Development of an Algal Phytoplankton Metric for the Lake Erie Nearshore

Prepared for the Lake Erie Protection Fund

January 1, 2016

Gerald V. Sgro

John Carroll University

1 John Carroll Blvd.

University Heights

OH 44118

jsgro@jcu.edu

Great Lakes Protection Fund Award – SG 491-2015

ABSTRACT

The primary outcomes for this project have been met. A set of environmental quality metrics that quantitatively measure the health of the algal phytoplankton assemblages in the Lake Erie nearshore have been created. The methods for collection and analysis have been determined and tested and an initial evaluation of the metrics within the limits of this project was made. The most promising metrics are two diatom metrics, one based on relative abundance and the other on biovolume, calibrated to total phosphorus and a soft algae metric based on relative abundance calibrated to total phosphorus. These metrics may show significant trends with the phosphorus gradient when challenged with sufficient data. The effectiveness of the metrics is inconclusive from this study. The next step in the development of these metrics is more rigorous analysis in a pilot project. These metrics may address the severe need for biological metrics for the Ohio Environmental Protection Agency's Lake Erie monitoring stations.

INTRODUCTION

The Lake Erie ecology is in constant flux. Pollution, invasive species, harmful algal blooms (HABs), and climate change are some of the pressures driving changes to Lake Erie water quality. Thus, understanding the ecology and systematically assessing the quality of our lake is imperative for effective management. To this end the Ohio Environmental Protection Agency (OEPA) is developing a nearshore monitoring program.

The OEPA, as stated in their 2014 integrated report (Ohio Environmental Protection Agency, 2014), needs long term monitoring tools that will provide data to evaluate water quality trends, assess effectiveness of remedial efforts and nutrient reduction programs, measure compliance with jurisdictional regulatory programs, identify emerging problems, and support implementation of remedial action plans in Ohio's four areas of concern. The OEPA can use the fish IBI, chlorophyll, Carlson's Trophic State Index, the P-IBI (Kane et al., 2009), and water chemistry to monitor the lake. However, all of these measures are inadequate for the needs of the OEPA. Currently the OEPA has no biological monitoring tools for use at the deeper nearshore monitoring stations (Scott Winkler personal communication).

Algae in the offshore areas of the Great Lakes have been used narratively to track ecological trends by the United States Environmental Protection Agency (USEPA) from twice yearly synoptic collections. Algae in the nearshore have not been used in a systematic monitoring program to assess ecological condition beyond the crude observations of the presence or absence of HABs, chlorophyll measurements, trophic state measurements, or satellite imaging.

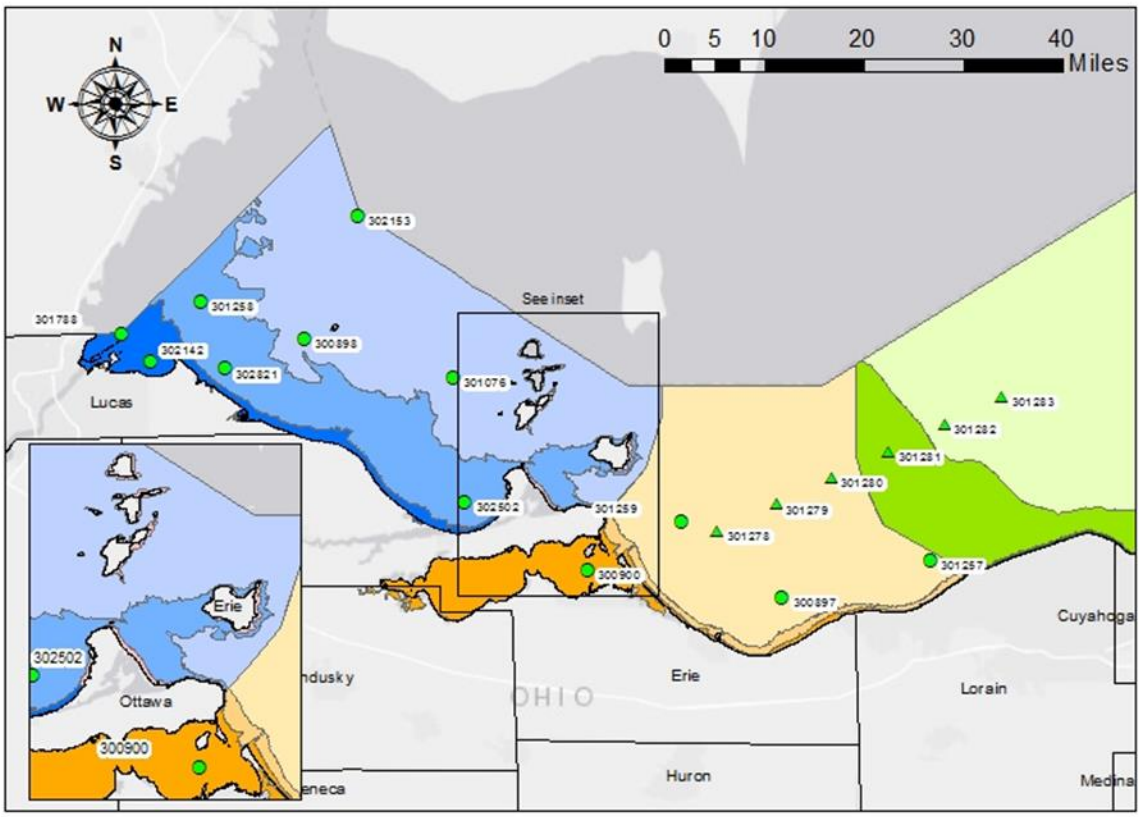
However, a benthic diatom index has been tested by the OEPA (Sgro, 2013) and has been shown to quantitatively assess the effects of phosphorus and other pollutants on the benthic diatom assemblages. This metric can provide a long term monitoring tool needed by the OEPA. However, this metric only assesses the benthic diatoms from samples collected at approximately one meter depth. There is still a need for biological monitoring tools in the deeper nearshore areas.

John Carroll University was awarded a grant from the Lake Erie Protection Fund to develop a phytoplankton water quality monitoring tool that could be used by the OEPA at deeper nearshore monitoring stations. This report describes the phytoplankton water quality metrics that resulted from this project. Further, this report describes the methods used for data collection and analysis for these metrics; what was learned about how and where the metrics can be applied; and how effective the metrics appear to be given the limited data from this project.

METHODS

Sites

The OEPA sampled six Lake Erie nearshore and shoreline sampling stations in the 2015 sampling season (Fig. 1). The sites were sampled in six different months (Table 1).


N
W
E
S
0 5 10 20 30 40
Miles
302153
301258
301788
302142
300898
302821
301076
See inset
Lucas
301283
301282
301281
301280
301279
301278
302502
301259
300900
301257
300897
Erie
302502
Ottawa
300900
Cuyahoga
Erie
Lorain
OHIO
Huron
Medina

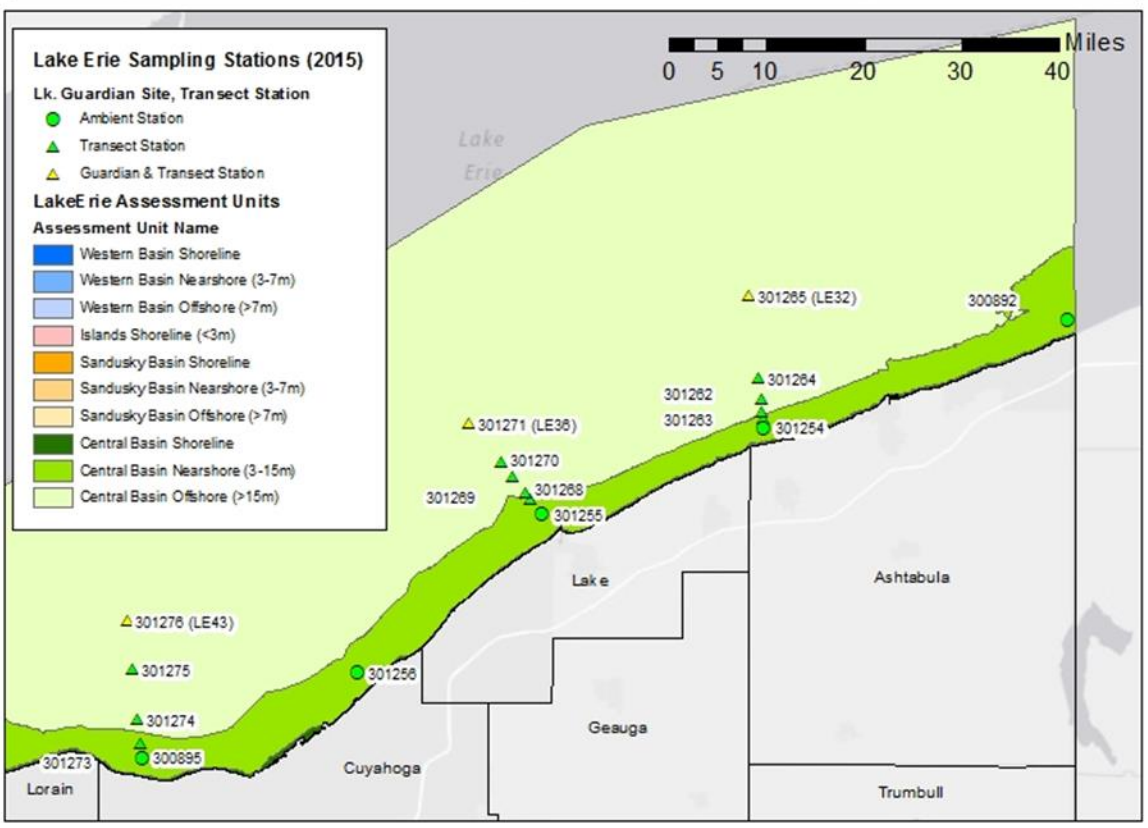

Lake Erie Sampling Stations (2015)
Lk. Guardian Site, Transect Station
Ambient Station
Transect Station
Guardian & Transect Station
LakeErie Assessment Units
Assessment Unit Name
Western Basin Shoreline
Western Basin Nearshore (3-7m)
Western Basin Offshore (>7m)
Islands Shoreline (<3m)
Sandusky Basin Shoreline
Sandusky Basin Nearshore (3-7m)
Sandusky Basin Offshore (>7m)
Central Basin Shoreline
Central Basin Nearshore (3-15m)
Central Basin Offshore (>15m)
0 5 10 20 30 40
Miles
Lake Erie
301265 (LE32)
300892
301264
301262
301263
301254
301271 (LE36)
301270
301269
301268
301255
Lake
Ashtabula
301276 (LE43)
301275
301256
301274
301273
300895
Geauga
Cuyahoga
Lorain
Trumbull

Fig. 1 Maps show all OEPA Lake Erie sampling stations. Stations sampled for this study are indicated in Table 1.

Site ID	Site	Date
301255	Fairport Harbor	9/15/2015
300895	Rocky River Ambient	5/7/2015
301076	Port Clinton	9/29/2015
302142	Maumee Bay of Maumee Bay State Park	4/15/2015
302502	North of Port Clinton	8/26/2015
302153	Off Detroit	7/28/2015
300895_2	Rocky River Ambient	7/1/2015
302142_2	Maumee Bay off Maumee Bay State Park	6/24/2015

Table 1. OEPA Lake Erie sampling stations sampled for this project including site description and data sampled.

Sampling Methods

The samples were collected by integrating equal fractions of water from throughout the water column. If the water depth was greater than 15 m, sample fractions were to be collected at 1 m, 5 m, 10 m, and 20 m or above the bottom. If the water depth was less than 15 m, samples were to be collected from the surface, middle, and bottom. If stratified conditions existed, fractions were to be taken from 1 m, 5 m, 10 m, and below the lower epilimnion. If the epilimnion was very shallow, fractions were to be taken from a maximum of 4 and a minimum of 2 sampling depths.

The integrated sample was split for diatoms and soft algae. The samples were filtered (< 5 lbs/m^2 pressure) in the field. The diatoms were filtered with a 47 mm 1.2 µ membrane filter and the soft algae was sampled with a 25 mm 1.2 µ membrane filter (EMD Millipore Company). The volume of water filtered was recorded. The water samples were treated with 2% by volume glutaraldehyde. The membrane filters were stored in urine sample cups and coated with glutaraldehyde.

Diatom Analysis

The membrane filters for diatom analysis were cleared by boiling in nitric acid diluted 50% by volume with water. The samples were allowed to cool then were centrifuged at 1800 RPM for ten minutes. The contents of the tubes were aspirated, refilled with deionized water and shaken to break up the pellet. This rinsing process was repeated five times. After the final rinse the pellet was diluted with two ml of deionized water and again broken up. Three microscope slides from each sample were prepared by

covering a microscope coverslip with .5 ml of the sample solution. The coverslips were allowed to dry then affixed to microscope slides with Naphrax mountant.

The diatom specimens were identified and enumerated using an Olympus B-MAX photomicroscope with Nomarski DIC optics at 1000X. Diatoms were identified to the most specific taxon possible using numerous diatom check lists, iconographs, and original literature from John Carroll University's extensive diatom library. Counts of approximately 500 valves per slide were made or for slides with fewer tha 500 valves an entire slide was counted (15 transects) and relative density was calculated on the basis of these counts. Digital micrographs of several taxa were taken and are on file at John Carroll University.

Soft Algae Analysis

The soft algae filter was scraped with a pipette bulb into a beaker containing 10 ml DI water and refrigerated. Each sample was shaken and a subsample was pipetted into a Tchen (Tchen 1952) counting chamber. Counts were made to 250 specimens or ten subsamples, whichever came first. At least one transect was counted for each subsample. Counts where based on single cell specimens. Each filament or colony was counted as one specimen for the counts and an estimate was made of the number of cells each filament or colony contained for abundance calculations.

The soft algae specimens were identified and enumerated using an Olympus B-MAX photomicroscope with Nomarski DIC optics at 200X. Specimens were identified to the most specific taxon possible using numerous soft algae references, iconographs, and original literature from John Carroll University's extensive algae library.

The 302142 sample (Maumee Bay off Maumee Bay State Park on 4/15/2015) was analyzed by clearing the membrane filter for soft algae analysis with immersion oil and identifying taxa on the cleared filter at 400X (Lind 1985). This method was replaced by the Tchen (1952) method to achieve better resolution for all other samples.

Chemistry analysis

Environmental chemistry parameters collected and used in this analysis include: total suspended solids (TSS) and dissolved phosphorus (DP) as orthophosphate. These parameters were analyzed at the water chemistry lab of the OEPA. All chemistry samples were collected by the OEPA at the study sites with the diatom samples. The OEPA water chemistry lab has not signed off on the TP values collected at the study sites due to possible problems with the analysis. TSS was substituted as a reasonable proxy for TP values in this report.

Metric Construction

Our objective was to develop metrics that can provide a quantitative score for a study site based on the sensitivity of the algal taxa to TP and/or DP. That is, the metrics should score the health of the phytoplankton assemblages as impacted by phosphorus and pollution for which phosphorus is a proxy.

These phytoplankton metrics were constructed along the lines of the successful benthic diatom metric (Sgro et al., 2007) already tested by the OEPA that used species weighted average coefficients transformed into species indicator values to calculate metric scores for sites. Here we used data from Reavie et al. (2014) to develop the phytoplankton indicator values.

Reavie et al. (2014) developed weighted average coefficients based on algal density and biovolume calibrated to TP and DP for 263 algal taxa. The data for the weighted average training set was collected as part of the USEPA's biological monitoring program for the Great Lakes. This data included synoptic sampling in the spring and fall from 2007 to 2011 from standard stations throughout the Great Lakes basin; a total of 717 sampling events.

The weighted average coefficients were scaled based on the range of the transformed phosphorus concentrations measured during the USEPA monitoring program (Reavie et al., 2014). These coefficients were again rescaled for this project to be more consistent with the benthic diatom metric created for the OEPA shoreline sample stations.

The relative abundance metric score for a sample is calculated as a weighted average by multiplying the abundance for each taxa in the sample by its indicator value for either TP or DP then summing over all taxa and dividing that value by the summed taxa abundance of taxa with indicator values in the sample:

$$\frac{\sum_1^n A \times V}{\sum_1^n A}$$

Where A is the abundance of each taxon with indicator values in the sample and V is the indicator value for either TP or DP and *n* is the number of taxa in the sample.

Biovolume metric scores are calculated by using biovolume in place of abundance (A) in the above formula. Biovolume was determined by calculating the biovolume for one specimen of a taxon using the formulas in Standard Operating Procedure for Phytoplankton Analysis (2010), then multiplying the biovolume for the single specimen by the total abundance of that taxon found in the sample. The calculation for biovolume for a single specimen was based on average measurements of the first ten specimens for each taxon encountered in the analysis and/or default measurements for the taxa from Standard Operating Procedure for Phytoplankton Analysis (2010).

Results

Chemistry

TSS, used in this study as a proxy for TP, ranged from 1 mg/L to 18 mg/L. All values except for the Maumee Bay off Maumee Bay State Park sample on 4/15/15 (302142; 18 mg/L) were 8 mg/L or less. All algae appeared dead in the 302142 sample. DP concentrations ranged from .001 mg/L to 0.178 mg/L. All values except for the Maumee Bay off Maumee Bay State Park sample on 6/24/15 (302142_2; .0178 mg/L) were 0.077 mg/L or less. Diatoms were too few to count in this 302142_2 sample (Table 2).

Sample	DP (mg/L)	TSS (mg/L)
300895	0.002	2.5
301076	0.0015	1
301255	0.006	1
302142	0.077	18
302153	0.001	5
302502	0.002	8
300895_2	0.015	6
302142_2	0.178	5

Table 2. DP and TSS chemistry concentrations used in this analysis.

Metric Indicator Values

Indicator values (*V*) for eight separate algal metrics (four for diatoms and four for soft algae) were created (Tables 3, 4). Number one indicates poorest water quality and the highest score for each metric indicates best water quality:

- Diatom relative abundance calibrated to TP on a 1 – 8 scale;
- Diatom relative abundance calibrated to DP on a 1 -8 scale;
- Diatom relative biovolume calibrated to TP on a 1 -7 scale;
- Diatom relative biovolume calibrated to DP on a 1 – 6 scale;
- Soft algae relative abundance calibrated to TP on a 1 – 6 scale;
- Soft algae relative abundance calibrated to DP on a 1 – 4 scale;
- Soft algae relative biovolume calibrated to TP on a 1 – 5 scale;
- Soft algae relative biovolume calibrated to DP on a 1 – 5 scale;

TAXA	AUTHORITY	DP-A	TP-A	DP-B	TP-B
Achnanthes clevei	Grun.	6	6	5	6
Achnanthes detha	Hohn & Hellerm.	4	3	5	6
Achnanthes exigua	Grun.	6	4	4	2
Achnanthes flexella	(Kütz.) Brun	7	7	5	6
Achnanthes flexella var. alpestris	Brun	4	3	4	4
Achnanthes lanceolata	(Breb.) Grun.	5	4	4	4
Achnanthes linearis	(W. Sm.) Grun.	8	7	6	6
Achnanthes microcephala	(Kütz.) Grun.	7	6	5	6
Achnanthes minutissima	Kütz.	5	4	5	5
Achnanthes sp.		4	5	5	6
Achnanthes suchlandti	Hust.	4	3	2	3
Actinocyclus normanii	(Juhl.-Dannf.) Hust. (?)	5	4	3	3
Amphora ovalis	(Kütz.) Kütz.	8	8	6	7
Amphora ovalis var. pediculus	(Kütz.) V.H. ex DeT.	5	5	4	5

Amphora sp.		5	4	4	5
Anomoeoneis vitrea	(Grun.) Ross	6	6	5	6
Asterionella formosa	Hass.	7	7	5	6
Aulacoseira ambigua	(Grun.) Simonsen	7	7	5	6
Aulacoseira distans	(Ehr.) Simonsen	7	7	5	6
Aulacoseira granulata	(Ehr.) Simonsen	4	3	3	3
Aulacoseira islandica	(O. Mull.) Simonsen	5	4	3	4
Aulacoseira italica	(Ehr.) Simonsen	4	5	2	4
Caloneis bacillum	(Grun.) Cl.	5	3	3	3
Cocconeis pediculus	Ehr.	6	6	5	6
Cocconeis placentula	Ehr.	4	3	3	3
Cocconeis placentula var. lineata	(Ehr.) V.H.	4	2	3	1
Cyclostephanos dubius	(Fricke) Round	6	4	4	4
Cyclostephanos invisitatus	(Hohn & Hell.) Ther. Stoer. Hak.	1	2	1	2
Cyclostephanos tholiformis	Stoerm. Hak. & Ther.	5	5	4	4
Cyclotella atomus	Hust.	7	7	5	5
Cyclotella atomus (fine form)	Hust.	7	7	5	6
Cyclotella comensis	Grun.	8	8	6	7
Cyclotella comensis r. c. w/ proc.	in house taxon	7	7	5	6
Cyclotella comensis var. 1		7	8	5	7
Cyclotella comta	(Ehr.) Kütz.	7	8	5	7
Cyclotella meneghiniana	Kütz.	6	5	4	4
Cyclotella michiganiana	Skv.	8	8	6	7
Cyclotella ocellata	Pant.	7	7	5	6
Cyclotella operculata	(Ag.) Kütz.	8	8	5	7
Cyclotella operculata var. unipunctata	Hust.	7	7	5	6
Cyclotella pseudostelligera	Hust.	7	7	5	6
Cyclotella rossi	Hak.	8	8	6	7
Cyclotella sp.		7	7	4	5
Cyclotella stelligera	(Cl. & Grun.) V.H.	7	7	5	6
Cyclotella tripartita	Kütz.	7	8	6	7
Cymatopleura solea	(Breb. & Godey) W. Sm.	6	6	5	6
Cymbella affinis	Kütz.	5	4	4	4
Cymbella cesatii	(Rabh.) Grun. ex A.S.	7	7	5	7
Cymbella cuspidata	Kütz.	7	7	5	6
Cymbella cymbiformis	Ag.	6	6	4	6
Cymbella microcephala	Grun.	5	4	4	4
Cymbella minuta var. silesiaca	(Bleisch ex Rabh.) Reim.	5	4	4	4
Cymbella pusilla	Grun.	6	6	5	6
Cymbella sinuata	Greg.	6	6	5	6

Cymbella sp.		6	5	4	5
Denticula sp.		4	3	3	3
Denticula subtilis	Grun.	7	7	5	6
Diatoma sp.		6	6	4	5
Diatoma tenuis	Ag.	7	6	5	6
Diatoma tenue var. elongatum	Lyngb.	5	5	4	5
Diatoma vulgare	Bory.	5	4	4	5
Diploneis ovalis	(Hilse) Cl.	6	5	4	5
Diploneis parma	Cl.	5	5	4	5
Diploneis pseudovalis	Hust.	5	4	3	3
Diploneis sp.		7	7	5	7
Fragilaria brevistriata	Grun.	4	3	3	3
Fragilaria capucina	Desm.	5	5	4	4
Fragilaria capucina var. mesolepta	(Rabh.) Grun.	5	4	4	4
Fragilaria construens	(Ehr.) Grun.	4	3	5	5
Fragilaria construens var. venter	(Ehr.) Grun.	6	5	4	5
Fragilaria crotonensis	Kitton	7	6	5	6
Fragilaria intermedia	Grun.	7	6	5	6
Fragilaria pinnata	Ehr.	5	4	4	4
Fragilaria sp.		8	8	6	7
Fragilaria vaucheriae	(Kütz.) Peters.	6	5	4	5
Gomphonema olivaceum	(Lyngb.) Kütz.	3	2	2	2
Gomphonema parvulum	(Kütz.) Kütz.	5	3	3	3
Gomphonema sp.		4	2	3	2
Gyrosigma scalproides	(Rabh.) Cl.	7	7	5	6
Hannaea arcus	(Ehr.) Patr.	8	8	5	7
Navicula capitata	Ehr.	6	6	5	6
Navicula cryptocephala	Kütz.	4	4	3	4
Navicula cryptocephala var. veneta	(Kütz.) Rabh.	4	3	3	3
Navicula decussis	Ostr.	7	7	4	6
Navicula gregaria	Donk.	3	4	1	2
Navicula menisculus	Schum.	5	4	4	4
Navicula minuscula	Grun.	5	4	3	3
Navicula pupula	Kütz.	7	8	5	6
Navicula pupula var. mutata	(Krasske) Hust.	7	8	5	7
Navicula radiosa	Kütz.	6	5	5	7
Navicula radiosa var. tenella	(Breb.) Cl. & Moll.	5	4	4	4
Navicula sp.		6	6	5	6
Navicula tripunctata	(O.F. Mull.) Bory	5	4	3	4
Navicula viridula	(Kütz.) Ehr.	5	3	3	4
Nitzschia acicularis	W. Sm.	7	7	5	6

Nitzschia amphibia	Grun.	4	3	3	5
Nitzschia angustata	(W. Sm.) Grun.	5	3	4	4
Nitzschia angustatula	Lange-Bertalot 1987	4	4	2	3
Nitzschia denticula	Grun.	3	1	3	2
Nitzschia dissipata	(Kütz.) Grun.	6	6	4	5
Nitzschia fonticola	Grun.	6	5	4	4
Nitzschia frustulum	(Kütz.) Grun.	6	6	4	5
Nitzschia gracilis	Hantz.	7	7	5	6
Nitzschia inconspicua	Grun.	7	6	4	4
Nitzschia lauenburgiana	Hust.	7	6	5	6
Nitzschia palea	(Kütz.) W. Sm.	5	5	4	5
Nitzschia paleacea	Grun.	7	7	5	6
Nitzschia recta	Hantz.	6	5	4	4
Nitzschia sp.		6	5	3	4
Nitzschia subacicularis	Hust.	6	6	4	5
Rhizosolenia eriensis	H.L. Sm.	8	8	5	7
Rhizosolenia longiseta	Zach.	7	8	5	7
Rhizosolenia sp.		8	8	6	7
Rhoicosphenia curvata	(Kütz.) Grun. ex Rabh.	3	2	4	4
Stephanocostis sp.	Genkal & Kosmina 1985	5	6	5	6
Stephanodiscus alpinus	Hust.	5	5	4	5
Stephanodiscus alpinus Type I	Hust.	6	6	5	6
Stephanodiscus alpinus Type II/III	Hust.	5	5	3	4
Stephanodiscus binderanus	(Kütz.) Krieg.	5	4	2	3
Stephanodiscus conspicueporus	Stoermer, Hakansson & Theriot 1988	7	8	5	7
Stephanodiscus hantzschii f. hantzschii	Hak. & Stoerm.	6	6	4	5
Stephanodiscus hantzschii f. tenuis	Hak. & Stoerm.	5	4	3	3
Stephanodiscus minutulus	Hak.	7	6	5	6
Stephanodiscus minutulus var. 1 JCU	JCU	5	5	5	6
Stephanodiscus minutulus var. 2 JCU	JCU	6	6	4	5
Stephanodiscus parvus	Stoerm. & Hak.	6	6		
Stephanodiscus sp. #10	in house taxon	7	7	5	6
Stephanodiscus sp. #51	in house taxon	6	7	5	6
Stephanodiscus subtransylvanicus	Gasse	8	8	6	7
Surirella angusta	Kütz.	7	7	5	6
Surirella ovalis	Breb.	4	5	3	4
Surirella ovata	Kütz.	4	3	2	2
Surirella sp.		4	4	3	4

Synedra amphicephala var. austriaca	(Grun.) Hust.	7	7	5	6
Synedra delicatissima	W. Sm.	7	7	5	6
Synedra delicatissima var. angustissima	Grun.	7	7	5	6
Synedra filiformis	Grun.	8	8	6	7
Synedra filiformis var. exilis	A. Cl.	7	8	5	7
Synedra ostenfeldii	(Krieg.) A. Cl.	7	7	5	6
Synedra parasitica	W. Sm.	7	6	5	5
Synedra radians	Kütz.	7	8	5	7
Synedra rumpens	Kütz.	7	7	5	6
Synedra ulna	(Nitz.) Ehr.	6	6	5	5
Synedra ulna var. biceps	Kütz.	7	7	5	6
Synedra ulna var. chaseana	Thomas	7	7	5	6
Tabellaria flocculosa	(Roth) Knud.	7	7	5	6

Table 3. Diatom taxa with indicator values: TP-A = relative abundance value for TP; TP-B = relative biovolume value for TP; DP-A = relative biovolume value for DP; DP-B = relative biovolume value for DP. There have been many changes in the taxa names. The names on this list have not been updated for this study. Refer to http://www.algaebase.org/ for current accepted names.

TAXA	AUTHORITY	DP-A	TP-A	DP-B	TP-B
Amphidinium sp.		3	6	5	5
Anabaena circinalis	Rabh.	2	3	3	2
Anabaena flos-aquae	(Lyngb.) Breb.	3	5	4	4
Anabaena sp.		4	6	5	5
Ankistrodesmus falcatus	(Corda) Ralfs	3	5	4	4
Ankistrodesmus falcatus var. fasciculatus	(Corda.)	3	5	4	4
Ankistrodesmus falcatus var. mirabilis	(W. & G.S. West) G.S. West	3	5	4	4
Ankistrodesmus gracilis	(Reins.) Kors.	3	5	4	4
Ankistrodesmus spiralis	(Turn.) Lemm.	4	6	5	5
Ankyra judayi	(G.M. Sm.) Fott	3	4	3	2
Aphanizomenon flos-aquae	(Lyngb.) Ralfs	3	4	4	4
Aphanocapsa sp.		3	5	4	4
Aphanothece sp.		3	5	4	4
Bitrichia chodatii	(Rev.) Chod.	3	5	4	4
Bitrichia ollula	(Fott) Nich.	3	6	4	5
Ceratium hirundinella	(O.F. Mull.) Schr.	3	5	4	4
Chlamydomonas sp.		2	4	4	4
Chlorella sp.		3	6	4	5

Chromulina sp.		3	5	4	4
Chroococcus limneticus	Lemm.	3	5	4	4
Chrysolykos planktonicus	Mack.	4	6	4	5
Chrysolykos skujae	(Nauw.) Bourr.	4	6	5	5
Chrysosphaerella longispina	Laut. emend. Nich.	3	5	4	4
Coelastrum astroideum	De-Not	3	5	4	4
Coelastrum microporum	Nag. in A. Braun	3	5	3	3
Cosmarium phaseolus	Breb. (?)	3	5	4	4
Cosmarium sp.		3	5	4	3
Crucigenia quadrata	Morr.	4	6	5	5
Cryptomonas erosa	Ehr.	3	5	4	4
Cryptomonas phaseolus	Skuja	2	4	4	3
Cryptomonas pyrenoidifera	Geitl.	3	5	4	4
Cryptomonas reflexa	Skuja	3	5	4	4
Cryptomonas rostratiformis	Skuja	3	5	4	5
Cryptomonas sp.		3	4	4	4
Desmarella moniliformis	Kent	3	6	4	4
Desmarella sp.		3	6	4	4
Dictyosphaerium ehrenbergianum	Nag.	3	5	4	4
Dictyosphaerium pulchellum	Wood	3	4	4	3
Dinobryon acuminatum	Rutt.	4	6	4	5
Dinobryon bavaricum	Imhof	4	6	4	4
Dinobryon bavaricum var. medium	(Lemm.) Krieg.	4	6	5	5
Dinobryon bavaricum var. vanhoeffenii	(Bachm.) Krieg.	3	6	4	5
Dinobryon borgei	Lemm.	3	6	5	5
Dinobryon cylindricum	Imhof	3	5	4	4
Dinobryon divergens	Imhof	4	5	4	4
Dinobryon sertularia	Ehr.	4	6	5	5
Dinobryon sociale	Ehr.	3	5	5	4
Dinobryon sociale var. americanum	(Brunnth.) Bachm.	3	5	4	4
Dinobryon sociale var. stipitatum	(Stein) Lemm.	4	6	5	5
Dinobryon sp.		4	6	4	5
Diplochloris lunata	(Fott) Fott	3	5	4	4
Elakatothrix genevensis	(Rev.) Hind.	3	5	4	4
Elakatothrix sp.		3	5	4	4
Epipyxis sp.		3	5	4	4
Eudorina sp.		3	5	4	4
Glenodinium sp.		3	5	4	4
Gloeocystis planktonica	(W. & G.S. West) Lemm.	3	4	3	2
Gloeocystis sp.		3	4	4	3
Gloeotila sp.		4	6	5	4

Golenkinia radiata	(Chod.) Wille	3	5	5	4
Gomphosphaeria lacustris	Chod.	3	4	4	3
Gymnodinium helveticum	Pen.	3	5	4	4
Gymnodinium sp.		3	5	4	5
Haptophyceae		3	5	4	4
Kephyrion boreale	Skuja	3	6	4	5
Kephyrion cupuliformae	Conr.	3	5	5	5
Kephyrion sp.		3	5	5	5
Mallomonas sp.		3	5	4	4
Merismopedia tenuissima	Lemm.	3	5	4	4
Micractinium pusillum	Fres.	2	4	3	3
Microcystis aeruginosa	(Kütz.) emend. Elenkin	1	1	2	1
Monoraphidium braunii	(Nag. in Kütz.) Kom.-Legn.	3	5	4	4
Monoraphidium contortum	(Thuret in Breb.) Kom.-Legn.	3	5	4	4
Monoraphidium griffithii	(Berkel) Kom.-Legn.	4	6	5	5
Monoraphidium irregulare	(G.M. Sm.) Kom.-Legn.	3	6	5	5
Monoraphidium minutum	(Nag.) Kom.-Legn.	3	4	3	3
Monoraphidium setiforme	(Nyg.) Kom.-Legn.	2	4	3	4
Monoraphidium skujae	Fott	3	6	4	5
Monoraphidium sp.		3	5	4	4
Monosiga sp.		3	5	4	4
Mougeotia sp.		1	2	2	2
Ochromonas sp. - ovoid		3	5	4	4
Oocystis borgei	Snow	3	5	4	4
Oocystis gigas var. incrassata	West & West sensu Skuja	3	6	4	4
Oocystis parva	W. & G.S. West	3	5	4	4
Oocystis pusilla	Hansg.	3	5	4	4
Oscillatoria agardhii	Gom.	3	4	3	2
Oscillatoria limnetica	Lemm.	3	5	4	4
Oscillatoria minima	Gick.	3	5	4	4
Oscillatoria sp.		3	5	4	4
Peridinium sp.		3	5	4	4
Phacus sp.		1	2	2	1
Pseudokephyrion attenuatum	Hill	4	6	5	5
Pseudokephyrion ellipsoidium	(Pasch.) Schm.	4	6	5	5
Pseudokephyrion millerense	Nich.	4	5	4	4
Pseudokephyrion minutissimum	Corr.	4	6	5	5
Rhodomonas lens	Pasch. & Rutt.	3	5	4	4
Rhodomonas minuta	Skuja	2	4	4	4
Scenedesmus bijuga	(Turp.) Lag.	3	4	4	4
Scenedesmus ecornis	(Ralfs) Chod.	3	4	4	3

Scenedesmus opoliensis	P. Richt.	2	3	3	2
Scenedesmus quadricauda	(Turp.) Breb.	2	4	3	3
Scenedesmus sp.		2	4	1	1
Schroederia setigera	(Schroed.) Lemm.	1	3	2	1
Sphaerocystis schroeteri	Chod.	3	4	3	3
Spiniferomonas sp.		4	6	5	5
Stichogloea sp.		3	5	4	4
Synechococcus sp.		3	5	4	4
Tetraedron minimum	(A. Braun) Hansg.	3	5	4	4
Tetraedron minimum var. tetralobulatum	Reins	4	6	5	5
Trachelomonas sp.		1	2	2	2

Table 4. Soft algae taxa with indicator values: TP-A = relative abundance value for TP; TP-B = relative biovolume value for TP; DP-A = relative biovolume value for DP; DP-B = relative biovolume value for DP. There have been many changes in the taxa names. The names on this list have not been updated for this study. Refer to http://www.algaebase.org/ for current accepted names.

Samples and Taxa

Only 166 diatom valves were counted from sample 302153 (off Detroit). Almost no diatoms were in the 302142_2 sample (Maumee Bay off Maumee Bay State Park on 6/24/2015), only soft algae was present. Almost no living diatom algae was found in the 302142 sample (Maumee Bay off Maumee Bay State Park on 4/15/2015) and no soft algae was present. No soft algae was present in sample 300895 (Rocky River ambient 5/7), only diatoms were present.

The most common soft algae species was *Oscillatoria (Planktothrix) agardhii* which appeared in five of six samples. The most common diatom species were *Cyclotella ocellata*, *Discotella pseudostelligera*, *Stephanodiscus parvus*, and *Aulacoseira ambigua*. Each appeared in six of seven samples. A total (gamma diversity) of 55 soft algal taxa and 116 diatom taxa were identified in this study (Tables 5, 6). Maumee Bay off Maumee Bay State Park on 4/15/15 had the highest diatom richness, however all diatom algae appeared dead. Fairport Harbor on 9/15/15 had the next highest diatom taxa richness (37). The highest soft algae richness (22) was found at Port Clinton on 9/29/15. Shannon diversity (a measure of alpha diversity that takes in to account both species richness and eveness) was highest for diatoms (aside from Maumee Bay off Maumee Bay State Park on 4/15/15) at the Port Clinton site on 9/29/15 (2.42). The highest Shannon index calculated for soft algae was at the off Detroit site on 7/28/15 (2.67; Table 7). These Shannon index scores indicate that these sites were dominated by a few species. The soft algae count with each colony and filament counted as one specimen was used for the calculations. Beta diversity (a measure of change in a set of samples) was 2.71 for soft algae and 2.48 for diatoms. A beta diversity score >5 is considered high beta diversity.

TAXA	AUTHORITY
Actinastrum hantzschii	Lag.
Anabaena sp.	
Ankistrodesmus convolutus var. minutus	(Nag.) Rabh.
Ankistrodesmus falcatus	(Corda) Ralfs
Centric Diatom	
Ceratium hirundinella	(O.F. Mull.) Schr.
Characium sp.	
Chlamydomonas sp.	
Chlorella sp.	
Chroococcus limneticus	Lemm.
Chroococcus minutus	(Kütz.) Nag.
Chroococcus sp.	
Chrysococcus sp.	
Coelastrum microporum	Nag. in A. Braun
Coelosphaerium dubium	Grun.
Cryptomonas erosa	Ehr.
Cryptomonas sp.	
Cylendrospermopsis sp.	
Dictyosphaerium pulchellum	Wood
Didymocystis sp.	
Dinobryon cylindricum	Imhof
Dinobryon divergens	Imhof
Euglena sp.	
Gloeotila sp.	
Gymnodinium sp.	
Mallomonas sp.	
Merismopedia sp.	
Micractinium sp.	Fresnius
Microcystis aeruginosa	(Kütz.) emend. Elenkin
Microcystis wesenbergii	(Komárek) Komárek
Oocystis borgei	Snow
Oocystis parva	W. & G.S. West
Oocystis sp.	
Oscillatoria agardhii	Gom.
Oscillatoria limnetica	Lemm.
Oscillatoria minima	Gick.
Oscillatoria sp.	
Oscillatoria subbrevis	Schm.
Pediastrum duplex	Meyen
Pediastrum simplex var. duodenarium	(Bail.) Rabh.

Pediastrum sp.	
Pennate Diatom	
Peridinium sp.	
Scenedesmus dimorphus	(Turp.) Kütz.
Scenedesmus quadricauda	(Turp.) Breb.
Scenedesmus quadricauda var. longispina	(Chod.) G.M. Sm
Scenedesmus sp.	
Schroederia setigera	(Schroed.) Lemm.
Sphaerocystis schroeteri	Chod.
Spiniferomonas sp.	
Staurastrum sp.	
Trachelomonas sp.	
Unidentified Coccoid Cyanophyta	
Unidentified coccoid spherical	
Unidentified Colonial greens	
Unidentified loricate sp.	

Table 5. Soft algae taxa found from all samples in this study. There have been many changes in the taxa names. The names on this list have not been updated for this study. Refer to http://www.algaebase.org/ for current accepted names.

TAXA	AUTHORITY
Achnanthes affinis	Grun.
Achnanthes frequentissima	(Lange-Bertalot) Lange-Bertalot
Achnanthes minutissima	Kütz.
Actinocyclus normanii	(Juhl.-Dannf.) Hust. (?)
Amphora copulata	(Kütz.)Schoeman & Archibald 1986
Amphora pediculus	(Kützing) Grunow ex A.Schmidt
Asterionella formosa	Hass.
Aulacoseira alpigena	(Grunow) Krammer
Aulacoseira ambigua	(Grun.) Simonsen
Aulacoseira granulata	(Ehr.) Simonsen
Aulacoseira granulata var. angustissima	(O. Mull.) Simonsen
Aulacoseira granulata var. valida	(Hust.) Simonsen
Aulacoseira islandica	(O. Mull.) Simonsen
Aulacoseira islandica alpha	(O. Mull.) Simonsen
Aulacoseira sp. 1 JCU	
Aulacoseira subarctica	(O. Mull.) Haworth
Craticula accomoda	(Hustedt) D.G.Mann
Craticula buderi	(Hustedt) Lange-Bertalot
Cyclostephanos costatilimbus	(Kobayasi & Kobayashi) Stoermer, Hakanss

Cyclostephanos dubius	(Fricke) Round
Cyclostephanos invisitatus	(Hohn & Hellerman) Ther. Stoer. Hak. 198
Cyclostephanos sp. 1 UMD	
Cyclostephanos tholiformis	Stoerm. Hak. & Ther.
Cyclotella atomus	Hust.
Cyclotella atomus (fine form)	Hust.
Cyclotella atomus var. 1	
Cyclotella comensis	Grun.
Cyclotella comensis var. 1	
Cyclotella comensis var. 2 UMD	
Cyclotella cryptica	Reimann. Lewin. & Guillard.
Cyclotella michiganiana	Skv.
Cyclotella michiganiana/comensis UMD	
Cyclotella ocellata	Pant.
Cyclotella operculata var. unipunctata	Hust.
Cyclotella RCWP	
Cyclotella rossi	Hak.
Cyclotella wolterecki	Hust.
Cymatopleura solea	(Breb. & Godey) W. Sm.
Diatoma tenuis	Ag.
Discotella pseudostelligera	(Hustedt) Houk & Klee
Discotella stelligera	(Cleve & Grunow) Houk & Klee
Fragilaria capucina	Desm.
Fragilaria capucina var. mesolepta	(Rabh.) Grun.
Fragilaria capucina/vaucheriae complex	
Fragilaria construens var. venter	(Ehr.) Grun.
Fragilaria crotonensis	Kitton
Fragilaria mesolepta	Rabenhorst
Fragilaria nanana	Lange-Bertalot
Fragilaria pinnata	Ehr.
Melosira varians	Ag.
Navicula antonii	Lange-Bertalot
Navicula atomus	(Kütz.) Grun.
Navicula capitata	Ehr.
Navicula capitatoradiata	Germain
Navicula costulata	Grun. in Cl. & Grun.
Navicula cryptocephala	Kütz.
Navicula cryptotenella	Lange-Bertalot
Navicula gregaria	Donk.
Navicula minima	Grun.
Navicula minuscula	Grun.

Navicula minuscula var. muralis	(Grun.) Lange-Bert.
Navicula rostellata	Kützing
Navicula tantula	Hust.
Navicula tripunctata	(O.F. Mull.) Bory
Nitzschia abbreviata	Hustedt
Nitzschia acicularis	W. Sm.
Nitzschia angustatula	Lange-Bertalot 1987
Nitzschia capitellata	Hust.
Nitzschia draveillensis	Coste & Ricard
Nitzschia fonticola	Grun.
Nitzschia graciliformis	Lange-Bert. & Simonsen
Nitzschia gracilis	Hantz.
Nitzschia inconspicua	Grun.
Nitzschia palea	(Kütz.) W. Sm.
Nitzschia palea var. debilis	(Kütz.) Grun.
Nitzschia paleacea	Grun.
Nitzschia perminuta	(Grun. in V.H.) M. Perag.
Nitzschia recta	Hantz.
Nitzschia solita	Hustedt
Nitzschia sp.	
Nitzschia sp. 1 JCU	JCU
Nitzschia subacicularis	Hust.
Nitzschia supralitorea	Lange-Bertalot
Pinnularia obscura	Kraske
Sellaphora mutatoides	Lange-Bertalot & Metzeltin
Skeletonema potamos	(Weber) Hasle & Evens.
Skeletonema subsalsum	(Cleve-Euler) Bethge
Staurosira elliptica	(Schumann) Cleve & Möller
Stephanocyclus meneghiniana	(Kützing) Skabichevskii
Stephanodiscus alpinus	Hust.
Stephanodiscus alpinus Type I	Hust.
Stephanodiscus alpinus Type II/III	Hust.
Stephanodiscus binderanus	(Kütz.) Krieg.
Stephanodiscus conspicueporus	Stoermer, Hakansson & Theriot 1988
Stephanodiscus delicatus	(Genkal) Kling & Hakansson
Stephanodiscus hantzschii f. hantzschii	Hak. & Stoerm.
Stephanodiscus hantzschii f. tenuis	Hak. & Stoerm.
Stephanodiscus medius	Håkansson
Stephanodiscus medius var. 1 JCU	JCU
Stephanodiscus medius/minutulus JCU	
Stephanodiscus minutulus	Hak.

Stephanodiscus niagarae	Ehr.
Stephanodiscus parvus	Stoerm. & Hak.
Stephanodiscus parvus var. 1 UMD	
Stephanodiscus sp. #51	in house taxon
Surirella brebissonii var. kuetzingii	Krammer & Lange-Bertalot
Surirella minuta	Brébisson
Synedra acus var. 1 JCU	
Synedra (Frgilaria) nanana	Lange-Bertalot
Synedra ostenfeldii	(Krieg.) A. Cl.
Synedra radians	Kütz.
Synedra rumpens var. familiaria	(Kützing) Grunow
Thalassiosira cf. pseudonana	
Thalassiosira lacustris	(Grunow) Hasle
Unidentified Centrales	
Unidentified Pennales	

Table 6. Diatom taxa found from all samples in this study. There have been many changes in the taxa names. The names on this list have not been updated for this study. Refer to http://www.algaebase.org/ for current accepted names.

Site ID	Site/Date	Dia. R.	Dia. S.	Soft R.	Soft S.
300895	Rocky River ambient 5/7/15	32	2.6	NA	NA
301076	Port Clinton 9/29/15	34	2.42	22	2.42
301255	Fairport Harbor 9/15/15	37	2.14	11	1.74
302153	Off Detroit 7/28/15	24	1.8	18	2.67
302502	North of Port Clinton 8/26/15	29	1.2	12	1.27
300895_2	Rocky River ambient 7/1/15	27	1.48	13	1.7
302142*	Maumee Bay off Mau. Bay State Park 4/15/15	49	2.84	NA	NA
302142_2	Maumee Bay off Mau. Bay State Park 6/24/15	NA	NA	13	2.33

Table 7. Diatom and soft algae taxa richness (Dia. R. and Soft R.) and diatom and soft algae Shannon index values (Dia. S. and Soft S.) for study sites.

Metric Scores

The highest relative abundance TP score for diatoms (indicating the highest percentage of pollution sensitive organisms and thus lowest level of pollution) was recorded from the Fairport Harbor site on 9/15/2015 (Score = 7.1); for soft algae Port Clinton on 9/29/2015 had the highest score (Score = 4.77). The lowest relative abundance TP score for diatoms and soft algae was recorded from the Rocky River ambient site on 7/1/2015 (Scores = 3.24 and 1.21 respectively). The highest relative biovolume TP score for diatoms (indicating the highest percentage of pollution sensitive organisms and thus lowest level of pollution) was recorded from the Fairport Harbor site on 9/15/2015 (Score = 5.83); the highest score for soft algae was recorded off Detroit on 7/23/2015 (Score = 3.67) . The lowest relative biovolume TP score

for diatoms was recorded off Detroit on 7/23/2015 (Score = 3.03); and the lowest soft algae biovolume score for TP was recorded from the Rocky River ambient site on 7/1/2015 (Scores = 2.18; Tables 8, 9).

The highest relative abundance DP score for diatoms (indicating the highest percentage of pollution sensitive organisms and thus lowest level of pollution) was recorded from the Fairport Harbor site on 9/15/2015 (Score = 7.04); for soft algae Port Clinton on 9/29/2015 had the highest score (Score = 3.22). The lowest relative abundance DP score for diatoms was recorded from the Rocky River ambient site on 7/1/2015 (Score = 3.96); and for soft algae the North of Port Clinton site on 8/26/2015 had the lowest score (Score = 1.59). The highest relative biovolume DP score for diatoms (indicating the highest percentage of pollution sensitive organisms and thus lowest level of pollution) was recorded from the Fairport Harbor site on 9/15/2015 (Score = 4.9,); the highest score for soft algae was recorded at Port Clinton on 9/29/2015 (Score = 3.42) . The lowest relative biovolume DP score for diatoms was recorded from the off Detroit site on 7/28/2015 (Score = 3.01); and the lowest soft algae biovolume score for DP was recorded from the Maumee Bay off Maumee Bay State Park site on 6/24/2015 (Score = 2.66; Tables 8, 9).

Note that diatom TP and DP abundance scores are on a 1 – 8 scale. Soft algae TP abundance scores are on a 1 – 6 scale and DP abundance scores are on a 1 – 4 scale. Diatom TP biovolume scores are on a 1 – 7 scale and DP biovolume scores are on a 1 – 6 scale. Soft algae TP and DP biovolume scores are on a 1 – 5 scale. The scales are based on the range of the transformed phosphorus concentrations measured during the USEPA monitoring program (Reavie et al., 2014).

Site ID	Site/Date	Dia. TP	Soft TP	Dia. DP	Soft DP
300895	Rocky River ambient 5/7/15	6.16	NA	6.18	NA
301076	Port Clinton 9/29/15	5.54	4.77	5.88	3.22
301255	Fairport Harbor 9/15/15	7.1	4.24	7.04	2.44
302153	Off Detroit 7/28/15	3.61	4.68	4.47	2.95
302502	North of Port Clinton 8/26/15	4.02	2.12	4.78	1.59
300895_2	Rocky River ambient 7/1/15	3.24	1.21	3.96	2.97
302142*	Maumee Bay off Mau. Bay State Park 4/15/15	5	NA	4.84	NA
302142_2	Maumee Bay off Mau. Bay State Park 6/24/15	NA	3.95	NA	2.46

* All specimens dead

Table 8. Metric scores calculated by relative abundance. NA = not available. Diatom TP and DP scores are on a 1 – 8 scale. Soft algae TP scores are on a 1 – 6 scale and DP scores are on a 1 – 4 scale.

Site ID	Site/Date	Dia. TP	Soft TP	Dia. DP	Soft DP
300895	Rocky River ambient 5/7/15	5.35	NA	4.5	NA
301076	Port Clinton 9/29/15	4.25	3	3.06	3.42
301255	Fairport Harbor 9/15/15	5.83	2.65	4.9	3.31
302153	Off Detroit 7/28/15	3.03	3.67	3.01	3.28
302502	North of Port Clinton 8/26/15	3.44	2.83	3.28	3.33
300895_2	Rocky River ambient 7/1/15	4.05	2.18	3.02	3.07
302142*	Maumee Bay off Mau. Bay State Park 4/15/15	3.87	NA	3.57	NA
302142_2	Maumee Bay off Mau. Bay State Park 6/24/15	NA	2.6	NA	2.66

* All specimens dead

Table 9. Metric scores calculated by relative biovolume. NA = not available. Diatom TP scores are on a 1 – 7 scale and DP scores are on a 1 – 6 scale. Soft algae TP and DP scores are on a 1 – 5 scale.

Metric Score/Environment Relationship

Scatterplots were performed with DP or TSS values against metric scores for sites. TSS was used in place of TP for these analyses because the OEPA has not yet signed off on the TP values for these samples. TSS was shown to be a reasonable proxy for TP in the benthic diatom metric analysis (Sgro, 2015). The Maumee Bay of Maumee Bay State Park sample on 4/15/2015 was removed as an outlier for the diatoms as all diatoms were dead.

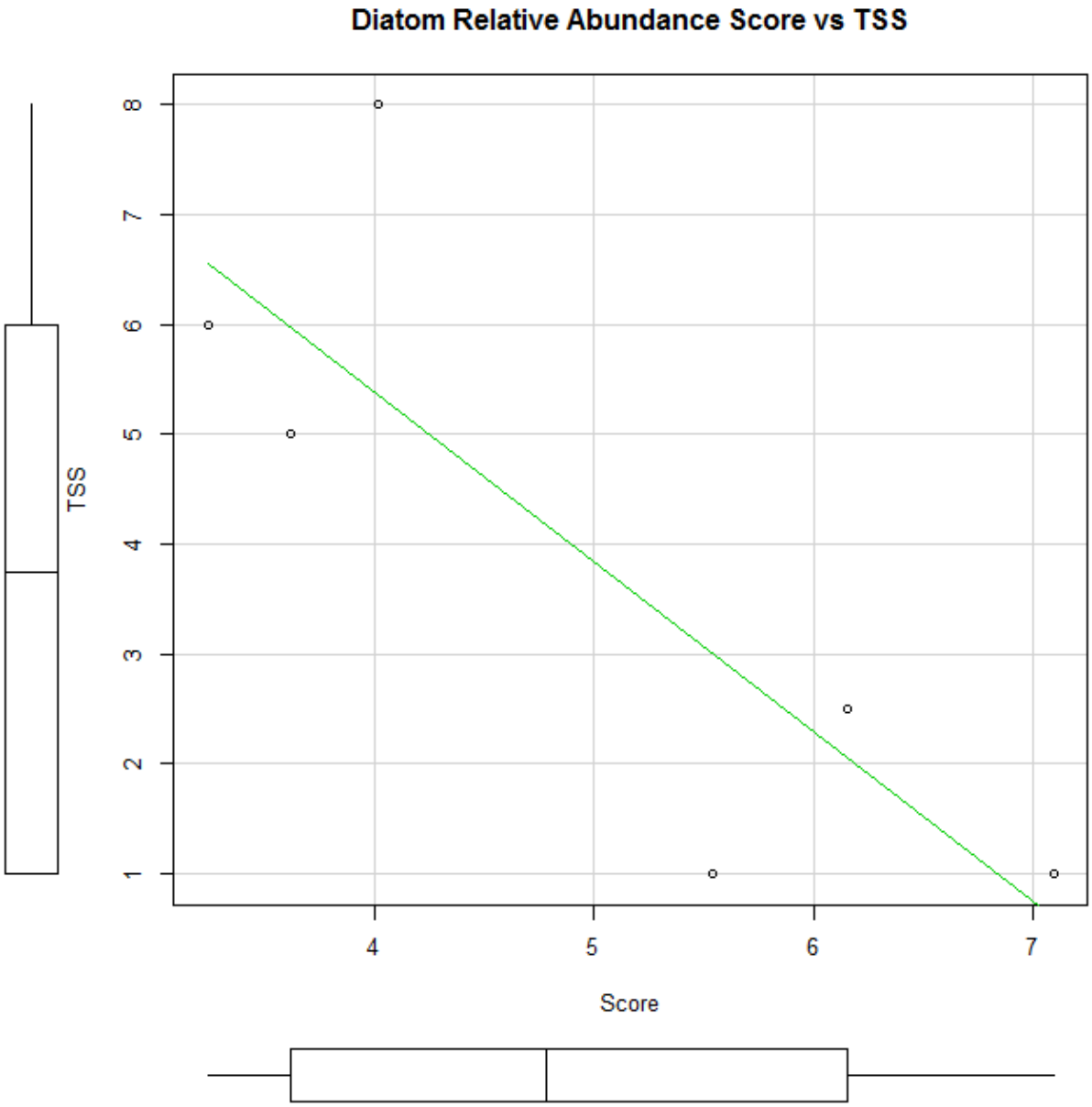


Fig. 2. The plot is showing a definite trend that may be significant given more data.

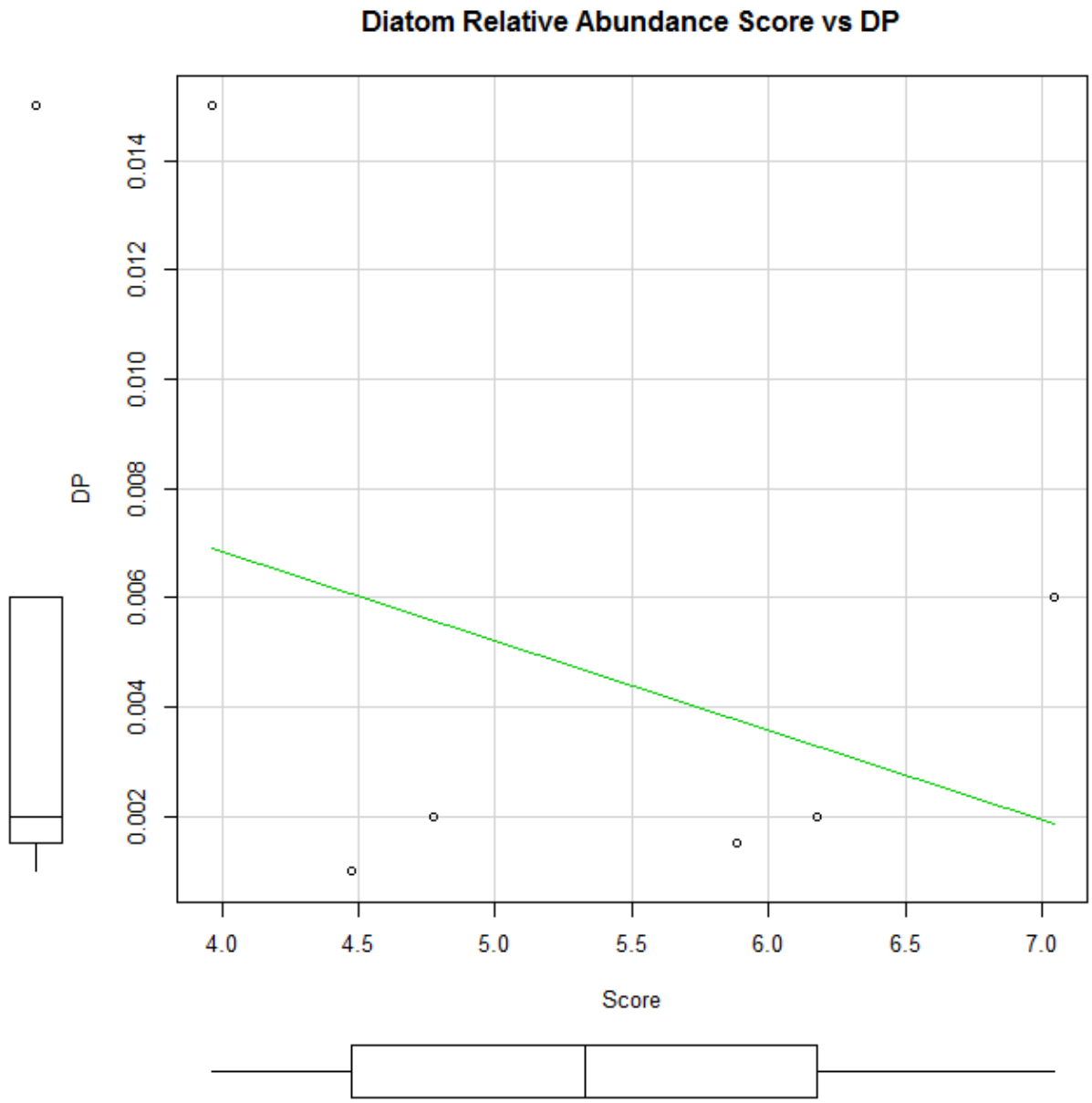


Fig. 3. The plot is showing only a weak trend leveraged by the Rocky River site on 7/1/2015.

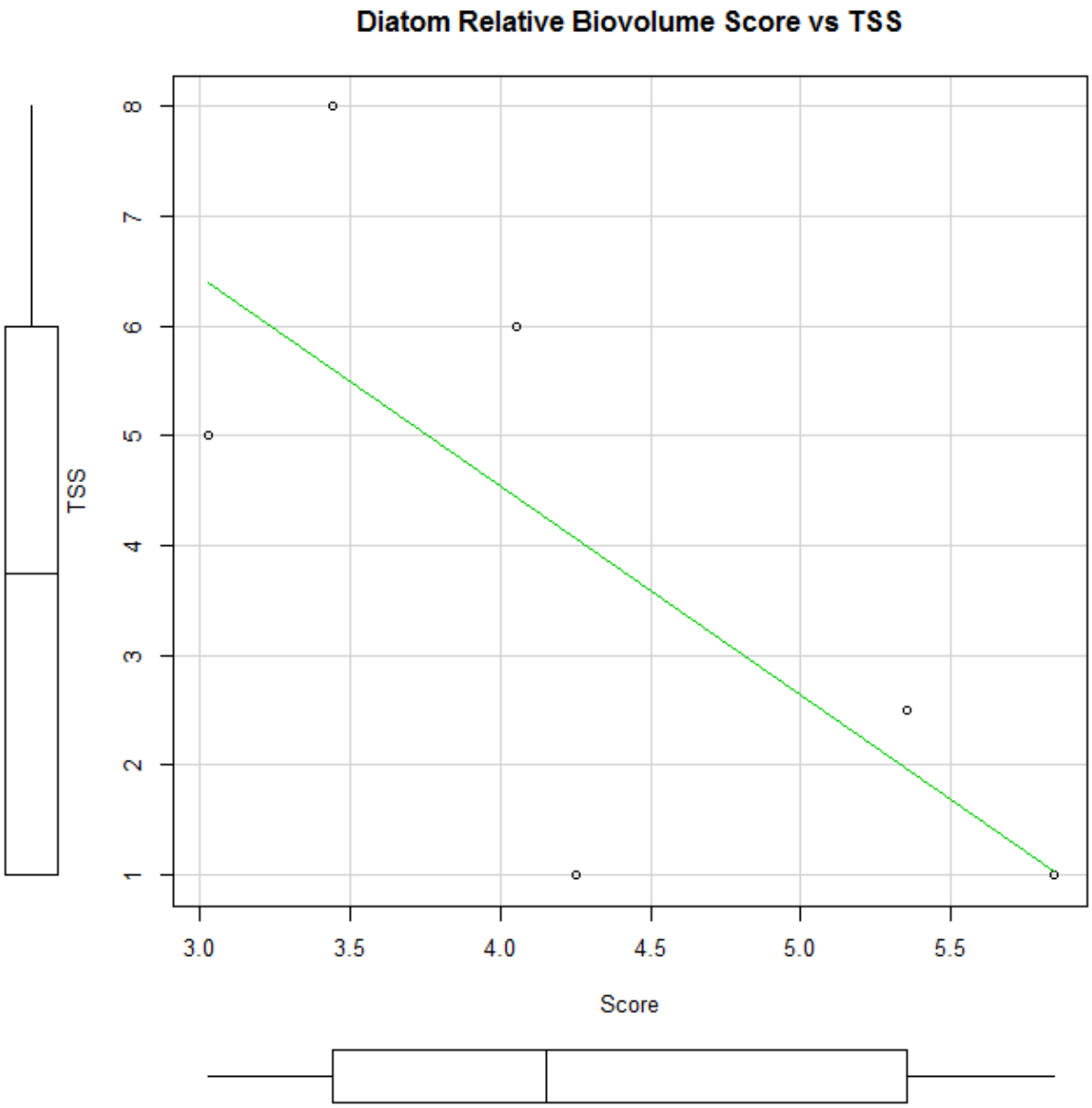


Fig. 4. The plot is showing a definite trend that may be significant given more data.

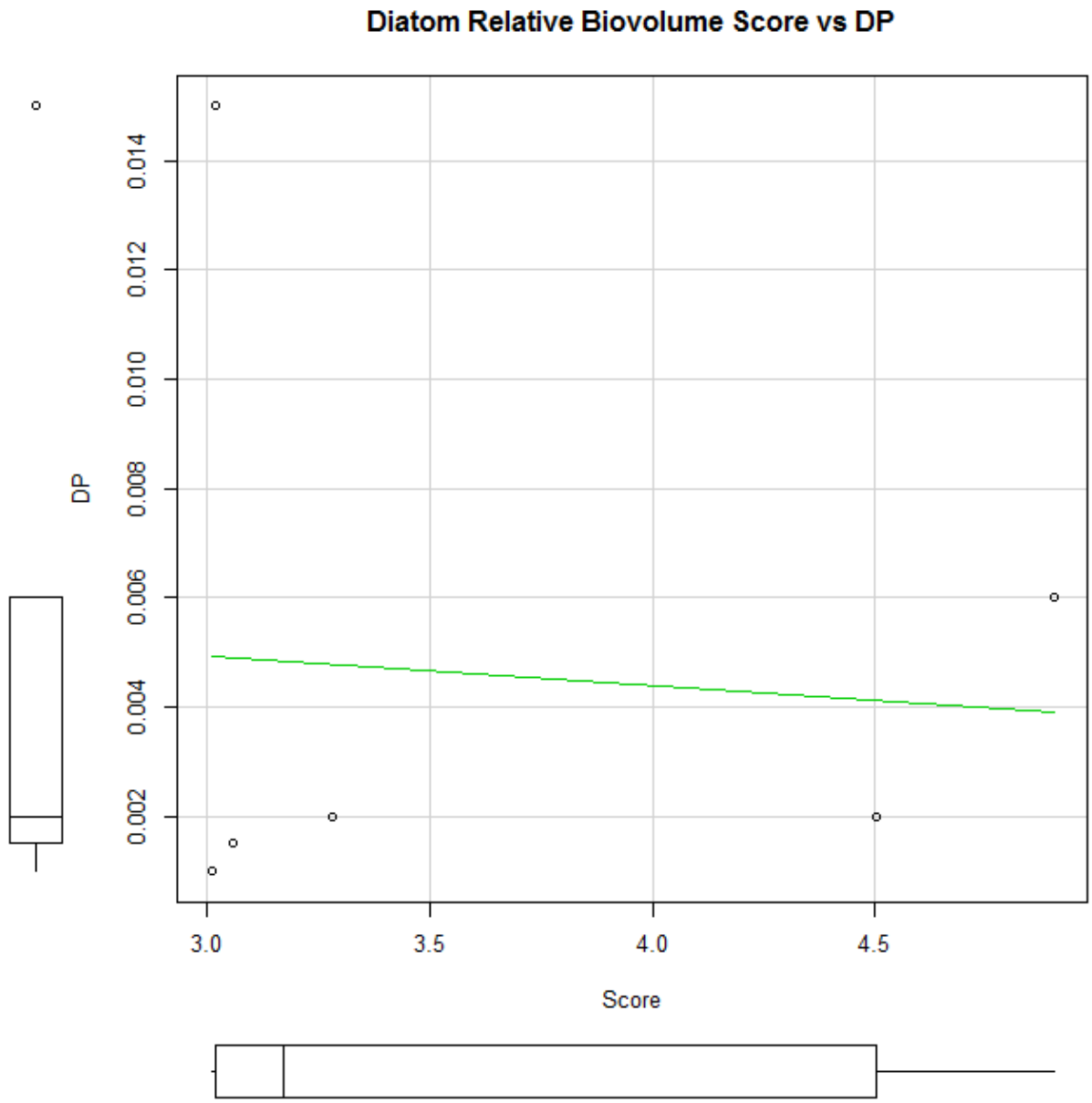


Fig. 5. The plot is showing only a weak trend leveraged by the Rocky River 7/1/2015 site.

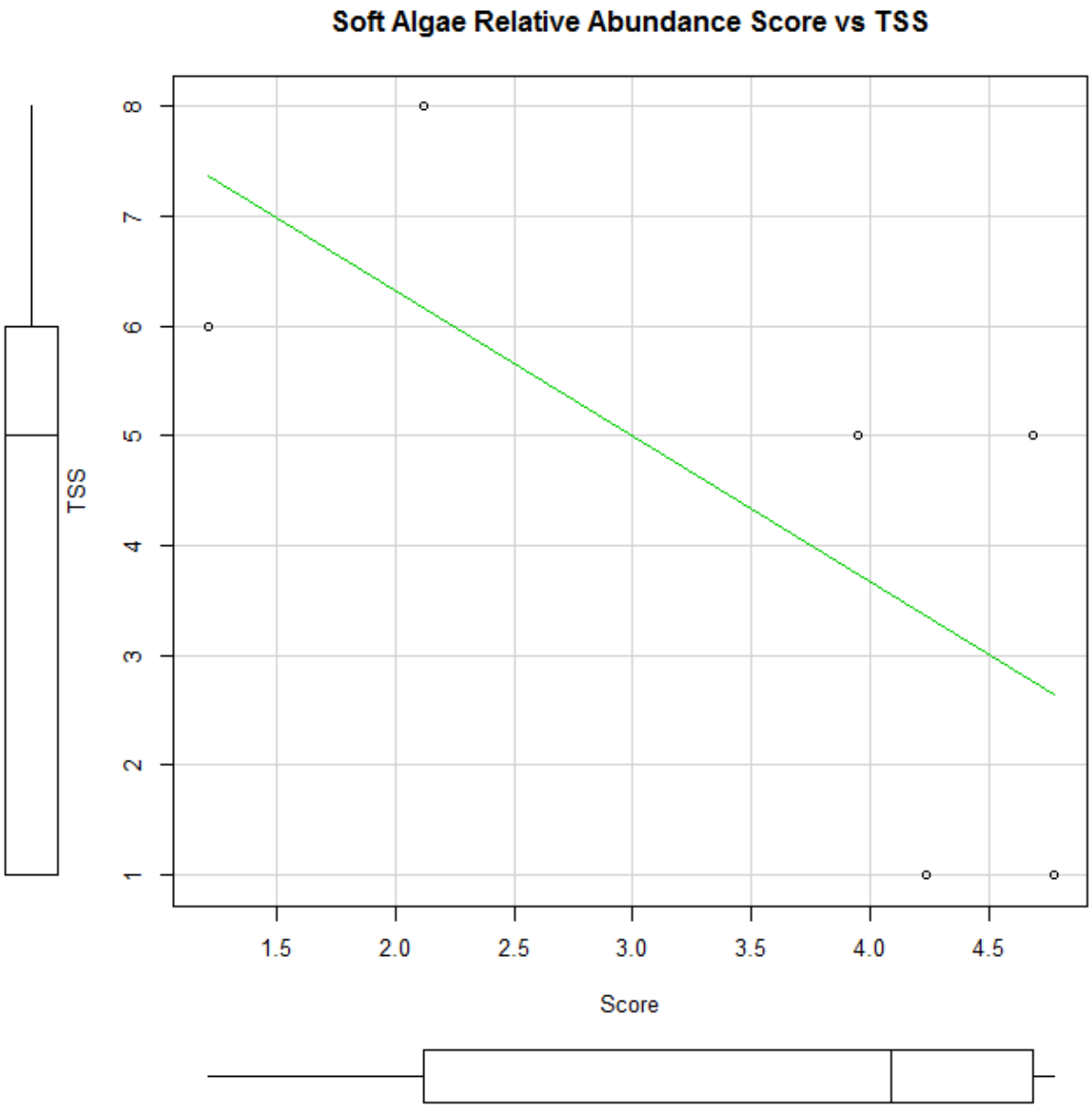


Fig. 6. The plot is showing a definite trend that may be significant given more data.

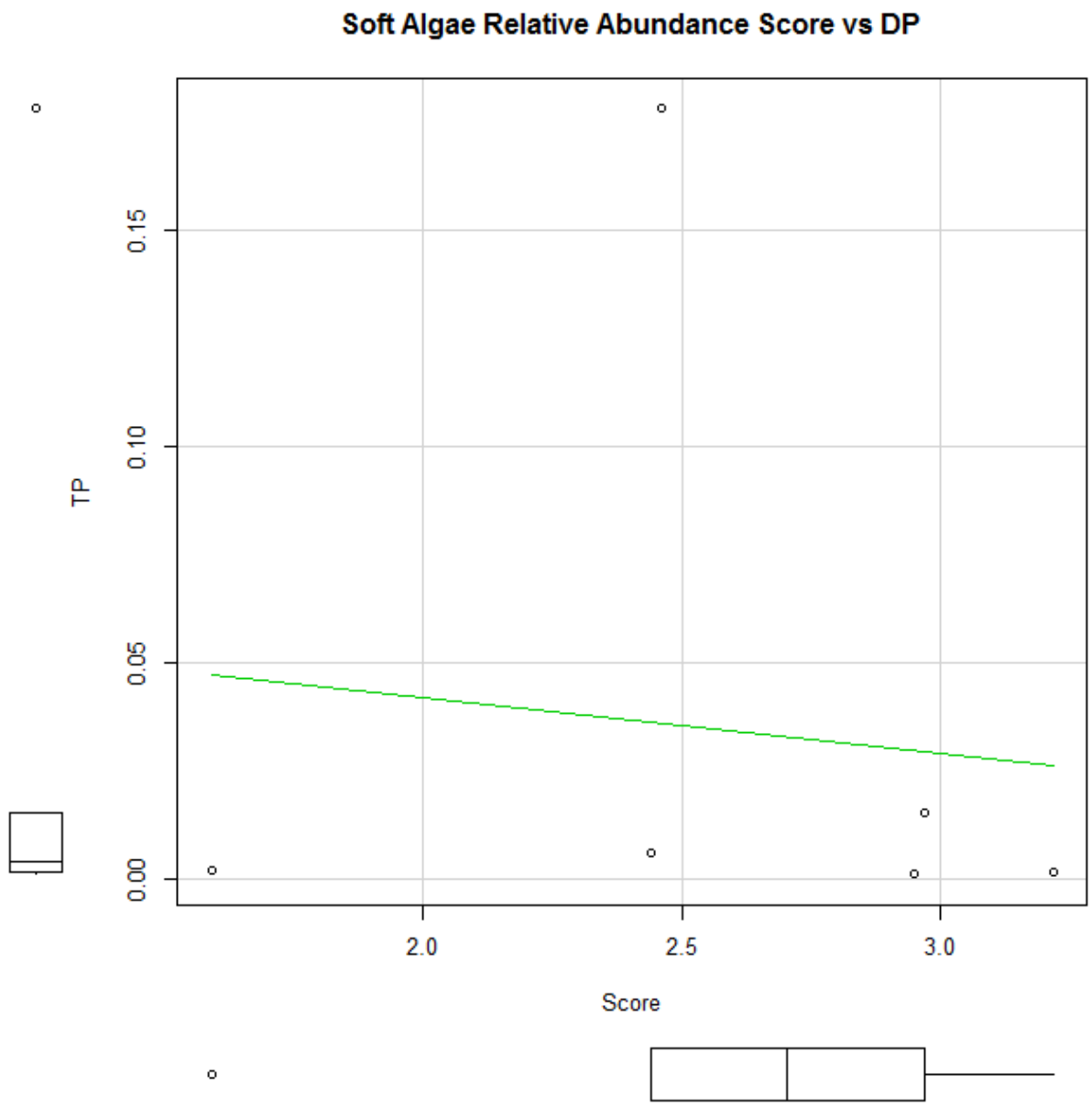


Fig. 7. The plot is showing only a weak trend.

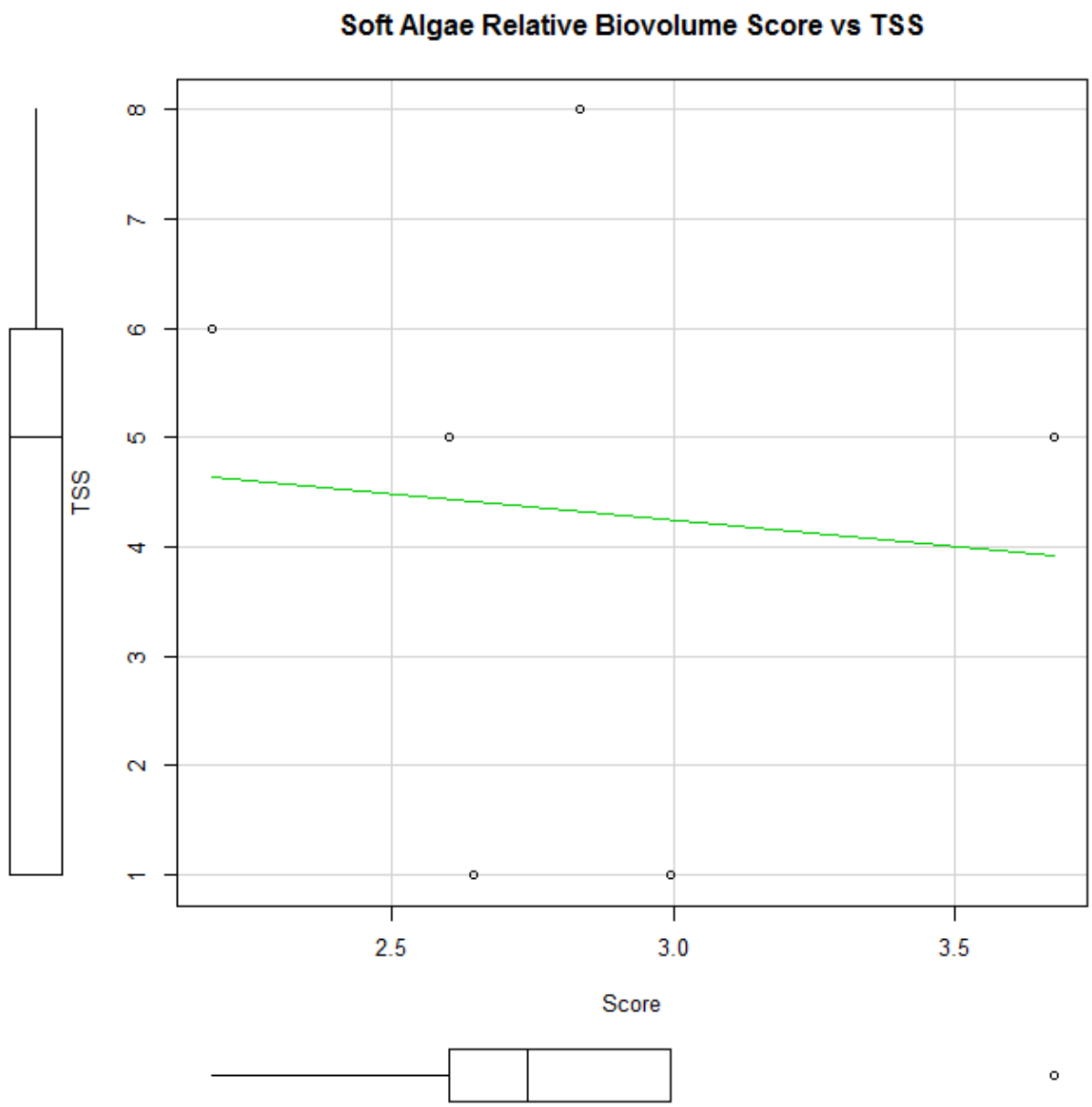


Fig. 8. The plot is showing only a weak trend.

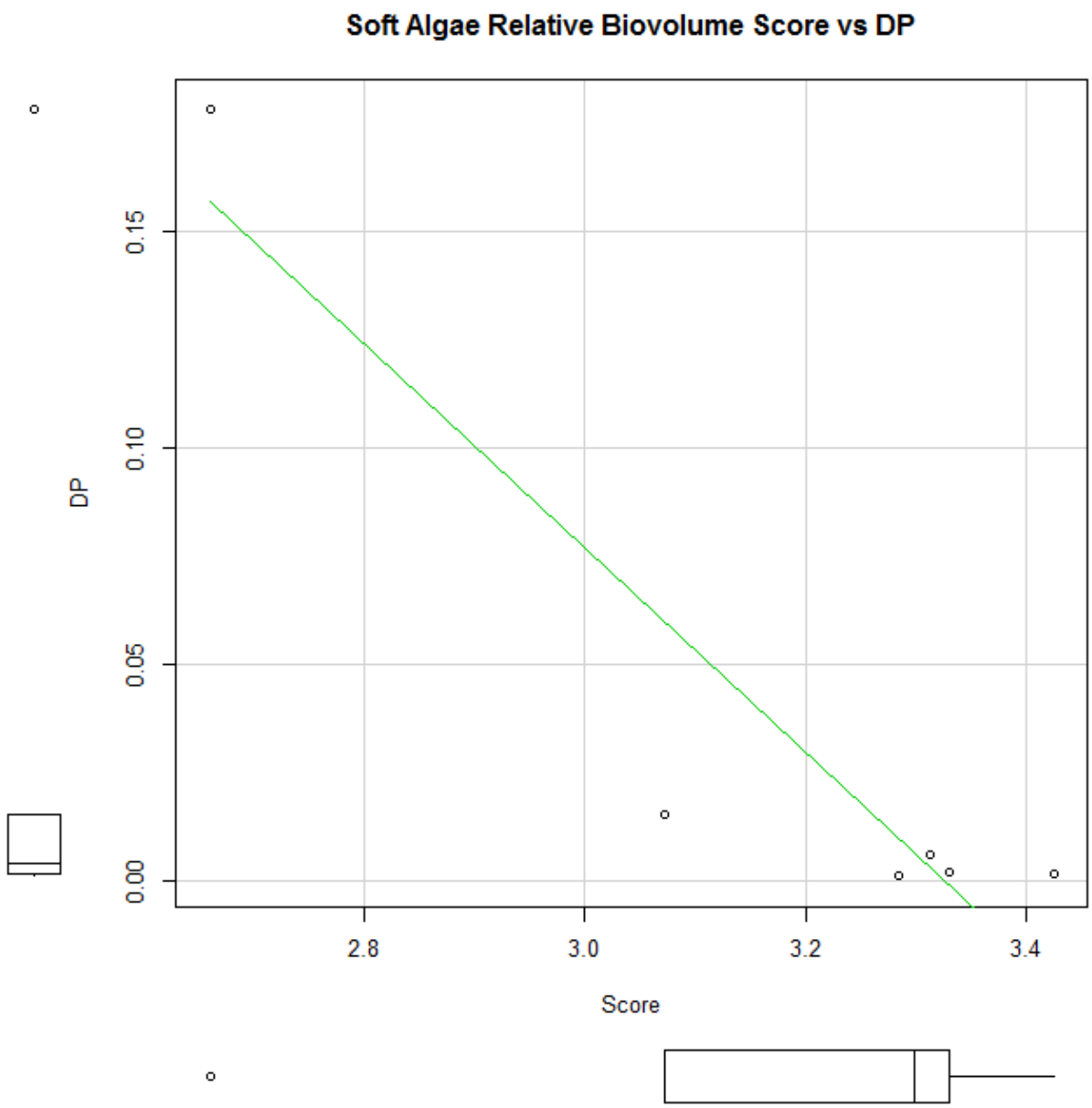


Fig. 9. The plot is showing a definite trend but leveraged by the 6/24/2015 Maumee Bay off Maumee Bay State Park site.

Discussion

The primary outcomes for this project have been met. A set of environmental quality metrics that measure the health of the algal phytoplankton assemblages in the Lake Erie nearshore have been created. The methods for collection and analysis have been explored and an initial evaluation of the metrics within the limits of this project was made. The metrics are ready for more rigorous analysis in a pilot project.

First, we needed to know if using algal phytoplankton as a biological monitor in the Lake Erie nearshore was feasible. There has been so little study of the algal phytoplankton in the nearshore that it was uncertain if there was enough algae and enough algal diversity at these sites to create an effective metric for monitoring the OEPA stations. It was clear from the number and abundance of algal taxa collected and the beta diversity of these samples that an algal phytoplankton metric is feasible for these sites. The most problematic sample was the Maumee Bay off Maumee Bay State Park sample collected on 4/15/2015. All algae appeared dead in this sample and there were very few non-diatom algae. It is possible, especially given the extremely high chemistry values recorded for this sample that the sample was taken from a bolus of Maumee River water during spate conditions. The Maumee Bay off Maumee Bay State Park sample on 6/24/2015 and the Rocky River ambient sample collected on 5/7/2015 had no diatoms and no soft algae respectively. Absence of these taxa at these sites meant that a metric score could not be calculated, however this absence itself might prove to be informative about the ecological condition of these sites.

Field sampling methods were determined and tested for sample collection. The OEPA was able to sample nearshore algal phytoplankton using these methods with few problems. The only problem of note is that some of the samples were collected and fixed with glutaraldehyde and then stored by the OEPA for as long as two months before delivering them to the lab at JCU for analysis. Storing the samples for this long in the fixative may have contributed to some of the mucus envelopes on some of the colonial soft algal forms breaking down, making analysis difficult. This was an unforeseen problem that can be addressed in a future pilot project.

Lab analysis for soft algae was initially attempted by clearing the filter membrane with oil and counting the soft algae taxa directly from the membrane. We found that this method resulted in unsatisfactory resolution for taxa identification because of the amount of suspended solids in the Lake Erie samples. We switched to using the Tchen counting chamber that gave satisfactory results given that we were only interested in relative biovolume and not total biovolume data for these analyses. An Utermöhl method (Lind, 1985) would also be satisfactory. We used glutaraldehyde as a preservative for the soft algae as our preference. Other labs more commonly use Lugol's solution. Either would be satisfactory. The diatom samples were counted from permanent diatom slides that we made in our lab according to the methods described. It is necessary to count the diatoms at 1000X using oil emersion to adequately identify these taxa.

We analyzed the effectiveness of the metric scores within the limits of this project. There were not enough samples collected to perform valid hypothesis testing. We instead attempted to discern a trend using scatterplots with the chemistry data against the metric scores. Thus, the effectiveness of any of these metrics is inconclusive until we perform a more comprehensive analysis.

The metric scores are calibrated to TP or DP. Unfortunately, the OEPA lab was not able to provide TP data that they were willing to sign off on, so for these analyses we used TSS as a proxy for TP. TSS was shown to be a good proxy for TP for the benthic diatom metric created for the Lake Erie shoreline sites (Sgro, 2015). It appeared from the scatterplots that metrics calibrated to TP will be more effective at these sites than those calibrated to DP. It may seem, given that the algae are thought to use DP, that the DP metric would be the most effective. However, it is generally the case that algal weighted average coefficients more commonly show a better relationship with TP rather than DP. We discuss this elsewhere (see Sgro, 2015). Future study might also examine nitrogen as it affects the metric scores.

Nitrogen was not shown to affect the benthic diatom metric scores (Sgro, 2015), though nitrogen may be more limiting for the algae of the nearshore.

Both relative abundance and relative biovolume of the diatoms appeared likely to have a significant relationship with TSS if given a more complete data set. The relative biovolume relationship for the soft algae with TSS and DP was not as encouraging. Soft algae relative abundance may prove to be significantly related to TSS (or TP) given a larger data set. Calculating biovolumes takes substantially more time than calculating abundance alone, and consequently will be more expensive. This is the case for both diatom and soft algae calculations.

Conclusions

Diatom relative abundance and relative biovolume metrics and the soft algae relative abundance metric all appear (though inconclusively) to be favorable candidates for assessing the health of the algal assemblages affected by phosphorus loads in the Lake Erie nearshore. Diatoms are easier to store in the field and can be made into permanent slides and archived in the lab. Soft algae are more problematic as the soft structures and flagella are easy to destroy if not handled carefully making identification less certain. At this point neither biovolume nor abundance should be rejected for use in a possible nearshore metric.

A pilot project to further test these metrics is certainly warranted. These metrics appear to be feasible and potentially effective tools for the OEPA's nearshore monitoring program. Testing the metrics in a pilot project along the lines of the project used to test the benthic diatom metric (Sgro, 2015) is the next step. This would involve sampling the OEPA sites over a two year period over different months of the year, collecting and analyzing about eighty samples to obtain a statistically valid data set.

These metrics can be useful management tools. If further study demonstrates that the metric scores are reasonably correlated with TP and variables correlated with TP (e.g. TSS), they will allow the OEPA to meet its reporting and management objectives. These metrics will also be diagnostic for pollution problems in the nearshore because changes in the algal flora will be statistically linked to the gradient of phosphorus pollution (i.e. a reasonably good significant correlation between nearshore phosphorus levels and metric scores). If the "good", "fair", "poor" ratings that are typically used for water quality indicators cannot be shown in this way to be statistically correlated with a gradient of anthropgenic disturbance such as pollution or habitat quality, they are useless as management tools. The lake is always "good", "fair", "poor", "eutrophic", or "mesotrophic". Unless an indicator can provide statistical evidence that link changes in the metric scores to changes in the environment, management decisions will be based on guesswork. It is harder to defend allocation of resources or convince people or businesses to change their behavior without evidence that removes guesswork from management decisions.

Final comment and acknowledgement

Though it is sometimes said that algae are too difficult to identify to be useful as biological indicators, this only true for those not trained in algal identification. It is easy to find skilled technicians who can perform this work at consulting or university labs. It is only necessary to be specific about methods that are to be used and be demanding about QA/QC protocols. This study has described the methods that can be followed for further work with these metrics.

We will gain an understanding of the rate and magnitude of change of the algal assemblages and possibly the mechanisms driving these changes by systematically monitoring and studying the algae and applying these metrics. The attempt to manage the problem of HABs has focused on water chemistry and computer models, but no amount of chemistry measurement or computer modeling will gauge how the algae respond to phosphorus like species level algae itself. Monitoring changes in the algal assemblages that are linked to phosphorus on a species level may lead to better management decisions rather than just monitoring changes in phosphorus (e.g. reduce phosphorus by 40%) and trying to predict the effect on HABs. For example, finding thresholds in the algal metrics may better inform phosphorus targets in the nearshore.

Little is known about the algal dynamics in the Lake Erie nearshore. Much of the research that has been done on the algae of the nearshore in the past has been funded by the Lake Erie Protection Fund. The algal surveys and other algal research funded by the Lake Erie Protection Fund has directly led to the creation of the metrics described in this study.

References

Ohio Environmental Protection Agency. 2014. Ohio Integrated Water Quality Monitoring and Assessment Report. http://www.epa.state.oh.us/dsw/tmdl/OhioIntegratedReport.aspx#123143421-2014.

Kane DD, Gordon SI Munawar M, Charlton MN,Culver DA. 2009. The Planktonic Index of Biotic Integrity (P-IBI): an approach for assessing lake ecosystem health. Ecol. Indic., 9, 1234.

Lind,OT. 1985. Handbook of common methods in Limnology. Kendall/Hunt, Debuque, IO

Reavie ED, Heathcote AJ, Shaw Chraibi VL. 2014. Laurentian Great Lakes phytoplankton and their water quality characteristics, including a diatom-based model for paleoreconstruction of phosphorus. PLoS ONE 9(8) e104705.dol:10.1371/journal.pone.0104705.

Sgro GV. 2013. Evaluation of a benthic diatom water quality metric (BDM) for the Lake Erie nearshore. Prepared for the Ohio Environmental Protection Agency. Great Lakes Restoration Initiative Subgrant number JOHNC-FDNear10.

Sgro GV. 2015. Great Lakes Restoration Initiative Subgrant number JOHNC-FDErie10 for the Ohio Environmental Protection Agency Nearshore Monitoring Study.

Sgro GV, Reavie ED, Kingston JC, Kireta AR, Ferguson MJ, Danz NP, Johansen JR. 2007. A diatom duality index from a diatom-based total phosphorus inference model. Environmental Bioindicators. 2:15–34.

United States Environmental Protection Agency. 2010. Standard Operating Procedure for Phytoplankton Analysis, http://www3.epa.gov/greatlakes/monitoring/sop/chapter_4/lg401.pdf.