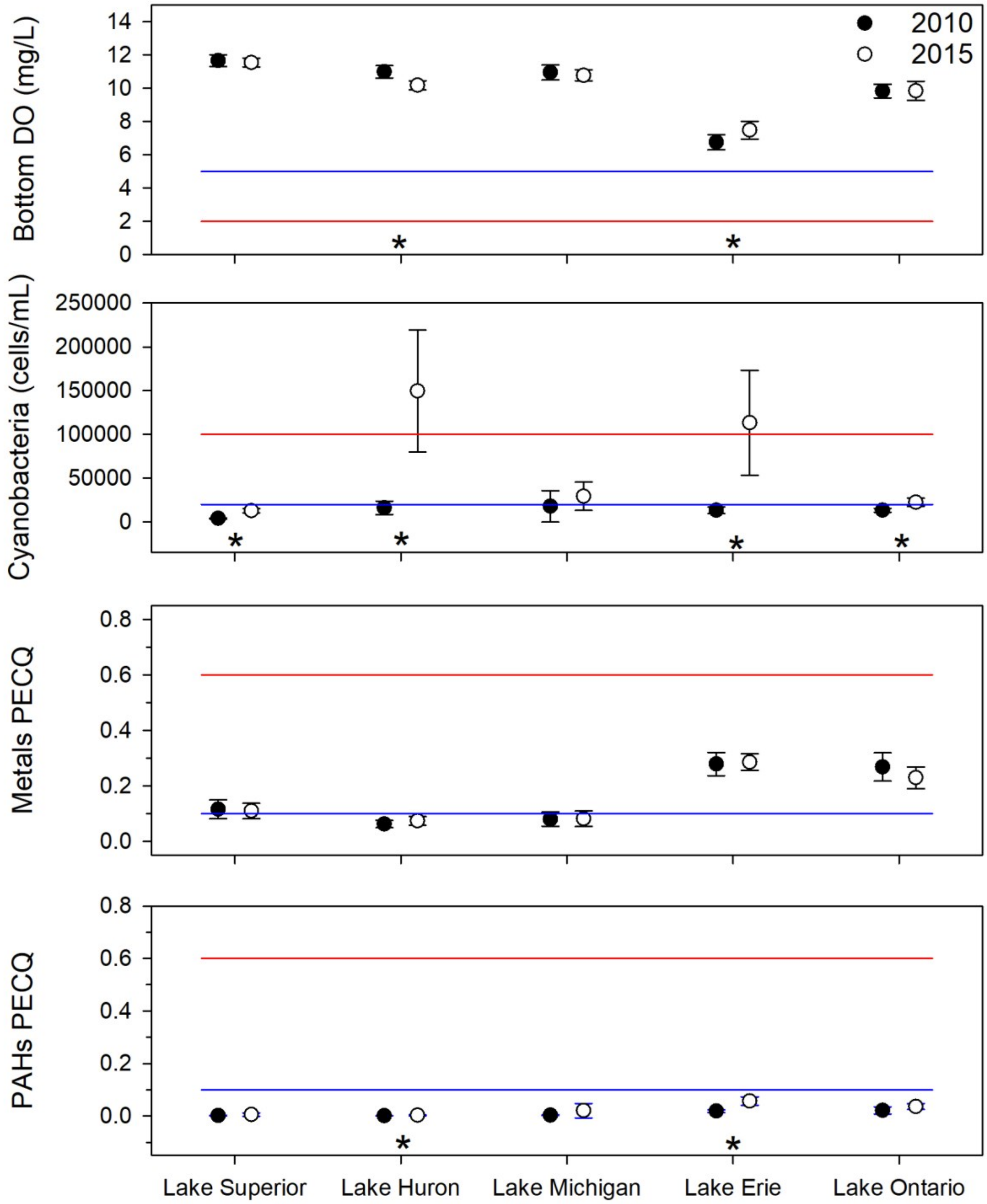

Figure 18b. Comparison of conditions among lakes and between 2010 to 2015. Plots show weighted mean concentrations of continuous assessment variables for 2010 and 2015 surveys and ±95% confidence intervals. Stars indicate where there was a significant difference between 2010 and 2015 based on a *Z*-test (α=0.05). For reference, NCCA thresholds are shown with blue (good/fair) and red (fair/poor) lines. For water quality, thresholds are lake specific.

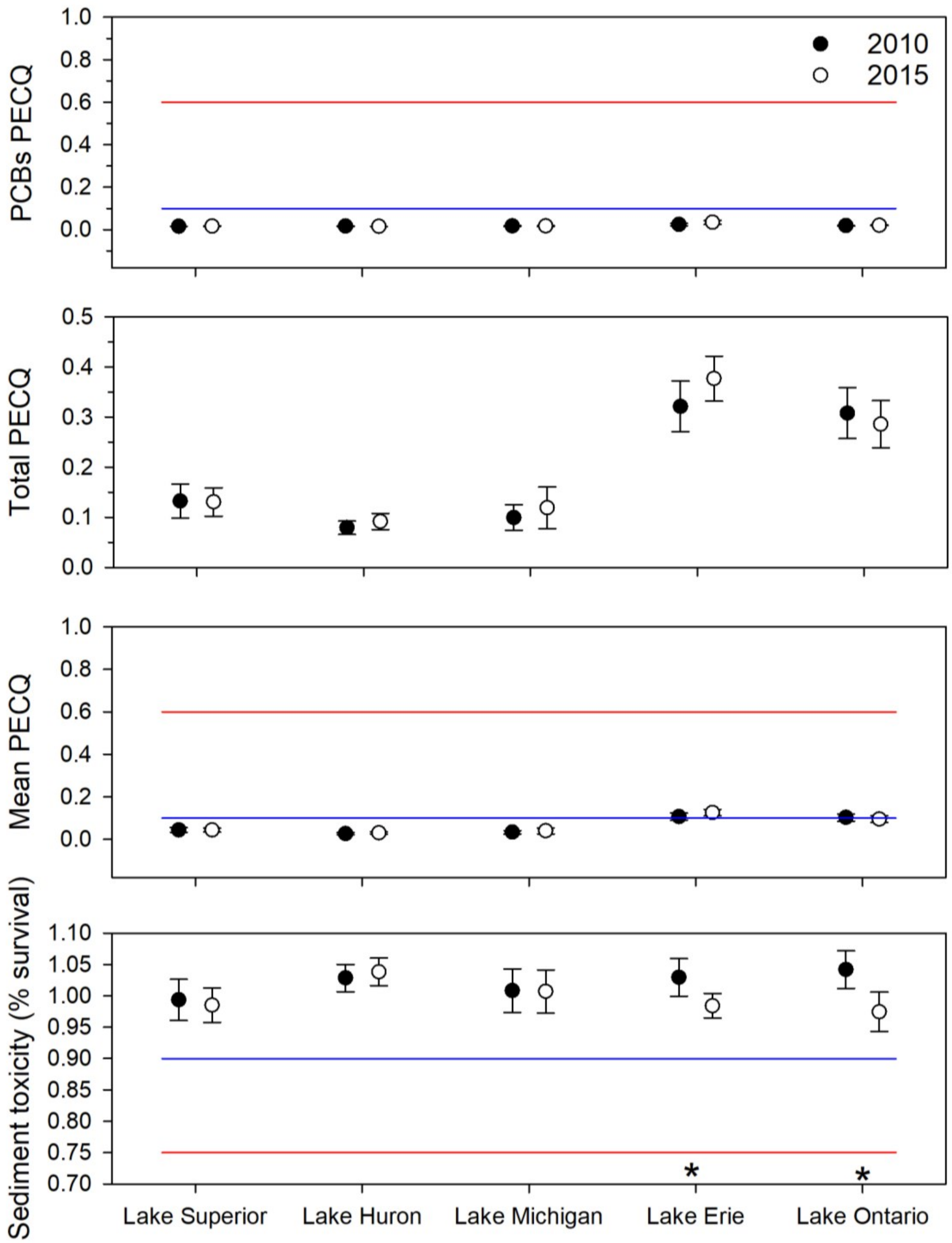

Figure 18c. Comparison of conditions among lakes and between 2010 to 2015. Plots show weighted mean concentrations of continuous assessment variables for 2010 and 2015 surveys and ±95% confidence intervals. Stars indicate where there was a significant difference between 2010 and 2015 based on a *Z*-test (α=0.05). For reference, NCCA thresholds are shown with blue (good/fair) and red (fair/poor) lines. For water quality, thresholds are lake specific.

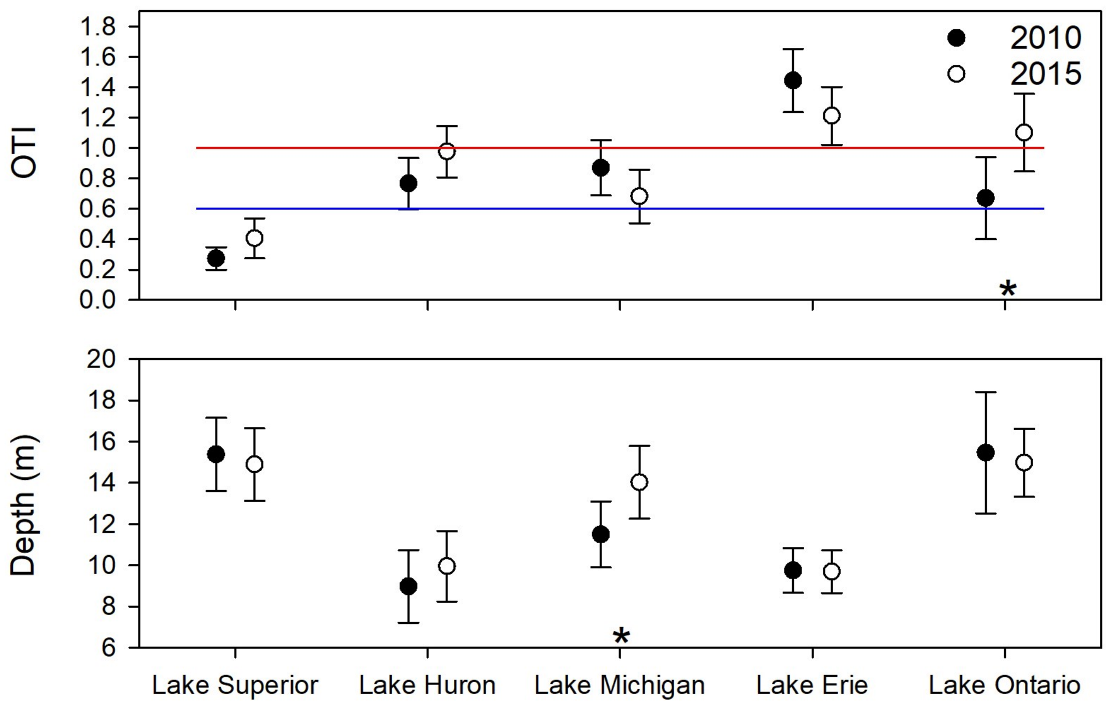

Figure 18d. Comparison of conditions among lakes and between 2010 to 2015. Plots show weighted mean concentrations of continuous assessment variables for 2010 and 2015 surveys and ±95% confidence intervals. Stars indicate where there was a significant difference between 2010 and 2015 based on a *Z*-test (α=0.05). For reference, NCCA thresholds are shown with blue (good/fair) and red (fair/poor) lines. For water quality, thresholds are lake specific.

To compare invasive species presence between 2010 and 2015, condition estimates (i.e., percent area with the species present) were compared. However, differences in the percent of area unassessed in the two survey years makes it challenging to directly compare invasive species results. In 2010, more of the Great Lakes nearshore and embayment area was unassessed for round gobies and dreissenid mussels than in 2015 due to poor video quality. For round goby in the combined nearshore and embayments, 54% of area was unassessed in 2010, and 19% was unassessed in 2015. In both years, Lake Erie had the highest percentage of area unassessed for round gobies (73% in 2010 and 54% in 2015). For dreissenids, 16% of the Great Lakes nearshore and embayment area was unassessed in 2010 and 8% was unassessed in 2015. In both years, Lake Erie had the highest percentage of area unassessed for mussels, 14% in 2015 and 28% in 2010.

To compare the presence of invasive species between 2010 and 2015, estimates were also normalized to the area assessed in each year. In the Great Lakes, round gobies were observed in a smaller portion of the assessed area of the combined nearshore and embayments in 2015 (6%) than in 2010 (18%). Lake Huron, Lake Erie, and Lake Ontario all had a greater percent assessed area with round goby in 2010 (35%, 7%, and 37%, respectively) than in 2015 (5%, 0%, and 5%, respectively). Lake Michigan had similar percent area with round goby in 2010 (12%) and 2015 (8%). Lake Superior had no assessed area with confident round goby detections in 2010 or 2015. In the entire Great Lakes combined nearshore and embayments, similar percentages of the assessed area had mussels in 2010 (57%) and 2015 (60%).

Comparisons Among Great Lakes in 2015

The weighted means of measured continuous variables used to assess ecological condition were compared among lakes using *Z*-tests (α=0.05). Comparisons of continuous data gives a spatial perspective on difference in indicator values among lakes. Because condition thresholds for water quality parameters vary among lakes, comparisons among lakes were not attempted.
The comparison of weighted means for continuous parameters showed that nutrient concentrations (i.e., total phosphorus and total nitrogen) were significantly higher in Lake Erie than in the other four lakes (Table 3). Average chlorophyll *a* concentration was significantly higher in Lake Erie than in any other lake. Dissolved oxygen and Secchi depth were significantly lower in Lake Erie than in any other lake. Some of the other lakes also differed from one another based on these water quality parameters, but the magnitude of the differences between the other lakes was not as great as the magnitude of the difference between Lake Erie and other Great Lakes (Fig. 18).

The parameters associated with the sediment PECQs show that Lake Erie had more contaminated sediments than other lakes (Table 3). The weighted averages for PECQs of metals, PAHs, and PCBs in Lake Erie sediments were all higher than the other lakes (Fig. 18b-c, Table 3). As a result, mean and total PECQs were also higher in Lake Erie than in the other lakes (Fig. 18c, Table 3).

Among-lake variation for most of the other ecological parameters was more complicated than for water and sediment quality parameters. For example, Lakes Erie and Huron both had much greater average cyanobacteria cell concentrations than the other lakes. But, in many other cases, sediment toxicity (% survival of test organisms), average OTI values, fish tissue mercury concentration, and microcystin concentrations were not significantly different between Lake Erie and the other lakes (Table 3). All the parameters that were significantly different between Lake Superior and Lake Erie also significantly differed between Lake Superior and Lake Ontario. But, most of the differences between parameters in Lakes Superior and Ontario were smaller than the differences between Lakes Superior and Erie.

Among lakes, Lake Erie was the most unlike the other lakes with 50 significant differences in lake-to-lake comparisons of parameters (from Table 3), followed by Lake Superior (47 differences). Lake Huron was least unlike the other lakes with 39 significant differences in lake-to-lake comparisons followed by Lake Michigan with 42 differences.

Table 3. Results from *Z*-tests for lake-to-lake comparisons of continuous variables for the combined nearshore and embayments in 2015. Upward arrows indicate that the lake listed before the "/" has a significantly larger ($p < 0.05$) area-weighted average for the given parameter and downward arrows indicate that lake had significantly smaller averages for the parameter. Cells without arrows indicate that the parameter did not differ significantly between lakes.

Indicator	LE/ LH	LE/ LM	LE/ LO	LE/ LS	LH/ LM	LH/ LO	LH/ LS	LM/ LO	LM/ LS	LO/ LS
Total phosphorus	↑	↑	↑	↑	↑		↑			↑
Total nitrogen	↑	↑	↑	↑		↓	↓			↑
Clarity (Secchi depth)	↓	↓	↓	↓			↓	↑		↓
Dissolved oxygen	↓	↓	↓	↓	↓		↓	↑	↓	↓
Chlorophyll *a*	↑	↑	↑	↑	↑		↑	↓	↑	↑
Metals PECQ	↑	↑	↑	↑		↓	↓	↓		↑
PAHs PECQ	↑	↑	↑	↑		↓				↑
PCBs PECQ	↑	↑	↑	↑		↓		↓		↑
Total PECQ	↑	↑	↑	↑		↓	↓	↓		↑
Mean PECQ	↑	↑	↑	↑		↓	↓	↓		↑
Sediment toxicity (% survival)	↓					↑	↑			
Cyanobacteria cell concentration		↑	↑	↑	↑	↑	↑		↑	↑
Enterococci cell concentration										
Microcystin concentration		↑		↑	↑		↑	↓	↑	↑
OTI value		↑		↑	↑		↑	↓	↑	↑
Fish tissue mercury concentration			↓	↑		↓	↑	↓	↑	↑

Comparisons Between the Nearshore and Embayments in 2015

The Great Lakes embayment enhancement was included in both 2010 and 2015 assessments. Based on the 2010 assessment, total phosphorus, dissolved oxygen, Secchi depth, and site depth differed significantly between sites in embayments and at non-embayment nearshore sites (Kelly et al., 2015). In general, nearshore water quality (e.g., temperature, specific conductivity, total phosphorus, and chlorophyll *a*) became more oligotrophic with increased depth, and total phosphorus concentrations were positively correlated with an indicator of watershed agriculture land-use. Assessments of nearshore conditions (percent of area in good, fair, or poor condition) inclusive of embayments differed from nearshore conditions in the original base design (excluding embayments) by less than 2% (Kelly et al., 2015). These results showed that that although some parameters differed between embayment and non-embayment nearshore, the influence of embayments on overall nearshore conditions at the Lake scale was small.

For 2015, differences in weighted mean indicator values were compared between embayments and the nearshore using *Z*-tests (α=0.05). For each indicator, the estimated percent area in good condition and amount of overlap in 95% confidence intervals were compared between the combined nearshore and embayments design (using all 361 sites) and the original base design (225 sites). The combined nearshore and embayments design completely overlaps with the base nearshore design and these comparisons were intended to determine how condition estimates change when the embayments enhancement sites are added to the base design, which only has seven sites in embayments. *Z*-tests were not used for these comparisons because this test assumes that the resources do not overlap (Kelly et al., 2015).

The differences in mean water quality parameters between the embayments and nearshore in 2015 for all the lakes combined were mostly consistent with results from 2010 reported by Kelly et al. (2015, Table 4). For all lakes combined, neither chlorophyll *a* nor total nitrogen differed between the embayments and the rest of the nearshore in 2015. Secchi depth and site depth were significantly shallower in embayments than the rest of the nearshore in both years (Table 4; Kelly et al., 2015). However, dissolved oxygen was not significantly lower in embayments than the rest of the nearshore in 2015, unlike in 2010. Total phosphorus concentrations were significantly higher in embayments than in the rest of the nearshore in most lakes (Table 4). Water and sediment quality parameters in Lake Superior suggested that embayments were less oligotrophic (e.g., lower bottom dissolved oxygen and higher total phosphorus, chlorophyll *a*, and cyanobacteria cells concentration) than the rest of the nearshore. Lake Erie had fewer significant differences between embayments and the rest of the nearshore than the other Great Lakes.

Among the Great Lakes, the percent nearshore area in good condition estimated from the base design or the combined nearshore and embayments design were similar (i.e., confidence intervals substantially overlapping) for all the indicators. This is unsurprising because the inclusion of results from a small area of the nearshore (embayments comprise about 5%), no matter how different, would not be expected to have much influence on overall condition estimates. These findings show that although the embayment enhancement revealed differences in conditions between embayments and the rest of the nearshore, it did not strongly or consistently influence the estimates of overall nearshore condition.

Table 4. Results from *Z*-tests comparing weighted means of continuous assessment variables in embayments and the rest of the nearshore in 2015. If means for embayment sites were significantly higher or lower than means for the rest of the nearshore based on two-tailed *Z*-test (α=0.05), it is denoted with an up arrow or down arrow, respectively. If no arrow is present, the difference was not significant at α=0.05.

Indicator	Great Lakes all	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario
Clarity (Secchi depth)	↓	↓	↓	↓		↓
Site depth	↓	↓	↓	↓	↓	↓
Dissolved oxygen		↓	↓			↓
Total nitrogen		↑			↑	
Total phosphorus	↑	↑	↑			↑
Chlorophyll *a*		↑				↑
Cyanobacteria cell concentration		↑				↑
Enterococci cell concentration						
Microcystin concentration				↓		
Mean metals PECQ		↑				
Total PAHs PECQ	↑			↑		↑
Total PCBs PECQ						↑
Mean PECQ	↑	↑				↑
Sediment toxicity (% survival)						
OTI value		↑				

Comparisons between Great Lakes and connecting river systems

Graphical comparisons of condition (e.g., the percent of the area in good or poor condition) between lakes and connecting river systems are possible for non-water-quality indicators from the bar plots for each lake or channel. For a comparison of water quality indicators between lakes and connecting river systems based on weighted mean values, see Wick et al. (2019).

Integrating the Great Lakes NCCA with Local Assessment Needs

The main objective of the NCCA is to assess system-wide conditions. However, both the site data and in some cases the resource assessments (e.g., connecting river systems) can address local needs. The NCCA probabilistic survey design can help managers understand the range of conditions for a given system for multiple indicators. Great Lakes Area of Concern (AOC, USEPA, 2019a) managers, for example, can compare hand-picked sites of interest to conditions in the larger system based on probabilistic surveys (e.g., Bellinger et al., 2016) to help define achievable remediation and restoration goals for removal of beneficial use impairments. Site-based findings can help identify areas that may need further study, or supplement existing studies. The following two case studies demonstrate how NCCA (or related connecting channel) data can supplement and provide context for local studies and projects. However, data collected during Great Lakes NCCA sampling are not intended as a replacement for AOC monitoring or assessment.

Detroit River sediment contamination

The Detroit River is the downriver-most waterbody in the Huron-Erie Corridor. This 51-km river connects Lake St. Clair to western Lake Erie. The river is bordered on the west by the Detroit, Michigan metro area, and to the east by Windsor, Ontario. The Detroit River is listed as a binational AOC under the Great Lakes Water Quality Agreement due to contaminants discharged to the river by industry, bacteria from municipal discharges, combined sewer overflows, habitat loss, and nonpoint source pollution (Esman, 2008).

USEPA, in partnership with state and local stakeholders, have done extensive sampling of targeted sites to identify areas needing remediation of sediments contaminated with high levels of PCBs, PAHs, and metals. Figure 19 shows sites sampled for sediment contamination for AOC assessment (USEPA, 2014a, 2014b, 2015a, 2016b, 2016c). The sites shown include available AOC assessment data sampled in 2013-2016 excluding one major remediation area, the north Trenton Channel. Sites sampled were along the Detroit shoreline in water <3 m deep at locations of historical contaminant sources. The total area characterized by the points shown was about 11 km^2. Based on these data, the area identified by AOC managers for remediation was about 3.5 km^2.

The sampling and analysis methods for sediment characterization in the AOC were different from NCCA methods used to sample sediment in the Huron-Erie corridor in 2014-2015. The AOC samples were full sediment cores. For comparing AOC results with NCCA data from PONAR surface samples, only the result from the top layer of the core was used. The AOC sites were analyzed for metals, PAHs, and PCB aroclors, and the connecting river system sites were analyzed for metals, PAHs, and PCB congeners. Congeners are individual PCBs, and aroclors are defined groups of PCB congeners that are commonly found together because of their use in industrial products. Because the sediment contamination indicator is calculated as total PCBs measured (aroclors or congeners) divided by a PEC, the resulting indicator is unitless and can be compared among data sets, with the caveat that the PCBs were measured differently. PECQs for the AOC sites were classified using the same thresholds as connecting river system sites (Fig. 19, Table 2).

At a site level, the range of conditions in these hotspots can be compared to conditions across the Detroit River. Sediment contamination conditions at connecting river system sites outside of the shallow area along the Detroit shoreline were generally classified as good or fair, whereas the sites along the Detroit shoreline were classified as fair or poor. Clearly these areas are degraded compared to the Detroit River generally.

Based on the 2014-2015 connecting river system assessment, 45% of the Detroit River was classified in good condition for sediment contamination, 45% was classified in fair condition, and only 4% was classified in poor condition (Fig. 17), despite the known contaminant issues along Detroit's waterfront. Six percent of the system was unassessed. Based on the targeted AOC sites, approximately 3.5 km^2 (including the north Trenton Channel) were identified as in poor enough condition to warrant remediation. This area represents 3.4% of the total area in the Detroit River system of 104 km^2, which is similar to the estimate of 4% poor conditions from the 2014-2015 NCCA assessment. The perception of the Detroit River is that contamination is widespread. However, as a percentage of the entire river area, it is quite localized. The probabilistic connecting river system survey indicated that the Detroit River system is in fair or good condition. However, areas that are contaminated were in (and represent a large proportion of) shallow shoreline areas that may be accessible to people. Supplementing a survey design with hand-picked sites at contaminated or reference sites can help ensure the entire range of conditions are identified and help cross-reference the probabilistic assessment with long-term or project-based datasets.

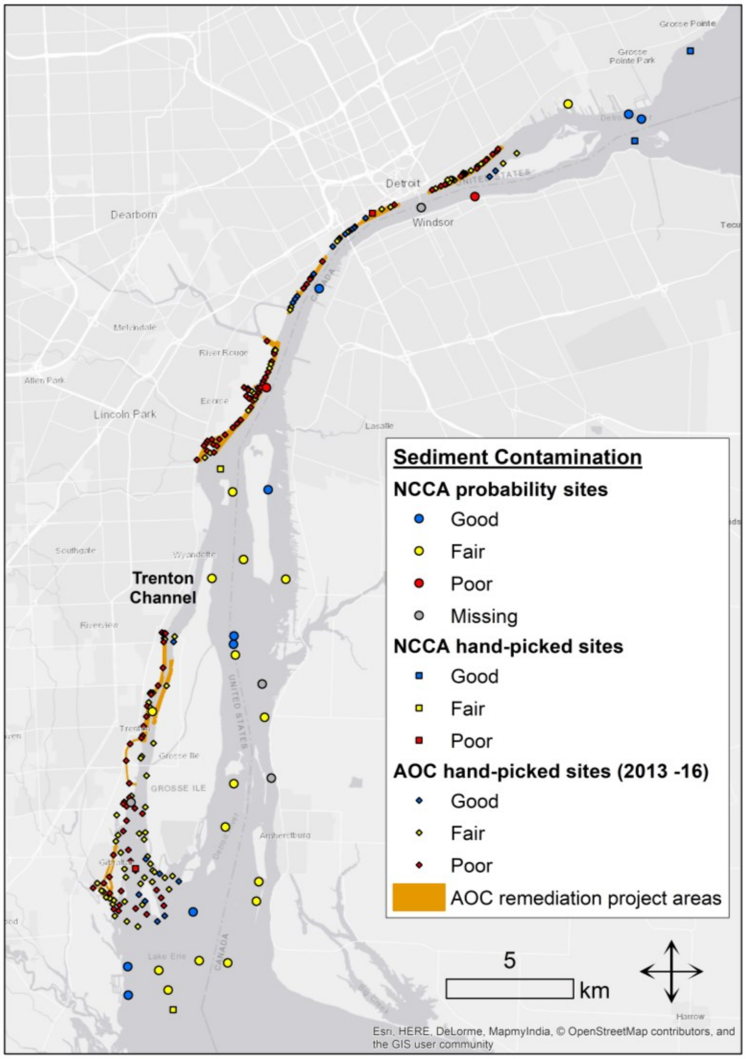

Figure 19. Sites sampled in the Detroit River in the connecting channel survey using NCCA methods and in targeted AOC sediment characterization sampling. In addition to the probability sites (totals shown in Table 1), 5 hand-picked sites were collected in the Detroit River (squares). These sites were selected because they are long-term monitoring sites, were previously restored or targeted for restoration, or have known impairments.

Lake St. Clair water quality

Harmful algal blooms (HABs) are a major concern across the Great Lakes (e.g., Carmichael and Boyer, 2016). HABs are caused when excess nutrients in the water and specific (but poorly understood) thermal and hydrodynamic conditions result in colonies of algae expanding quickly and producing toxins (e.g., Ho and Michalak, 2015; Paerl et al., 2011). HABS can be poisonous to wildlife, pets, and humans, affect drinking water supplies, contribute to hypoxic dead zones, and impact coastal economies. The NCCA or connecting river system surveys are not intended as a HABs monitoring program, but these data can be useful in identifying spatial and temporal patterns to help define where further monitoring or research is needed. Several indicators used in NCCA relate to HABs, including total phosphorus, chlorophyll *a*, Secchi depth, dissolved oxygen, cyanobacteria, and microcystins.

HABs are transient seasonal events, and sampling of connecting river systems was conducted during a short period (about a week) within an index period from May through September. Seasonal variation cannot be addressed in the NCCA GRTS designs; the index period is assumed to be representative for annual assessment purposes (Messer et al., 1991). However, in both 2014 and 2015, Lake St. Clair, which has frequent HABs (Davis et al., 2014), was sampled in September, which is a peak time for algal blooms. At a site level, results based on connecting river system sampling can be compared with nearly coincidental satellite imagery for the lake during sampling (Fig. 20). Across several indicators, including total phosphorus, chlorophyll *a*, cyanobacteria concentration, and microcystin concentration, poor conditions were detected along the south shore of Lake St. Clair. For microcystin, there were very few detections in the HEC, but all detections were in this region of Lake St. Clair. Blooms are visible in satellite photos along that shore, corroborating the physical sampling. Michigan Tech Research Institute's HAB model (publicly available at https://greatlakesremotesensing.org/, Shuchman et al., 2013) utilizes satellite imagery to map harmful algal blooms. Their model also mapped blooms along the south shore of Lake St. Clair during the time of sampling. NCCA site-scale data can be useful for understanding spatial variability within a system and can help provide the basis for further studies.

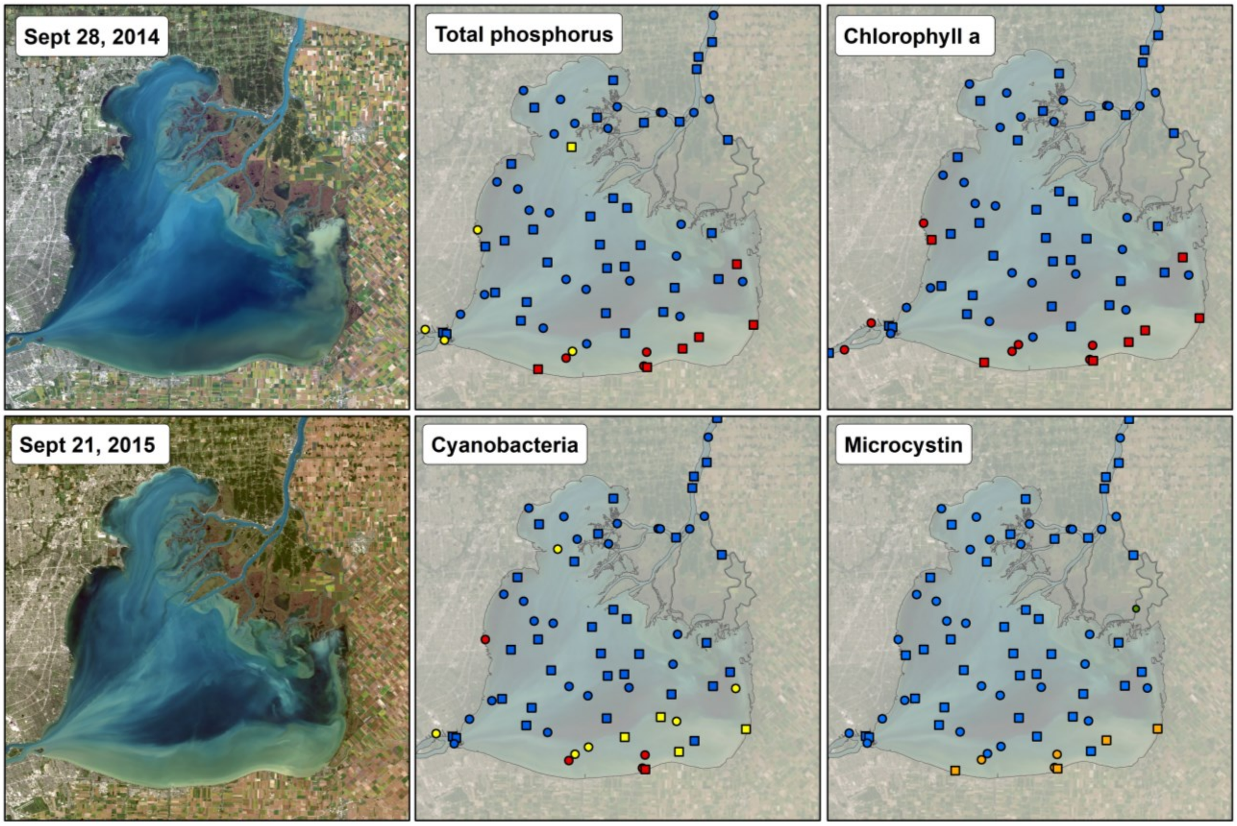

Figure 20. Satellite photos (https://earthexplorer.usgs.gov/) and maps of water quality indicators in Lake St. Clair. Sites in Lake St. Clair were sampled between 9/26 – 10/2/2014 and 9/23 –26/2015. Algal blooms are visible in satellite imagery from both 2014 and 2015, and are reflected in total phosphorus, chlorophyll *a*, cyanobacteria, and microcystin results. Squares indicate the site was sampled in 2014 and circles indicate the site was sampled in 2015. For total phosphorus, chlorophyll *a*, and cyanobacteria, blue indicates good conditions, yellow indicates fair condition, and red indicates poor condition. For microcystin, all sites were below the threshold of 8 µg/L (Table 2b). Sites shown in orange were above 1 µg/L, which is the WHO threshold for drinking water (WHO, 2003b; note that NCCA thresholds are based on EPA guidelines for recreational use, USEPA 2017a). Sites in blue for microcystin were below 1 µg/L. Three of the sites on the south shore of the lake were hand-picked based on anecdotal evidence of nutrient enrichment associated with the input of the Thames River.

Future Improvements of the Great Lakes NCCA

The probabilistic design and standardized methods of data collection make the NCCA a useful tool to assess the conditions of the Great Lakes nearshore waters and connecting river systems over time. Through the collection and analyses of the 2010 and 2015 NCCA data, some gaps and methodological shortcomings were identified. As these are addressed, future iterations of this assessment will be able to better detect changes in conditions through time.

Microcystins

More than 99% of the combined nearshore and embayment area in the Great Lakes was in good condition based on microcystin concentrations despite known issues with *Microcystis* blooms in portions of the Great Lakes. Microcystin concentrations are highly dependent on many poorly understood factors that change quickly in space and time. Additional research may reveal indicators more sensitive to the risks posed by microcystins. Because it is based on a short period of sampling, the current NCCA design and approach may not be ideal for assessing Great Lakes conditions based on microcystin. Additional research is also needed to assess conditions based on other types of algal toxins present in the Great Lakes.

Benthic Index

Because of missing benthic indicator information that resulted from the absence of tolerance-classified oligochaetes in samples and coarse substrate that prevent PONAR sampling, there has been an ongoing collaboration among GLTED, the Great Lakes National Program Office (GLNPO), and others towards developing alternative approaches to assessing the benthic community. Possible future approaches might include application of a modified oligochaete trophic index (Burlakova et al., 2018) or a benthic index that is not limited to oligochaetes, like the one used in the marine NCCA assessment (Gillett et al., 2015).

Underwater Video

Underwater video collection and analysis methods for use in NCCA is an area of active research at GLTED. Video quality is a concern because poor quality videos can result in unassessed area, which is already a problem for PONAR sampling. Improvements in video technology and collection protocol between 2010 and 2015 resulted in a reduction in proportions of area unassessed, and new video collection methods tested in the Niagara River further reduced proportions of area unassessed and reduced the uncertainty of invasive species detection. This improved method addresses previous issues with camera movement, lighting, and focal distance, and was implemented throughout the Great Lakes in NCCA 2020-21.

Underwater video classification and analysis methods are also in development. In this report, the presence of round gobies was based on underwater video, and the presence of dreissenid mussels was based on video and PONAR samples. Underwater video also contains additional information about habitat characteristics (bottom type, vegetation information) and anthropogenic impacts like litter and human-made features. Methods are being developed to extract these data from the videos and to standardize underwater video analysis methods. To improve the reliability and efficiency of underwater video analysis, USEPA ORD GLTED, GLNPO, USEPA Region 5, USEPA Office of Water, and state and federal partners piloted a crowdsourcing application, *Deep Lake Explorer*, to facilitate classification and interpretation of underwater video (https://www.zooniverse.org/projects/usepa/deep-lake-explorer). Results showed that crowdsourcing applications like Deep Lake Explorer may be helpful for large video imagery datasets resulting from lake wide assessments (Wick et al., 2020).

Key Findings

- Among the Great Lakes, water quality, including nutrients, water clarity, chlorophyll *a*, and dissolved oxygen, was poorest in Lake Erie basins. Among Lake Erie basins, conditions were poorest in the western basin.
- Based on water quality indicators, more of the Great Lakes combined nearshore and embayment area was in good condition than in fair or poor condition. Embayments in the Great Lakes had a higher percentage of area with poor conditions than the nearshore.
- Based on weighted mean values, water clarity was generally lower and total phosphorus concentration was generally higher in embayments than the nearshore.
- Weighted mean total phosphorus concentrations were higher in 2015 than in 2010 for Lakes Superior, Huron, and Erie. Weighted mean total nitrogen concentrations were higher in 2015 than in 2010 for Lakes Erie and Ontario.
- Based on water quality, more of the lower Niagara River was in good condition than the upper Niagara River.
- In the Great Lakes combined nearshore and embayment area, condition based on cyanobacteria concentrations was good in 64% of the area.
- Weighted mean cyanobacteria cell concentrations were over five times higher in 2015 than in 2010 for Lakes Huron and Erie. It is important to note that year to year variability in cyanobacteria blooms can be large, and the sampling design is not suited to capture peak conditions or seasonal averages.
- For most indictors, water quality was poorer in the western basin of Lake Erie than anywhere else in the survey.
- Greater than 99% of the combined nearshore and embayment area in the Great Lakes was in good condition based on microcystin concentrations relative to a recreational contact threshold.
- Ninety-eight percent of the combined nearshore and embayment area was in good condition based on enterococci concentration.
- Sediment quality in the Great Lakes was in good condition in 62% of the combined nearshore and embayments. Sediment quality conditions were driven primarily by sediment contamination rather than sediment toxicity.
- Assessed condition based on sediment quality was generally poorer in embayments than the nearshore.
- Weighted mean sediment toxicity was lower in 2015 than in 2010 for Lakes Erie and Ontario.

- Benthic condition could not be assessed at many sites either because no PONAR sample could be collected (75 of 550 sampled Great Lakes and connecting river systems sites) or because the OTI could not be calculated (67 of 550 sampled Great Lakes and connecting river systems sites).
- Because of the rocky substrate and swift currents of the Niagara River, NCCA methods for collecting benthic samples and underwater video performed poorly there than in the other systems.
- Except for Lake Superior, Lake Michigan, and the St. Marys River, more of the assessed area was in poor benthic condition than was in either good or fair condition.
- Invasive species (dreissenid mussels and round gobies) were detected over a greater percent of the nearshore area than embayment area.
- Combining data from underwater video and PONAR sampling increased the number of sites at which dreissenids were detected.
- Because embayments comprise a small percentage of the total nearshore area, conditions in embayments had a small effect on estimates of nearshore conditions at lake scales.
- Data collected during Great Lakes NCCA sampling, including in connecting river systems, can directly or indirectly support local assessment needs, including monitoring and assessment within Great Lakes Areas of Concern, but NCCA designs, methods, and findings are not intended as replacements for locally-managed AOC monitoring or assessment.

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Appendices

Appendix references included in main references above.

Appendix A - Water Clarity

For the eutrophication indicator, water clarity is characterized by Secchi depth (m) and light extinction coefficient (K_d; m-1). Secchi depth can be assigned a condition class (e.g., good, fair, poor) according to established thresholds (Table 2a from main text). In 2015, approximately 30% of sites (includes all NCCA and enhancements) did not have Secchi depth measurements. This was because the Secchi disk was visible resting on the bottom (designated as "clear-to-bottom" sites) or Secchi depth could not be measured for safety or logistical reasons. Crews were able to collect profiles of photosynthetic active radiation (PAR), from which K_d is calculated, at most sites.

To assign a Secchi depth condition class to a clear-to-bottom site, site depth was considered first. If site depth was greater than the good/fair Secchi depth threshold for that waterbody (Table 2a from main text), then the Secchi depth condition was classified "good". If site depth was less than or equal to the good/fair threshold then a condition class could not be unambiguously assigned as fair or poor. At those sites, the missing Secchi depth could be estimated using the site's K_d. If neither PAR data nor

Secchi depth were available or data did not meet QA criteria (next section) and site depth was less than the good/fair threshold, then Secchi depth and its condition class, were considered unassessed.

Methods for measuring water clarity
According to NCCA sampling protocols, Secchi depth was measured three times with a weighted 20-cm diameter black and white Secchi disk (USEPA, 2015c). The mean of three Secchi depth measurements was used as the indicator.

PAR profiles were measured with a LI-COR LI-1500 PAR meter equipped with two PAR (LI-COR LI-192) sensors. An underwater sensor was lowered (downcast) and then raised (upcast) through the water column. Light intensity (I_z; $\mu E \cdot m^{-2} s^{-1}$) was recorded at prescribed depths (z; meters) during both casts (USEPA 2014c). An ambient (air) sensor reported varying surface light intensity (I_o) arising, for instance, from passing clouds. The normalized PAR attenuation (I_z/I_o) is assumed to follow Beer's law where light intensity decreases exponentially with distance (equation 1). Applied here, the negative slope of the linearized relationship, K_d (m^{-1}), is the reduction of light per meter of water depth (equation A2). Light extinction (K_d) was calculated for each site by fitting a linear regression to the combined downcast and upcast PAR profile data. For quality assurance, regressions required at least four PAR data points and an R^2 >0.7 to yield a valid K_d^{-1} value. Smaller values of K_d indicate more clear water.

(A1) $\mathrm{Iz/Io} = \exp(-K_d * \mathrm{z})$

(A2) $\ln(\mathrm{Iz/Io}) = -K_d * \mathrm{z}$

Predicting Secchi Depth from Extinction Coefficient
A power function was used to model the relationship between Secchi depth and K_d for 2015 data (Tyler, 1968). A Secchi depth – K_d model is derived for each NCCA cycle based on that year's dataset. The relationship between Secchi depth and K_d depends on a combination of site-specific factors like chlorophyll *a*, suspended solids, colored dissolved organic matter (e.g., Brezonik et al., 2019). If these factors change across the Great Lakes over time, this relationship may also change. By basing estimated Secchi depth on a model derived based on that years' data, each NCCA cycle is an independent assessment. States wishing to estimate Secchi depth for a given lake or region can either apply the Great Lakes or Great Lakes/connecting river systems models reported here, or use the methods described here and a subset of the data to define the Secchi depth - K_d regression for their region of interest.

Two different models were derived and applied for this report. For sites located in the Great Lakes, the model was based on all sites located in the lakes including multiple site visits and enhancement sites (embayments, Lake Erie enhancement; equation A3 and Fig. A1). A total of 298 sites with both qualified PAR profile data and Secchi depths were used.

(A3) $Secchi\ depth_{est} = 1.3891 * K_d^{-0.983}$ $r^2 = 0.90$

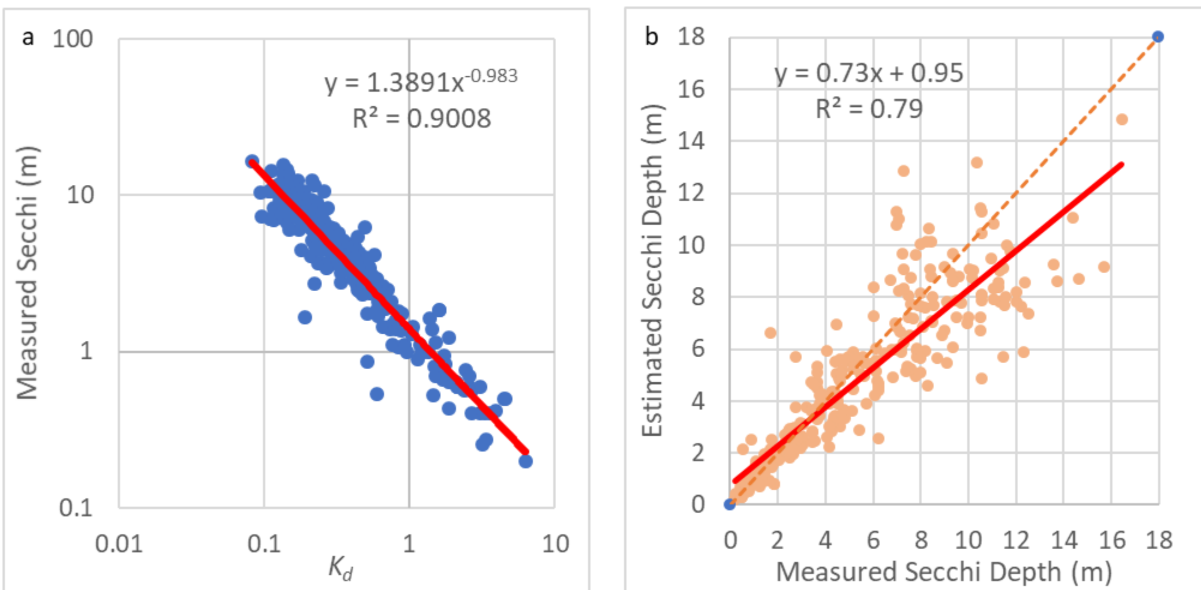
For sites located in the connecting river systems, the model was based on all sites located in the lakes (including multiple site visits and enhancement sites) as well as sites located in the connecting river systems and collected 2014 – 2016 (equation A4 and Fig. A1). A total of 454 sites with both qualified PAR profile data and Secchi depths were used.

(A4) $\quad Secchi\ depth_{est} = 1.3035 * K_d^{-0.977} \qquad r^2 = 0.86$

These models were similar to the model derived for the Great Lakes NCCA in 2010 (equation A5; EPA 2016d).

(A5) $\quad Secchi\ depth_{est} = 1.31 * K_d^{-0.91} \qquad r^2 = 0.79$

Based on the site location, either equation A3 or A4 was used to estimate Secchi depth based on a site's K_d at clear-to-bottom sites where site depth was less than the good/fair threshold for that waterbody, and to assign those sites a condition class.



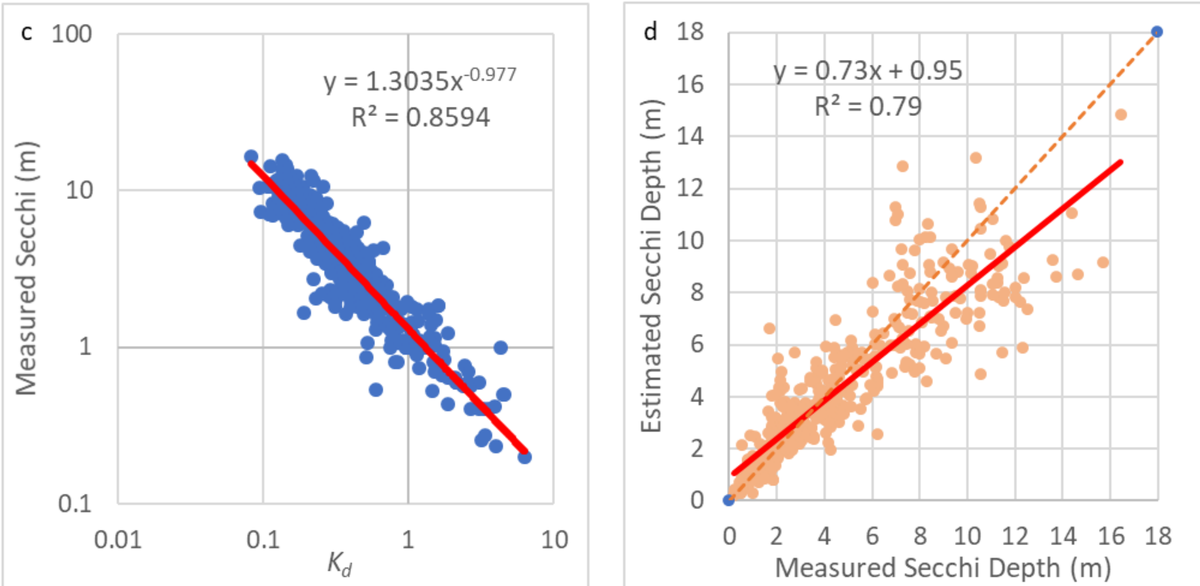


Figure A1. Secchi depth – K_d regression model from equation A3 is shown in (a) and comparison of predicted to measured Secchi depth (b). Secchi depth – K_d regression model from equation A4 is shown in (c) and comparison of predicted to measured Secchi depth (d). A perfect model would follow the dashed 1:1 line. Models are more accurate at Secchi depths less than 6m, which includes most clear-to-bottom sites.

Appendix B - Sediment Quality

Background

Both contaminant concentrations and acute toxicity of sediments can be used to evaluate the ecological condition of sediment in nearshore coastal waters. The NCCA sediment quality indicator is based on contaminant and toxicity indicators to estimate whether a site's sediments are likely to cause adverse health effects to benthic organisms.

For the sediment contamination indicator, sediment samples were analyzed for a suite of contaminants and concentrations were compared to literature-based sediment quality guidelines (SQGs) to predict toxicity due to contamination. The sediment contamination indicator uses mean probable effects concentration quotient (mean PECQ) and established thresholds for good, fair, and poor sediment contaminant conditions. SQGs identify concentrations of individual contaminants that may adversely affect benthic organisms. SQGs are adequate for assessing individual contaminant levels in sediments, but contaminants are usually present as complex mixtures. For this survey, mean SQG quotients were used to produce overall unitless measures of contamination to predict aggregate toxicity (Fairey et al., 2001; Long et al., 2006) using the probable effects concentrations quotient (PECQ: MacDonald et al., 2000; Ingersoll et al., 2001) for freshwater sediments.

The toxicity indicator is based on survival tests in which laboratory organisms were exposed to the collected sediments, capturing responses to a broader range of sediment properties that might contribute to overall toxicity. The sediment toxicity indicator compares control-corrected survival of the amphipod *Hyalella azteca* to preestablished thresholds. To assess sediment toxicity, acute 10-day sediment toxicity tests were used to measure the survival of *Hyalella azteca* in sediments.

Field collection

For both sediment contamination and toxicity sample collection, field crews collected the top 2 cm of surface sediments at the predetermined probabilistic site or a proximal location as prescribed in the Field Operations Manual (USEPA, 2015c). Great Lakes crews used a stainless-steel standard PONAR grab sample. Crews composited samples to reach the total sediment volume required for analysis.

Laboratory Analysis

Samples were analyzed for contaminant concentrations of metals (including mercury), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and organochlorine pesticides using a variety of spectrometry methods (USEPA, 2016a).

Sediment toxicity tests were performed to determine the percent survival of laboratory amphipods (*Hyalella azteca*) following 10 days of exposure to sample sediments (USEPA, 2015c). Control tests using reference sediments were run in parallel with the sample tests. Sample and control tests used a flow-through approach with 4 replicate chambers with 10 organisms in each chamber; a minimum of 80% survival of control organisms was required to meet test acceptability criteria (USEPA, 2000; USEPA, 2015c).

Sediment Contamination Calculations

For any given contaminant, results were excluded from the sediment contamination indicator calculations if the associated laboratory method detection limits (MDLs) exceeded the threshold effect concentration (TEC) values for freshwater sediments (Table B1; Field and Norton, 2014). Sample results reported as non-detects (values less than the MDL) were substituted with one-half of the MDL.

Total PAH and total PCB concentrations (in units of ng/g) were computed before estimating PECQs for these two chemical classes. The specific PAHs and PCB congeners included in the total PAH and PCB concentrations are listed in Table B1. PECQs were calculated (equation B1) for total PAHs, total PCBs, and individually for each of the seven metals with consensus-based probable effects concentration values (arsenic, cadmium, chromium, copper, lead, nickel, and zinc concentrations in µg/g; Table B1) as the contaminant concentration result divided by the PEC for that chemical class (i.e., total PAH, total PCB) or metal (Table B1):

(B1) $$PECQ = \frac{concentration}{PEC}$$

Once PECQs for the seven individual metals were calculated, a mean PECQ for metals was calculated (equation B2) as the sum of the PECQs for the seven individual metals, divided by seven, which is the number of metals included in the analysis:

(B2) $$Mean\ PECQ_{metals} = \frac{\sum Individal\ metal\ PECQs}{7}$$

The mean PECQ was calculated (equation B3) as the average of the above PECQs:

(B3) $$Mean\ PECQ = \frac{(mean\ PECQ_{metals} + PECQ_{Total\ PAHs} + PECQ_{Total\ PCBs})}{n}$$

where n is the number of contaminant classes (i.e., metals, PAHs, PCBs) for which site data were available. Data were considered not available only if the lab did not attempt to measure the concentrations of chemicals in a chemical class. Labs measured concentrations of all three contaminant classes for Great Lakes and connecting river systems samples, so n was always 3 in this report.

Sediment Toxicity Calculations

Control-corrected survival of *H. azteca* was calculated (equation B4) for each sample by dividing sample mean percent survival, or average survival across sample replicates, by control mean percent survival, or average survival across corresponding control replicates, as follows:

(B4) $$Control\text{-}corrected\ survival = \frac{sample\ mean\ percent\ survival}{control\ mean\ percent\ survival}$$

Thresholds

Sediment contamination thresholds were based on literature review and best professional judgment. Mean PECQ thresholds were developed from prior studies relating guideline exceedances and observed toxicity levels (Ingersoll et al., 2001; Crane et al., 2002; Crane and Hennes, 2007). Good sediment contamination conditions were assigned to sites with mean PECQs ≤ 0.1, fair conditions were assigned to sites with mean PECQs >0.1 and <0.6, and poor conditions were assigned to sites with mean PECQs ≥0.6 (Table 2b from main text).

Thresholds for control-corrected survival of *H. azteca* (USEPA, 2004) were used to determine the sediment toxicity indicator condition for freshwater samples (Table 2b from main text). Good conditions were assigned to sites with ≥90% control-corrected survival, fair conditions were assigned to sites where control-corrected survival was ≥75% and <90%, and poor conditions were assigned when control-corrected survival was <75% (Table 2b from main text).

Sediment Quality Indicator

The sediment contamination and sediment toxicity indicators contribute equally to the sediment quality indicator (Table 2b from main text). A site was assessed as good if both component indicators were classified as good. A site was assessed as fair if either or both indicators were assessed as fair. A site was assessed as poor if either or both component indicators were rated poor. If either sediment contamination or sediment toxicity data were missing for an individual site, good, fair, or poor condition was assigned based on the indicator that was available.

Table B1: Chemicals with reliable, published threshold and probable effects concentrations. TEC values are used to screen results for exclusion from analyses and PEC values are used to estimate PECQs for each metal individually and for total PAHs and PCBs. The PAHs and PCBs included in these totals are summarized in the footnotes. PECQ calculations for metals should use metal concentrations in µg/g; PECQ calculations for PAHs and PCBs should use concentrations in ng/g.

Contaminant	Consensus-based threshold effects concentration (TEC) values	Consensus-based probable effects concentration (PEC) values
Arsenic	9.7	33.0
Cadmium	0.99	4.98
Chromium	43.4	111
Copper	31.6	149
Lead	35.8	128
Nickel	22.7	48.6
Zinc	121	459
Total PCB congeners[1]	60	676
Total PAHs[2]	1610	22800

[1]Total PCBs included the following congeners: 8, 18, 28, 44, 52, 66, 77, 101, 105, 110, 118, 126, 128, 138, 153, 170, 180, 187, 195, 206, 209

[2]Total PAHs included sum of low molecular weight (LMW) PAHs (Acenaphthene, Acenaphthylene, Anthracene, Fluorene, 2-methylnaphthalene, Naphthalene, and Phenanthrene) and high molecular weight (HMW) PAHs (Benz(a)anthracene, Benzo(a)pyrene, Chrysene, Dibenz(a,h)anthracene, Fluoranthene, and Pyrene)

Sources: MacDonald et al., 2000; Crane and Hennes, 2007; CCME, 1999; Crane et al., 2002

Appendix C - Benthic Index

Of the 512 sites in the Great Lakes and connecting river systems from 2014-2018 where benthos samples could be collected, only 444 samples were assessed for benthic condition (Table 1 from main text). This is because the oligochaete trophic index (OTI) used for classifying benthic condition requires a sample to have oligochaetes that are listed in Table C1. Benthos samples from 68 of the 512 sites where benthos samples could be collected either did not contain any oligochaete species or did not contain the oligochaetes listed in Table C1 and the benthic condition for these sites was classified as unassessed. Benthic condition was also classified as unassessed at sites where benthos samples could not be collected due to PONAR failures (due to hard substrate, mussel shells, etc.). OTI values were calculated (equation C1) for the 444 Great Lakes and connecting river systems samples that did contain the proper oligochaetes according to the methods described below. Once calculated, OTI values were compared to the thresholds in Table 2c from main text to assign condition classes.

The OTI value is calculated for each site as:

(C1) $$\mathrm{OTI} = c\,\frac{\frac{1}{2}\sum n_0 + \sum n_1 + 2\sum n_2 + 3\sum n_3}{\sum n_0 + \sum n_1 + \sum n_2 + \sum n_3}$$

Where $\sum n_0$, $\sum n_1$, $\sum n_2$, and $\sum n_3$ refer to the sum of the densities (number per m^2) of all species in tolerance groups 0, 1, 2, and 3, respectively (Table C1). The constant c adjusts the ratio to the total density (n_{all}, in units of number per m^2) of all mature and immature tubificid and lumbriculid oligochaetes in the sample. The possible values for c are:

c = 1 when $n_{all} \geq 3600$
c = 0.75 when $1200 \leq n_{all} < 3600$
c = 0.5 when $400 \leq n_{all} < 1200$
c = 0.25 when $130 \leq n_{all} < 400$
c = 0 when $n_{all} < 130$

Table C1. Oligochaete Trophic Index categories used for Benthic Indictor. Classifications are from State of the Great Lakes 2011 (EC and USEPA, 2014) – Benthic Diversity and Abundance Table 1, which was based on classifications from Howmiller and Scott (1977), Milbrink (1983), Krieger (1984), and Lauritsen et al. (1985). Only species in the families, Naididae (formerly Tubificidae) and Lumbriculidae were included. Taxa in bold were not observed in the Great Lakes or connecting river systems in 2014-2016.

Group 0	Group 1	Group 2	Group 3	Unassigned[4]
Limnodrilus profundicola	*Arcteonais lomondi*[2]	*Aulodrilus pluriseta*	*Limnodrilus hoffmeisteri*	*Branchiura sowerbyi (2)*
Rhyacodrilus coccineus	*Aulodrilus americanus*	***Limnodrilus angustipenis***	*Tubifex tubifex*[1]	*Chaetogaster diaphanus (2)*
Rhyacodrilus montana	*Aulodrilus limnobius*	*Limnodrilus cervix*		*Dero* sp. (2)
Rhyacodrilus sp.	*Aulodrilus pigueti*	***Limnodrilus claparedianus***		*Ilyodrilus frantzi*
Spirosperma nikolskyi	*Dero digitata*[2]	*Limnodrilus maumeensis*		*Naidinae*
Stylodrilus heringianus	*Ilyodrilus templetoni*	*Limnodrilus udekemianus*		*Nais* sp.
Lumbriculidae[3]	*Isochaetides freyi*	*Potamothrix bedoti*		*Nais bretscheri*
Trasserkidrilus superiorensis	*Slavina appendiculata*[2]	*Potamothrix moldaviensis*		*Ophidonais serpentina (2)*
Trasserkidrilus americanus	*Spirosperma ferox*	*Potamothrix vejdovskyi*		***Paranais grandis***
Tubifex tubifex[1]	*Uncinais uncinata*[2]	*Quistadrilus multisetosus*		*Paranais litoralis*
				Piguetiella sp.
				Piguetiella blanci (2)
				Specaria
				Stylaria lacustris (2)
				Tubificinae
				Varichaetadrilus
				Vejdovskyella intermedia (1)

[1]*Tubifex tubifex* is assigned to Group 0 or Group 3 according to the following rules (ECCC and USEPA, 2017):
if the ratio of abundances of n_0 oligochaetes to n_3 oligochaetes (*L. hoffmeisteri*) < 1 then *T. tubifex* is classified as a 3; if the ratio is >1 then *T. tubifex* is classified as a 0; however, if the ratio is close to one (0.75 to 1.25) then *T. tubifex* is a 3 if $c \geq 0.5$ and a 0 if $c < 0.5$;
- if $n_0 : n_3 < 0.75$ then Group 3;
- if $n_0 : n_3 > 1.25$ then Group 0;
- if $n_0 : n_3$ = 0.75 – 1.25 then Group 0 if c < 0.5 or Group 3 if c ≥ 0.5;
- if $n_3 = 0$ then Group 0 if n_0 is relatively high and/or c is low (i.e., c = 0 or 0.25); otherwise Group 3

[2] These species were not included in State of the Great Lakes 2011 (EC and USEPA, 2014) list presumably because they were thought to be in the family Naididae, not Tubificidae, although they were included in group 2 in earlier publications. However, recent taxonomy changes have reclassified Tubificidae to Naididae which has several subfamilies including Naidinae and Tubificinae, so they were included in Group 1.

[3] SOLEC (ECCC and USEPA, 2017) classified all immature Lumbriculidae as *Stylodrilus heringianus*. Therefore, taxa in NCCA 2015 GL samples that were identified as Lumbriculidae are assigned Group = 0.

[4] Unassigned oligochaete taxa with numbers in parentheses are group assignments recommended by Kurt Schmude, Univ. of Wisconsin – Superior (Burlakova et al., 2018). These assignments were not applied in these calculations of OTI but are included in case future changes are made to the OTI.

Appendix D - Ecological Fish Contamination

An ecologically based method was used to assess contaminant burdens in whole fish using an approach based on USEPA's *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments* (USEPA, 1997). Field crews targeted fish species based on a recommended species list (USEPA, 2015c). Whole fish tissue samples of mostly forage-sized fish were then analyzed for measurable concentrations of 13 contaminants of concern (Table D1; USEPA, 2016a). Fish tissue concentrations of contaminants were compared to screening values, which consider receptor body weight, food ingestion rate, and contaminant-specific toxicity reference values (TRVs). TRVs are concentrations above which ecologically relevant adverse effects might occur in wildlife after long-term dietary exposure to the contaminant. The methods for estimating screening values for each receptor group and contaminant are described in detail in the 2015 NCCA technical support document (USEPA, 2021b). These methods differed from the methods used in the 2010 NCCA report in two key ways. The first change involved using TRVs based on no observed adverse effect levels (NOAELs) to estimate screening values rather than using lowest observed adverse effect levels (LOAELs) themselves as screening values (which was done in 2010). The second change involved using an updated approach for estimating the selenium screening values which is based on new guidance for selenium in freshwater (USEPA 2021b).

Some of the contaminants of concern include multiple, related compounds whose tissue concentrations must be summed before being compared to screening values (Table D1). In addition, screening values for arsenic were derived for inorganic arsenic. Because the labs reported the total concentration of arsenic (i.e., the sum of its organic and inorganic forms), the concentration of inorganic arsenic was estimated by taking 10% of the total arsenic concentration reported by the lab (USEPA, 2003). Finally, the screening values represent estimated effects concentrations in dried fish tissue. However, the lab results are reported as contaminant concentrations in fresh (frozen) fish. To address this, the final step before comparing fish tissue contaminant concentrations to screening values was to convert each concentration from a wet weight concentration to a dry weight concentration. This was done by dividing the wet weight concentrations of each contaminant or contaminant group by 0.28, which adjusts for the 72% of fish tissue made up of water (USEPA, 1993).

To derive the overall fish tissue contaminant indicator at each site, the number of receptor groups with screening value exceedances are counted and good, fair, and poor conditions are assigned according to the rules in Table 2c.

Table D1. Summary of estimated fish tissue screening values in mg/kg (dry weight) for each freshwater receptor group.

Ecological contaminant of concern	**Freshwater fish**	**Freshwater mammal**	**Piscivorous birds**
Cadmium	1125.9217	11.6807	7.9001
Dieldrin	0.9658	0.4361	0.5216
Hexachloro benzene	0.026	12.736	0.9012
Inorganic Arsenic[a]	0.4039	1.3849	28.5892
Lindane	221.0475	101.892	4.5878
Mercury	2.1081	0.4076	0.1682
Mirex	5.8274	0.836	0.0561
Selenium	6.05	2.5473	2.2423
Total Chlordane[b]	NA	50.3383	4.4846
Total DDT[c]	4.1878	10.1892	1.2394
Total Endosulfan[d]	0.004	15.5742	67.3318
Total Endrin[e]	2.3035	1.978	0.158
Total PCBs[f]	1.1463	0.714	1.009

[a] Thresholds for arsenic represent inorganic arsenic only. Inorganic arsenic concentrations in fish tissue are estimated from total arsenic concentrations by multiplying total arsenic by 0.10 (USEPA, 2003)
[b] Total Chlordane includes the sum of alpha-chlordane, cis-nonachlor, gamma-chlordane, heptachlor, heptachlor epoxide, oxychlordane, and trans-nonachlor. There is no established NOAEL value for total chlordanes for freshwater fish (NA = Not Applicable).
[c] Total DDT includes the sum of concentrations of OPDDD, OPDDE, OPDDT, PPDDD, PPDDE, PPDDT
[d] Total Endosulfan is the sum of the concentrations of Endosulfan Sulfate, Endosulfan I, and Endosulfan II
[e] Total Endrin is the sum of the concentrations of Endrin, Endrin Ketone, and Endrin Aldehyde
[f] Total PCBs includes the sum of the concentrations of congeners 8, 12, 18, 28, 44, 52, 66, 77, 101, 105, 110, 118, 128, 138, 153, 170, 180, 187, 195, 206, 209

Appendix E - Summary of additional Great Lakes NCCA and connecting river system data not included in assessments

This appendix summarizes spatial patterns in parameters sampled in the Great Lakes in the 2015 NCCA survey that were not included in the main report. These include water quality parameters, algal toxin data, sediment chemistry data, phytoplankton taxa richness, and macroinvertebrate taxa richness. The water quality and algal toxin parameters included here do not have established condition thresholds and are not included in the population estimates presented in the body of the report. For sediment chemistry, constituent parameters (mean metals PECQ, PAH PECQ, PAH PECQ) not shown in the main report are included here. These data are available to the public on the NCCA website and may be useful for state, regional, or local management needs. Plotted data is from first visits to each site; second visit data are available on the NCCA website. Sites with no data are a result of a sample not being collected or analyzed for that parameter.

Water Quality

Included here are results for total nitrogen, chloride, conductivity, sulfate, pH, and silica. Silica was only sampled at 23 sites in Wisconsin waters in Lake Michigan and Lake Superior. Additional parameters determined for some or all sites but not reported here include temperature, and soluble reactive phosphorus (SRP), dissolved organic carbon (DOC), and turbidity.

Total nitrogen concentrations were consistently relatively low in the nearshore of Lake Huron, northern Lake Michigan, and the east basin of Lake Erie (Fig. E1) and was relatively high in the St. Marys River, western Lake Erie, and Lake Ontario. Chloride concentrations were lowest in the nearshore of Lake Superior and the St. Marys River (Fig. E2) and was highest in the nearshore of Lake Ontario and Lake Erie. As for chloride, conductivity was highest in the nearshore of Lake Erie and Lake Ontario (Fig. E3), and lowest in the nearshore of Lake Superior and the St. Marys River. Sulfate concentrations were highest in the nearshore of Lake Ontario and eastern Lake Michigan (Fig. E4) and was lowest in the nearshore of Lake Superior and the St. Marys River. Sites in Lake Superior consistently had a lower pH than the other Great Lakes (Fig. E5), Silica was only measured at a few sites; concentrations ranged from the detection limit of 0.1 mg/L to 2.55 mg/L (Fig. E6).

Algal Toxins

In addition to microcystin analysis using the ELISA method reported in the main report, algal toxins analyzed by liquid chromatography-mass spectrometry (LCTX method) were also included as a research indicator in the 2015 NCCA. Toxins determined included Anatoxin-a, Azaspiracid-1, Cylindrospermopsin, Domoic acid, Dinophysistoxin-2, Gymnodimine, Microcystin-HiLR, Microcystin-HtYR, Microcystin-LA, Microcystin-LF, Microcystin-LR, Microcystin-LW, Microcystin-LY, Microcystin-RR, Microcystin-WR, Microcystin-YR, Nodularin-R, Okadaic acid, Pectinotoxin-2, and 13-desmethyl spirolide-C. Reported here are the sums of individual algal toxin concentrations measured (Figure E7). Most locations for which at least one toxin was above the detection limit were in Lake Erie or the Huron-Erie Corridor, although detections occurred in Green Bay, Lake Michigan, Saginaw Bay, Lake Huron, and eastern Lake Ontario.

Sediment Chemistry

Included here are the three components of the sediment contamination indicator reported in the main report: Mean probable effects concentration quotient (PECQ) for metals, total PECQ for PAHs, and total PECQ for PCBs. Each PECQ is a unitless measure of the concentration of the contaminant in a site's sediment compared to concentrations that may adversely affect benthic organisms. For more detail about how these indicators are calculated, see Appendix B.

Sites with high mean PECQ for metals, high total PECQ for PAHs and high total PECQ for PCBs occurred in all the Great Lakes (Figs E8, E9, E10). The St. Marys River, Lake Erie, and Lake Ontario has consistently had the highest PECQs for metals and PAHs. Lake Erie, Lake Ontario, and Green Bay, Lake Michigan had the most sites with high PECQ for total PCBs

Phytoplankton

Diatom richness, or the number of diatom taxa present in the sample, was highly variable across the Great Lakes. Diatom richness was high in Grand Traverse Bay, Lake Michigan and at sites scattered throughout the Huron-Erie Corridor, Green Bay (Lake Michigan), Thunder Bay and Saginaw Bay (Lake Huron), and Western Lake Erie (Fig. E11). Richness of non-diatom phytoplankton taxa was also highly variable, but generally high in Saginaw Bay and Green Bay (Fig. E12). A small number of more isolated sites in other areas of the Great Lakes also had high non-diatom phytoplankton taxa richness.

Macroinvertebrates

Macroinvertebrate richness, or the number of macroinvertebrate taxa present in the benthos sample, was highest in the Huron-Erie Corridor, Chequamegon Bay and Keweenaw Bay (Lake Superior), and in around the Straights of Mackinaw between Lake Michigan and Lake Huron (Fig. E13). Macroinvertebrate richness was low in the St. Mary River, western and eastern Lake Erie, and along the south shore of Lake Ontario. Many sites (especially in eastern Lake Erie and Lake Ontario) had no data because PONAR samples could not be collected due to rocky substrates.

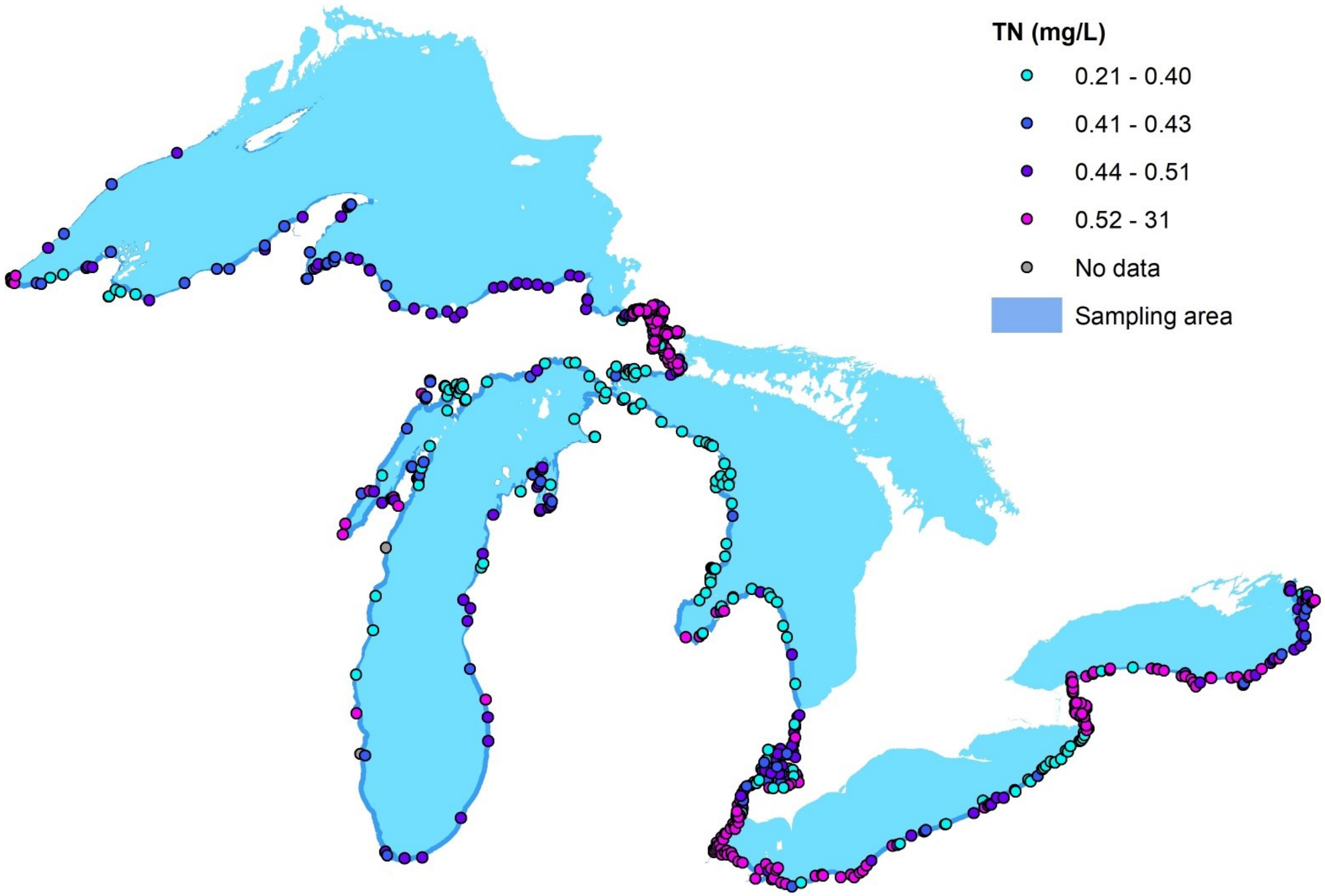


Figure E1. Total nitrogen concentration at sites sampled in the Great Lakes and connecting river systems for the 2015 NCCA. Figure symbology is based on value thresholds that represent quartiles of the measured results for sites in the Great Lakes, excluding the connecting river systems.

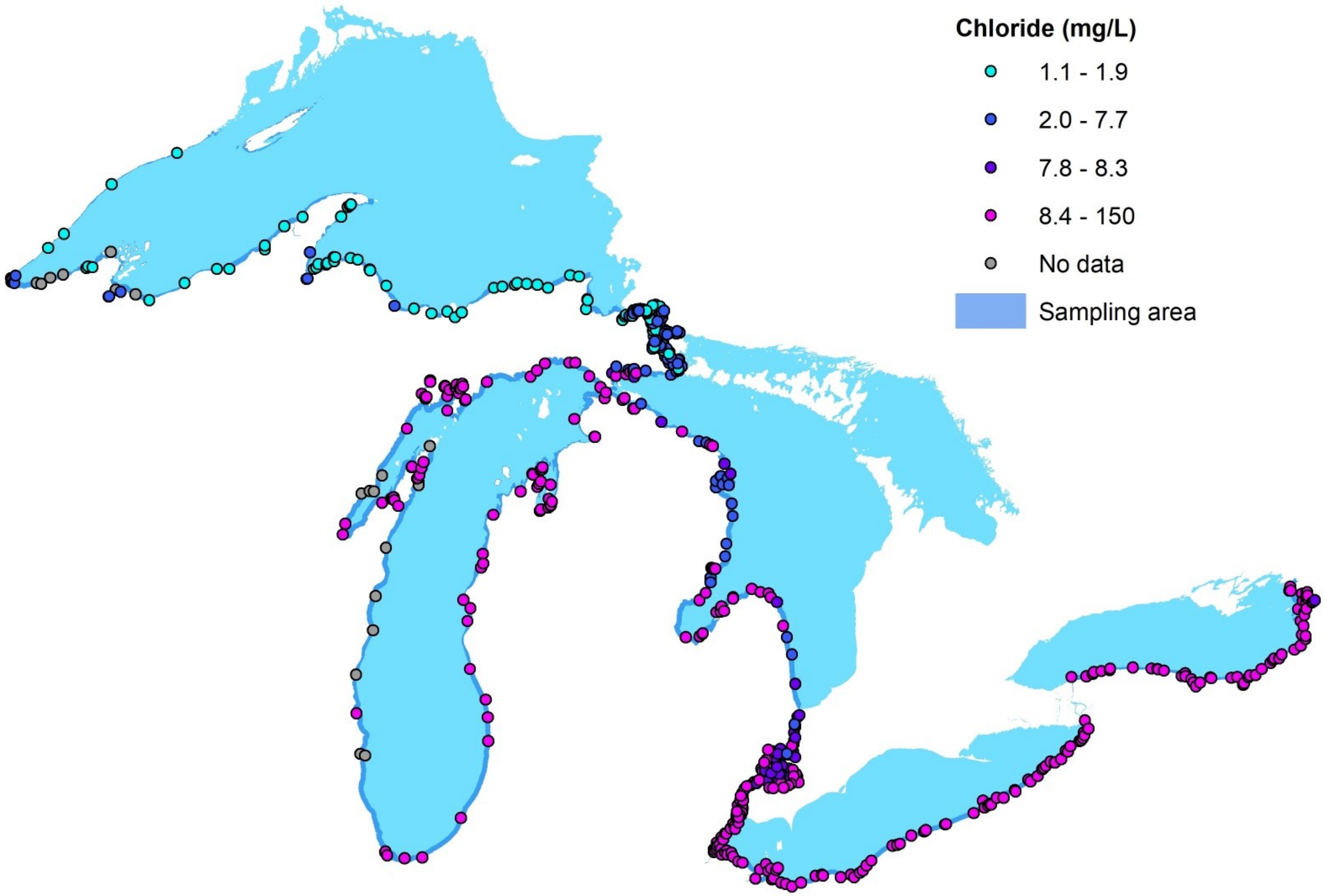


Figure E2. Chloride concentration at sites sampled in the Great Lakes and connecting river systems for the 2015 NCCA. Figure symbology is based on value thresholds that represent quartiles of the measured results for sites in the Great Lakes, excluding the connecting river systems.

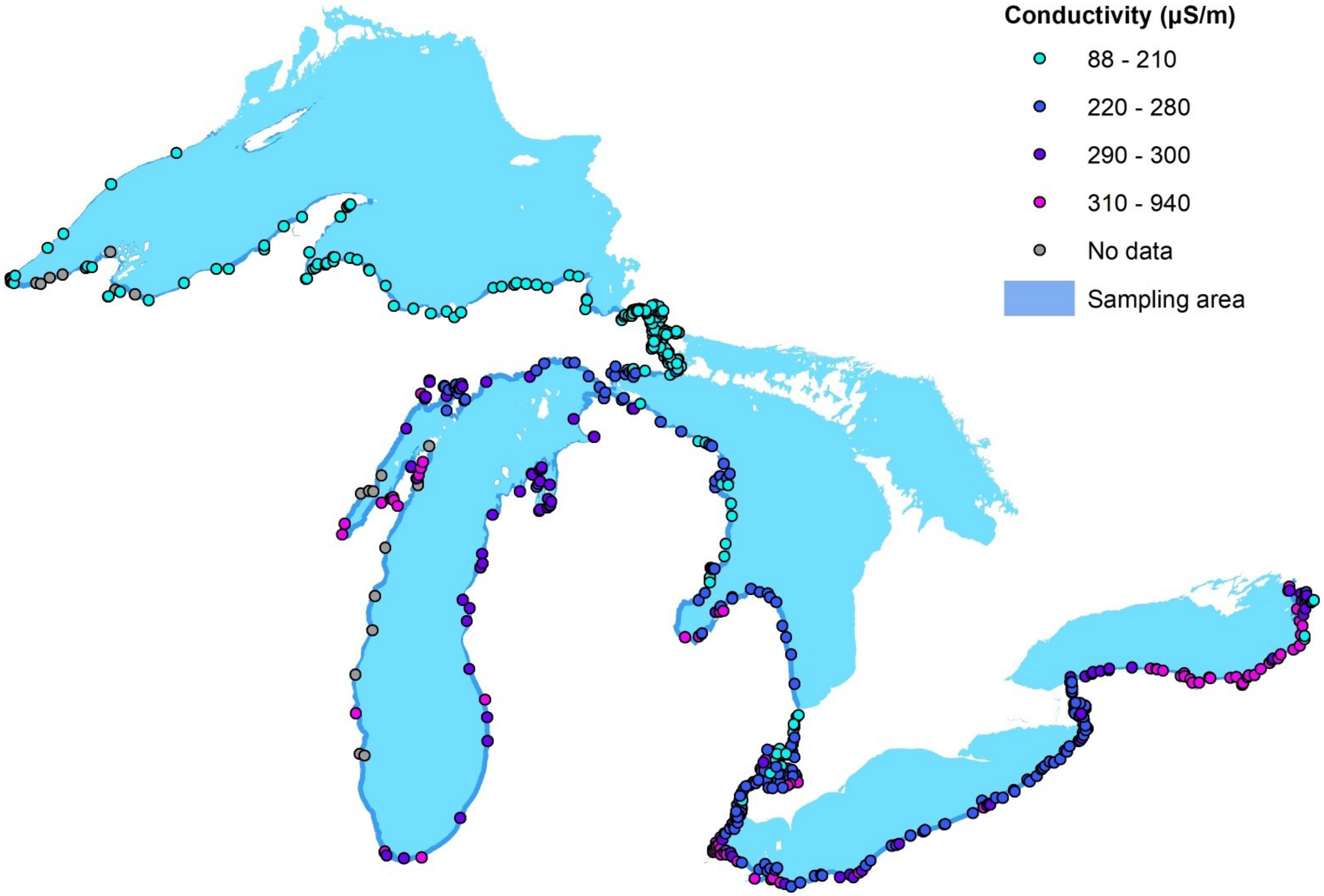


Figure E3. Conductivity at sites sampled in the Great Lakes and connecting river systems for the 2015 NCCA. Figure symbology is based on value thresholds that represent quartiles of the measured results for sites in the Great Lakes, excluding the connecting river systems.

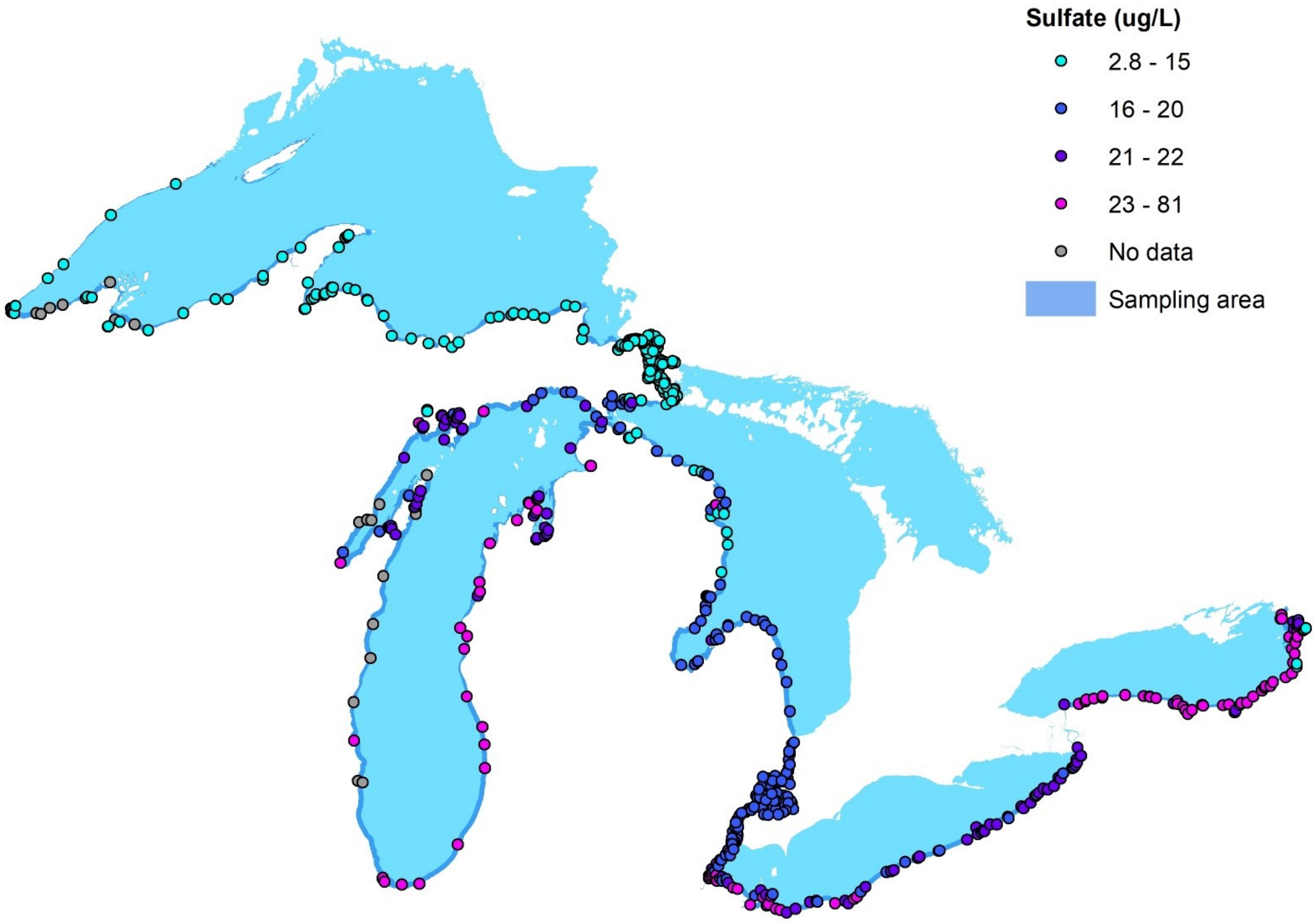


Figure E4. Sulfate concentration at sites sampled in the Great Lakes and connecting river systems for the 2015 NCCA. Figure symbology is based on value thresholds that represent quartiles of the measured results for sites in the Great Lakes, excluding the connecting river systems.

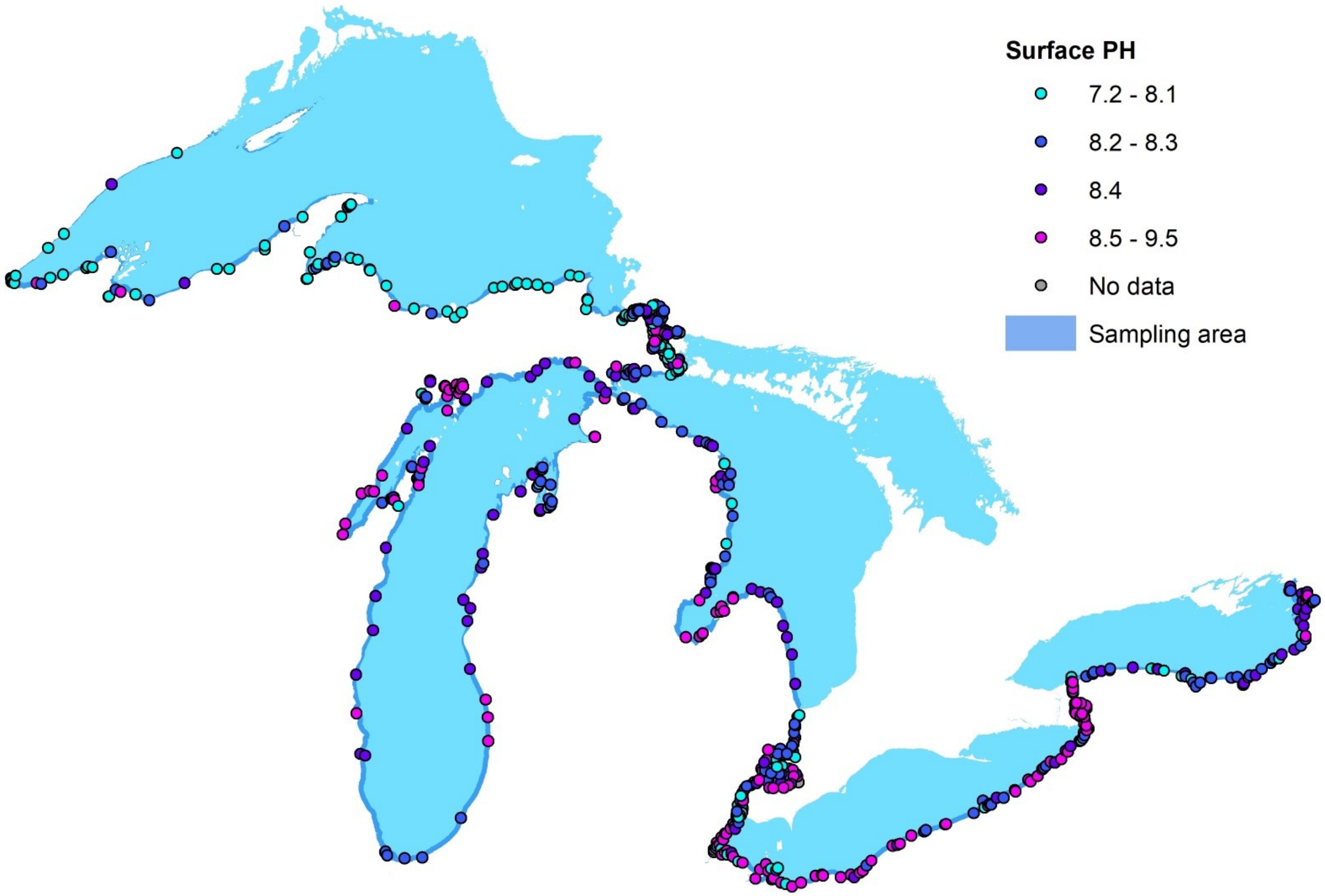


Figure E5. pH measured at sites sampled in the Great Lakes and connecting river systems for the 2015 NCCA. Figure symbology is based on value thresholds that represent quartiles of the measured results for sites in the Great Lakes, excluding the connecting river systems.

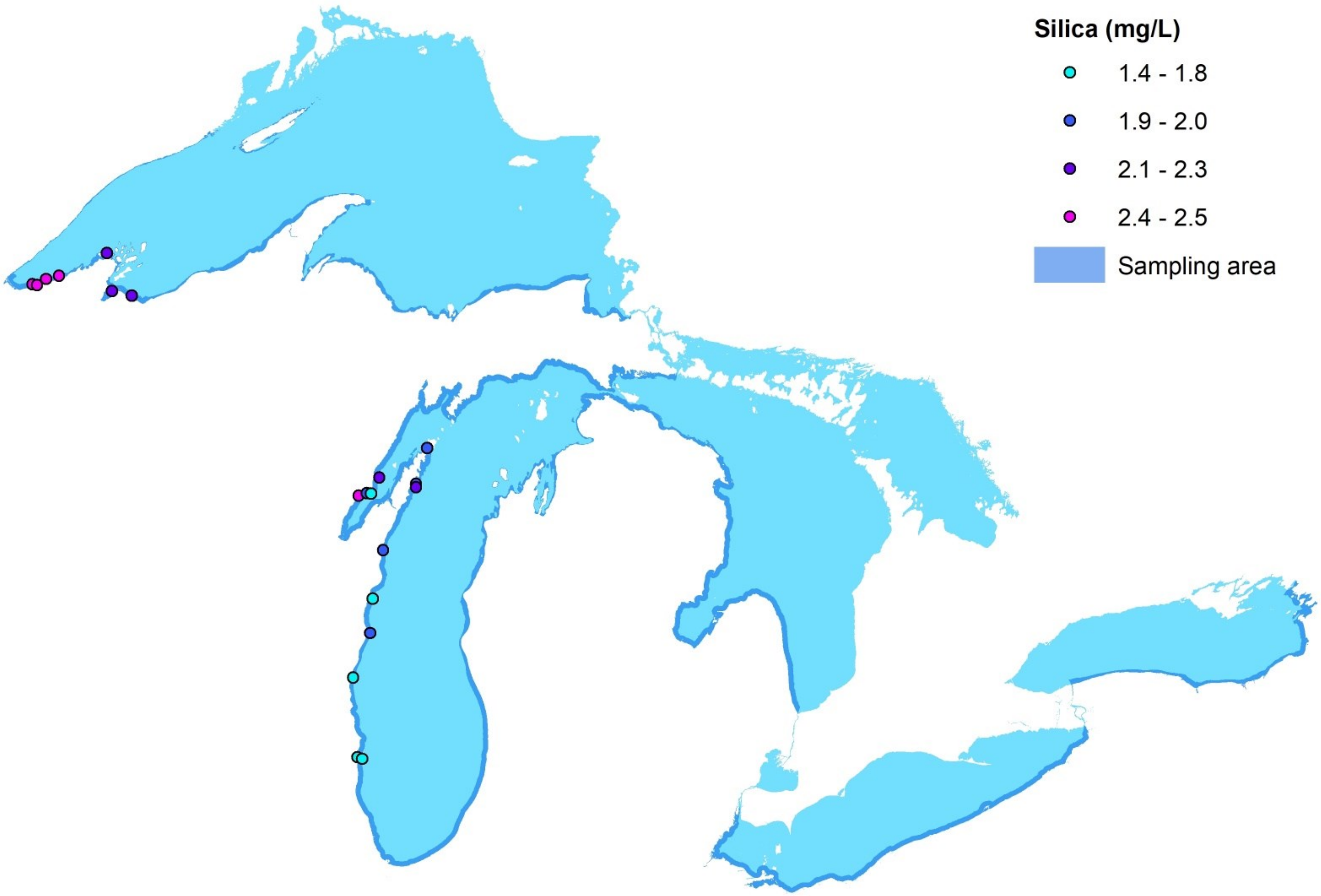


Figure E6. Silica concentration measured at sites sampled in the Great Lakes and connecting river systems. Silica was only measured at the sites shown. Figure symbology is based on value thresholds that represent quartiles of the measured results.

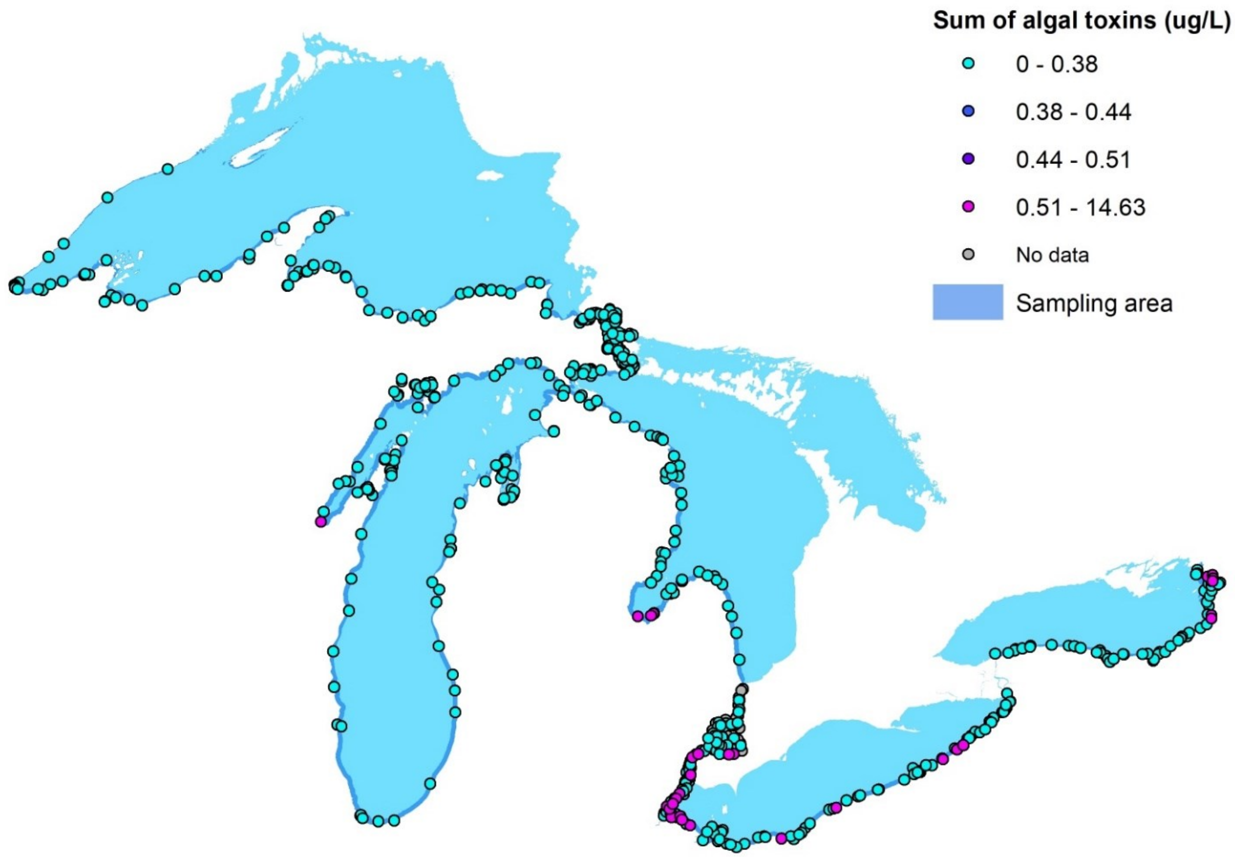


Figure E7. Sum of algal toxin concentration determined with the LCTX method at sites sampled in the Great Lakes and connecting river systems for the 2015 NCCA. Figure symbology is based on value thresholds that represent quartiles of the measured results for sites in the Great Lakes, including the connecting river systems. The lowest threshold of 0.38 µg/L(turquoise) represents a total for which all sites where all algal toxins measured were below their respective detection limits.

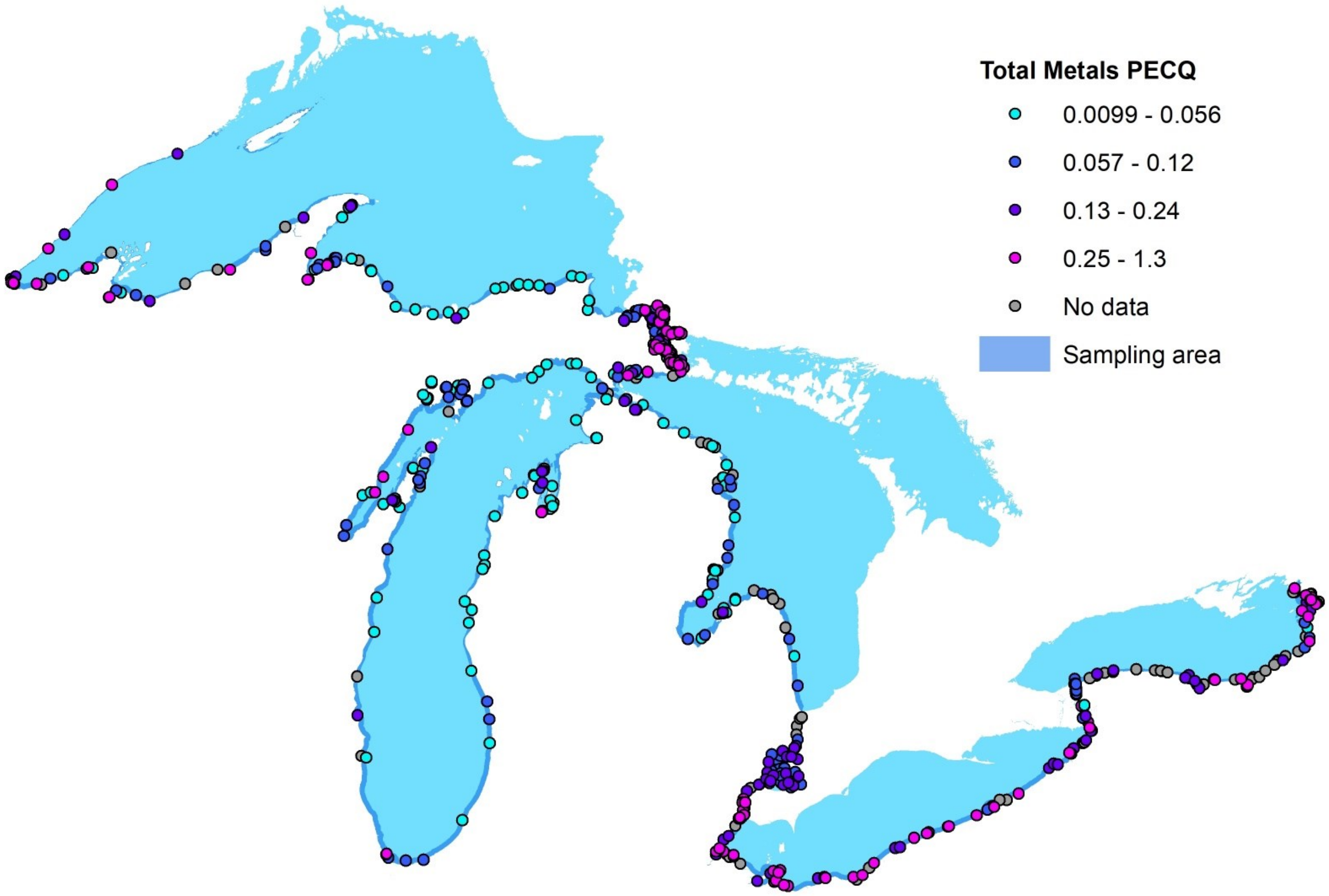


Figure E8. Mean PECQ for metals at sites sampled in the Great Lakes and connecting river systems for the 2015 NCCA. Figure symbology is based on value thresholds that represent quartiles of the measured results for sites in the Great Lakes, including the connecting river systems.

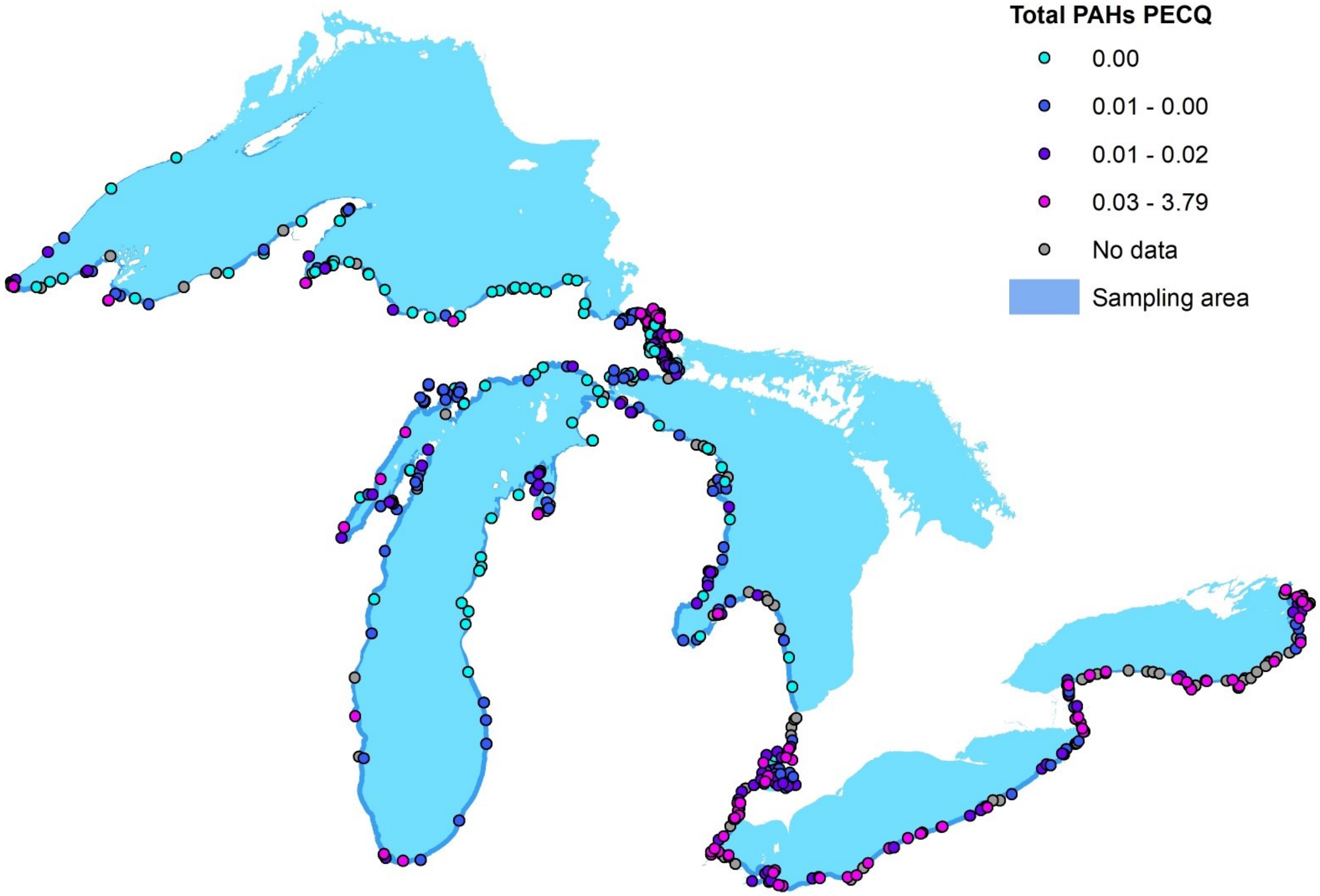


Figure E9. Total PECQ for sediment PAHs at sites sampled in the Great Lakes and connecting river systems for the 2015 NCCA. Figure symbology is based on value thresholds that represent quartiles of the measured results for sites in the Great Lakes, including the connecting river systems.

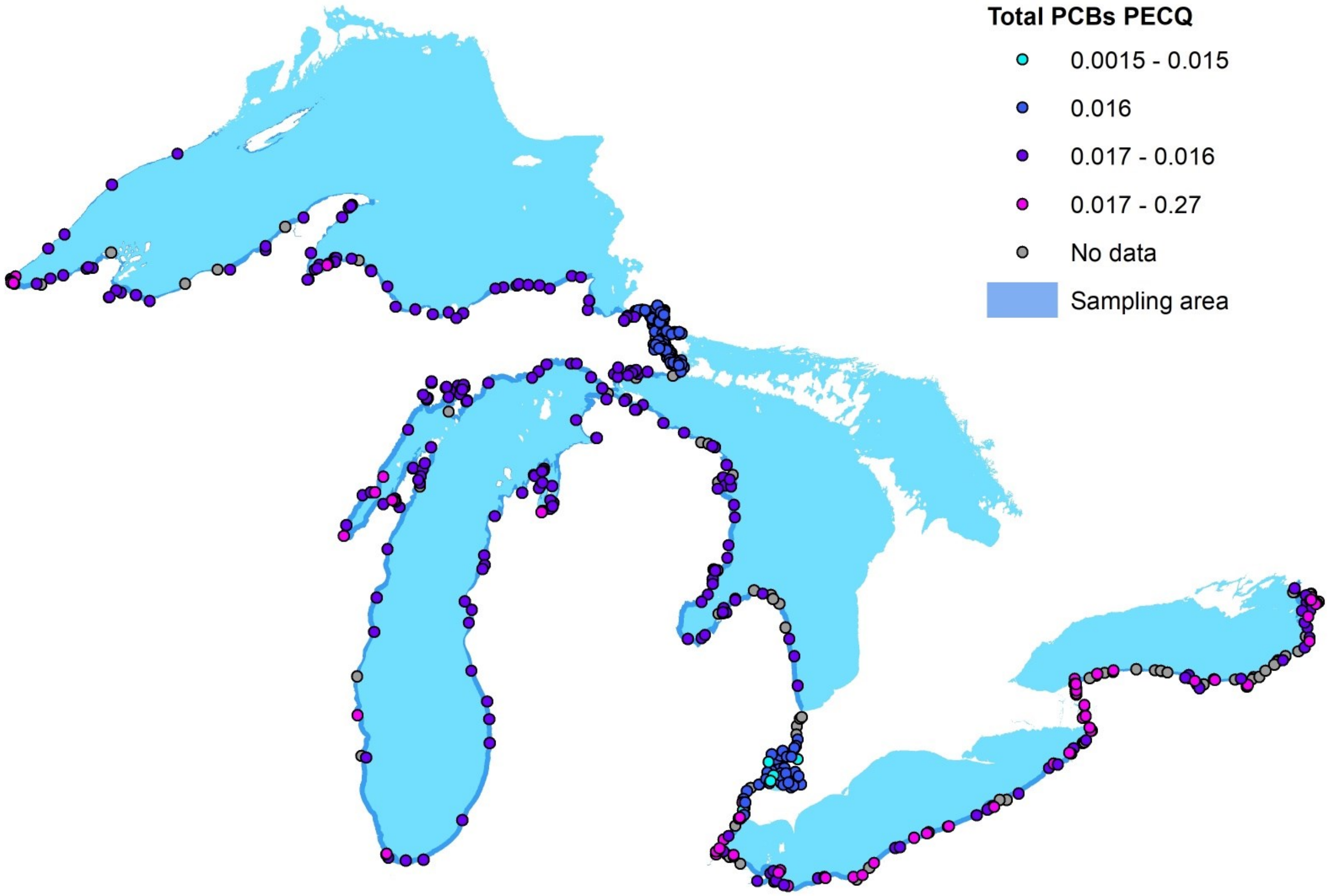


Figure E10. Total PECQ for sediment PCBs at sites sampled in the Great Lakes and connecting river systems for the 2015 NCCA. Figure symbology is based on value thresholds that represent quartiles of the measured results for sites in the Great Lakes, including the connecting river systems.

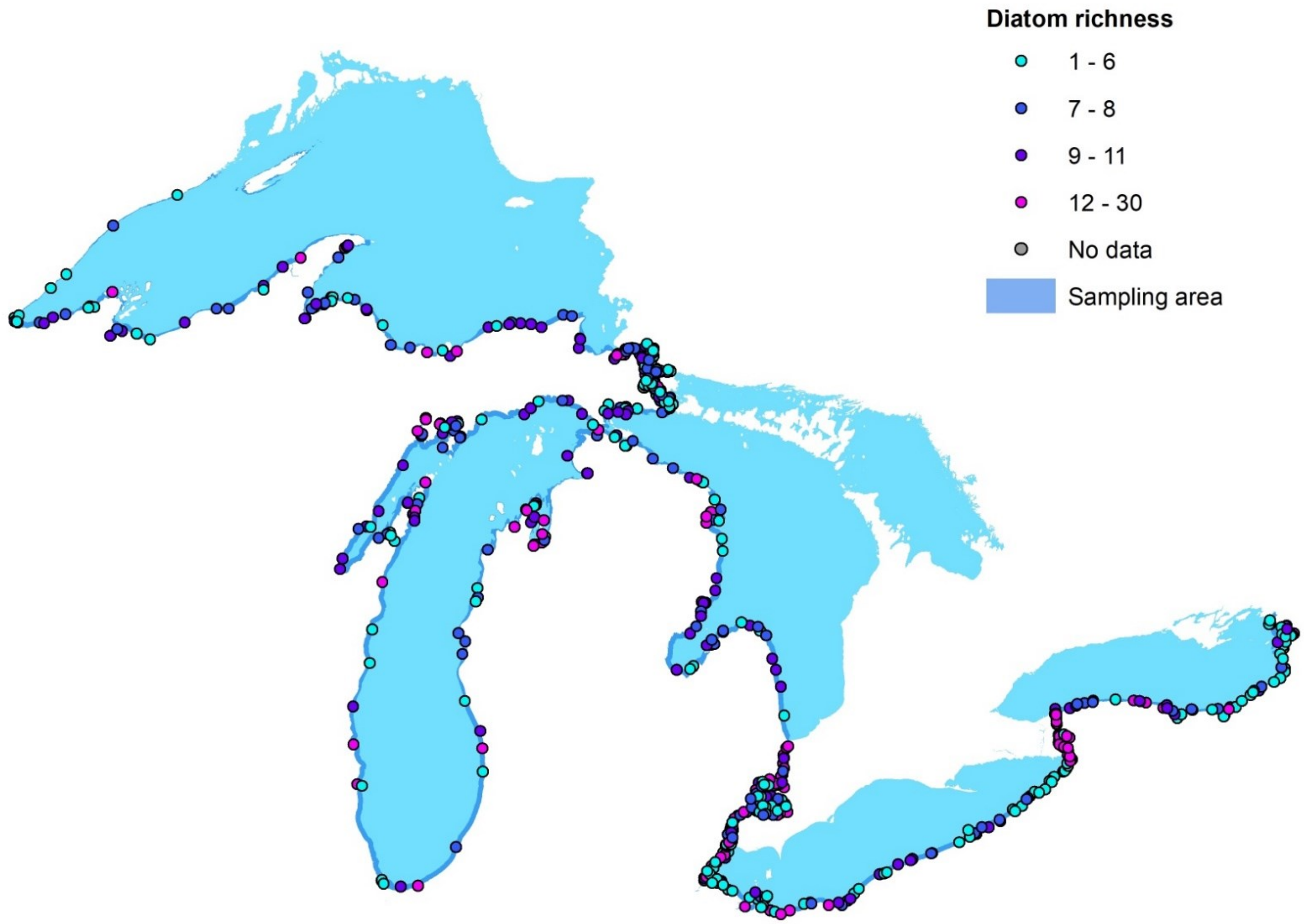


Fig. E11. Diatom taxa richness at sites sampled in the Great Lakes and connecting river systems for the 2015 NCCA. Figure symbology is based on value thresholds that represent quartiles of the measured results for sites in the Great Lakes, including the connecting river systems.

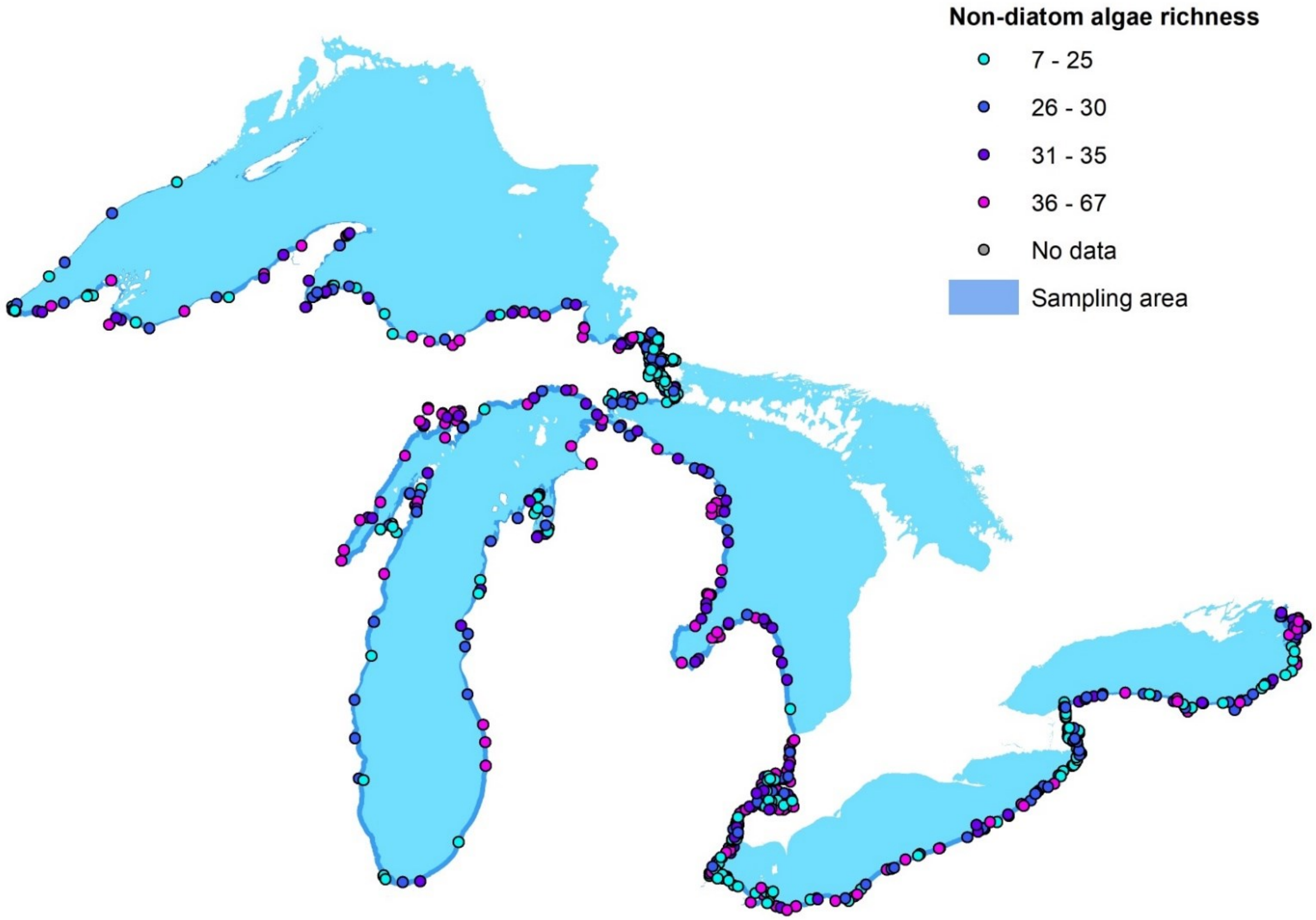


Fig. E12. Non-diatom phytoplankton taxa richness at sites sampled in the Great Lakes and connecting river systems for the 2015 NCCA. Figure symbology is based on value thresholds that represent quartiles of the measured results for sites in the Great Lakes, including the connecting river systems.

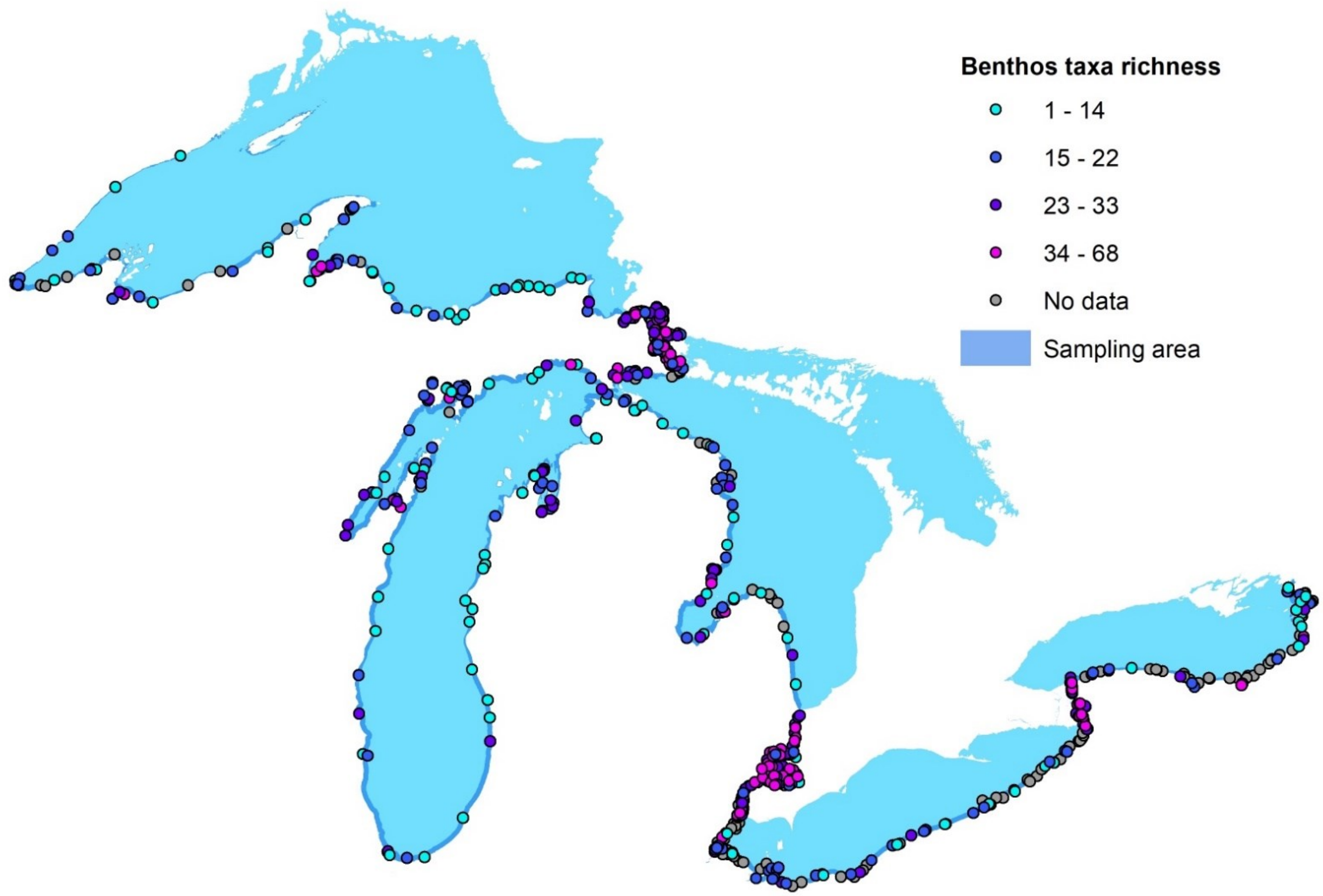


Fig. E13. Benthic macroinvertebrate taxa richness at sites sampled in the Great Lakes and connecting river systems for the 2015 NCCA. Figure symbology is based on value thresholds that represent quartiles of the measured results for sites in the Great Lakes, including the connecting river systems.