# Lake Michigan water chemistry data, including dissolved and particulate phosphorus, chlorophyll a, carbon dioxide, total dissolved inorganic carbon, and dissolved organic carbon from 2017 to 2020

**Website**: https://www.bco-dmo.org/dataset/737176
**Data Type**: Cruise Results
**Version**: 3
**Version Date**: 2023-12-20

**Project**
» Collaborative Research: Regulation of plankton and nutrient dynamics by hydrodynamics and profundal filter feeders (Filter Feeders Physics and Phosphorus)

| Contributors | Affiliation | Role |
|---|---|---|
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**Abstract**

This dataset provides Lake Michigan water chemistry data collected over several cruises conducted from 2017 to 2020. Water chemistry and conductivity-temperature-depth (CTD) profiles were measured at several stations in Lake Michigan, ranging in depth from 10 to 55 m, in a region northeast of Milwaukee Harbor. Measurements included soluble reactive phosphorus, total dissolved phosphorus, particulate phosphorus, chlorophyll a, the concentrations and stable isotope ratios of particulate carbon and particulate nitrogen, dissolved carbon dioxide, dissolved total inorganic carbon, and dissolved organic carbon. In addition, continuous lake surface and atmospheric CO2 data were collected in 2019 and 2021 on a Lake Michigan transect between Milwaukee, WI and Muskegon MI. The CO2 and CTD data are provided in separate datasets. Measurements were made with a CO2 monitoring system mounted on a high-speed ferry that crosses the lake 4 to 6 times daily between May and October. The monitoring system consists of a "wet" box which includes a peristaltic pump that draws water from the ship's sea chest and an equilibrator in which dissolved gases are equilibrated with a recirculating air flow. The air is pumped through a desiccant to remove moisture, after which it flows to a "dry" box where it passes through an infrared gas analyzer. A similar system, without the peristaltic pump or equilibrator, is mounted near the bow of the ship to record atmospheric CO2 concentration. These chemical measurements have several applications, including: 1) Constructing an annual carbon and nutrient budget for the water column, which is used along with direct measurements of quagga mussel nutrient recycling to assess the role of invasive quagga mussels in the lake's carbon and nutrient cycles; 2) When combined with separate measurements of the vertical structure of water density and currents, to quantify vertical fluxes of dissolved nutrients and inorganic carbon, to determine how carbon and nutrient recycling by profundal quagga mussels may affect plankton production in the euphotic zone; 3) The calibration and validation of physical / biogeochemical models used to better understand how invasive quagga mussel have altered energy flow and nutrient dynamics in the Great Lakes, and guide management decisions with regard to nutrients and fish stocking.

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## Coverage

**Spatial Extent**: **N**:43.09932 **E**:-87.7187 **S**:43.06992 **W**:-87.86447
**Temporal Extent**: 2017-05-11 - 2020-07-10

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## Dataset Description

Water chemistry data, including dissolved and particulate phosphorus, chlorophyll *a*, carbon dioxide, total dissolved inorganic carbon, and dissolved organic carbon were collected from a Lake Michigan transect between Milwaukee, WI and Muskegon MI from 2017 to 2020.

### Methods & Sampling

**Field sampling:** Research cruises were conducted on& R/V Neeskay and R/V Osprey. Water samples were collected using 5-liter Niskin sampling bottles suspended on a 1/4" cable from a hydrographic winch. Immediately after collection, samples were transferred to 4-liter HDPE sample bottles. Sample bottles were rinsed with sample water 3 times before filling. Prior to use, sample bottles were acid washed (48 hours in 5% HCl), followed by multiple rinses with distilled, deionized water. Samples in bottles were stored in a cooler on ice until return to the laboratory. Samples were filtered immediately upon return to the laboratory (usually less than 8 hours after collection). Samples were filtered through pre-combusted Whatman GF/F filters. Filters were retained for particulate Phosphorus (P), stable isotope (particulate Carbon (C) and Nitrogen (N)), and chlorophyll *a* analyses. At least twice during the field season, field blanks are collected, which consist of clean bottles brought into the field where they are filled with distilled water, followed by analysis for dissolved and particulate phosphorus.

**Nutrients:** Samples were collected and analyzed as described in Mosley and Bootsma (2015). Soluble Reactive Phosphorus (SRP) was analyzed using the standard molybdate method and a 10 cm path length in the spectrophotometer. Total Dissolved Phosphorus (TDP) and Particulate Phosphorus (PP) were digested to convert to phosphate, followed by analysis with the standard molybdate method. SRP and TDP were measured within 12 hours of sample filtration.

**Chlorophyll *a***: Samples were collected and analyzed as described in Mosley and Bootsma (2015). Chl *a* was extracted with a 68:27:5 methanol-acetone-deionized water extraction solvent for 24 hours at -28 degrees Celsius and measured on a Turner Model 10 Series fluorometer, which was calibrated using a chlorophyll extract, the concentration of which was determined spectrophotometrically (Stainton et al. 1977).

**$CO_2$ / DIC:** Samples for CO2 and Dissolved Inorganic Carbon (DIC) analyses were collected in stoppered 120 mL glass serum bottles. Prior to sampling, bottles were flushed with nitrogen gas and then evacuated, to ensure they contained no CO2. At the time of sampling, a double-ended needle was inserted into the discharge tube of the Niskin bottle while water was flowing out, and the other end of the needle was inserted through the rubber cap of the serum sample bottle, allowing the vacuum in the bottle to draw in the sample water. The bottle was filled approximately 3/4. CO2 and DIC analyses were carried out following the method described by Davies et al. (2003). Briefly, 50 microliter (uL) subsamples are taken from the bottle headspace using a pressure-lok syringe and injected into a gas chromatograph, calibrated with CO2 standard gases. Samples are run in triplicate. Dissolved CO2 is then determined based on the temperature-dependent solubility of CO2, corrected for CO2 lost to the headspace and for the change in inorganic carbon species distribution accompanying the CO2 loss to headspace. Following CO2 analysis, samples are acidified by adding 150 uL of concentrated phosphoric acid, converting all inorganic carbon to CO2, after which the above analysis was repeated to determine total dissolved inorganic carbon concentration. In-lake CO2 concentrations are determined by correcting for any difference between in situ temperature and temperature at time of analysis, which affects the inorganic carbon partitioning coefficients. CO2 samples were measured within 24 hours of collection, and DIC samples were measured within 3 days of collection.

**Continuous CO2**: The components of the continuous CO2 monitoring system include a peristaltic pump that forces water through an air-water equilibrator (Membrana mini-module membrane contactor). Reverse-flow air from the equilibrator is pumped through desiccant, after which it flows through an infrared gas analyzer (Li-Cor Li-820) which measures the partial pressure of CO2 normalized to 1 atmosphere. The system also includes a temperature sensor and a WETLabs flow-through fluorometer. The system is controlled by a Campbell

CR1000 Controller / Datalogger. Input from a GPS on the ship's upper deck allows all data to be geo-referenced. The system is mounted in the engine room of the Lake Express high-speed ferry, where it draws water from a sea chest that has a residence time of several seconds. Additional details are provided in Zagorski and Bootsma (2006).

**Stable isotopes:** Samples for stable isotope (13C:12C and 15N:14N ratios) analyses were collected by filtering lake water samples through GF/F glass fiber filters (nominal pore size = 0.7 to 0.8 micrometers (um)). Following filtration, filters were doused with 5% HCl for ~ 3 minutes to remove any inorganic carbon, followed by rinsing with distilled, deionized water. Filters were then freeze dried and packed in tin foil disks. Samples were then analyzed on an isotope ratio mass spectrometer, following the methods as described in Turschak et al. (2014). After every 12th sample, an acetanilide control was run to ensure instrument calibration.

**Dissolved organic carbon:** 25 ml of filtered water was transferred to an amber glass ampule and acidified to a pH of less than 2 by adding 2-3 drops of 1 N hydrochloric acid (HCl), converting all inorganic carbon to CO2, which was then purged from the sample bubbling with carbon-free gas prior to OC analysis. DOC was then measured using the combustion catalytic oxidation method on a total organic carbon analyzer (Shimadzu TOC-L analyzer equipped with an ASI-5000 auto sampler). The analyzer was calibrated with a dilution series of reagent grade potassium hydrogen phthalate in 0.3 molar hydrochloric acid.

### Data Processing Description

**Data Processing:**
All nutrient data are stored in a common database. Following analyses, nutrient standard curves are examined to ensure that calibration coefficients are within the range of variability of a long-term (5-year) dataset (±3%). Fluorometer measurements are entered into a spreadsheet containing the fluorometer calibration coefficients, which are used to calculate chlorophyll *a* and phaeophytin concentrations. The fluorometer is calibrated annually against extracted chlorophyll *a* standards. CO2 and DIC gas chromatograph measurements are entered into a spreadsheet program that calculates all inorganic carbon species concentrations, as well as pH and carbonate alkalinity. Concentrations are then corrected for any temperature difference between in situ and time of analysis. Stable isotope measurements are stored in a stable isotope database, while DOC measurement data are stored along with nutrient, chlorophyll and inorganic carbon measurements in a chemistry database.

### BCO-DMO Processing Description

Versions 1 and 2:
- modified parameter names to conform with BCO-DMO naming conventions;
- re-formatted date to ISO format;
- replaced missing data with nd ("no data");
- updated to version 2 on 2019-05-20.

Version 3:
- converted dates to YYYY-MM-DD format;
- converted times to hh:mm format;
- modified parameter names to conform with BCO-DMO naming conventions;
- removed 'nd' as the missing data identifier (missing data are empty/blank in the final CSV file);
- updated to version 3 on 2023-12-20 as file name "737176_v3_lake_michigan_chemistry.csv".

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## Data Files

| File |
|---|
| **737176_v3_lake_michigan_chemistry.csv**(Comma Separated Values (.csv), 26.53 KB)<br>MD5:510784e1d65b9e76909cd89cda7c4ad4<br>Primary data file for dataset ID 737176, version 3 |

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## Related Publications

Davies, J.-M. (2003). PCO2 method for measuring photosynthesis and respiration in freshwater lakes. Journal of Plankton Research, 25(4), 385–395. doi:10.1093/plankt/25.4.385
*Methods*

Mosley, C., & Bootsma, H. (2015). Phosphorus recycling by profunda quagga mussels (Dreissena rostriformis bugensis) in Lake Michigan. Journal of Great Lakes Research, 41, 38–48. doi:10.1016/j.jglr.2015.07.007
*Methods*

Shen, C., Liao, Q., Bootsma, H. A., Troy, C. D., & Cannon, D. (2018). Regulation of plankton and nutrient dynamics by profundal quagga mussels in Lake Michigan: a one-dimensional model. Hydrobiologia, 815(1), 47–63. https://doi.org/10.1007/s10750-018-3547-6
*Results*

Stainton, M.P., M.J. Capel, and F.A.J. Armstrong. (1977). The chemical analysis of fresh water, 2nd ed. Fish. Mar. Serv. Misc. Spec. Publ. 25:166 p. http://www.dfo-mpo.gc.ca/Library/110147.pdf
*Methods*

Turschak, B. A., Bunnell, D., Czesny, S., Höök, T. O., Janssen, J., Warner, D., & Bootsma, H. A. (2014). Nearshore energy subsidies support Lake Michigan fishes and invertebrates following major changes in food web structure. Ecology, 95(5), 1243–1252. doi:10.1890/13-0329.1
*Methods*

Zagorski, J., & Bootsma, H. (2006). High spatial-resolution monitoring of surface CO2 concentrations in Lake Michigan. OCEANS 2006. https://doi.org/10.1109/oceans.2006.307084
https://doi.org/10.1109/OCEANS.2006.307084
*Methods*

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## Parameters

| Parameter | Description | Units |
|---|---|---|
| Year | Four digit year | unitless |
| Date_UTC | Date (UTC) of sampling | unitless |
| Time_UTC | Time (UTC) of sampling | unitless |
| Site | Station name/number | unitless |
| Lat | Latitude. Locations south of equator are negative. | degrees North |
| Long | Longitude. Locations west of prime meridian are negative. | degrees East |
| Depth_Site | Lake bottom depth at sampling location | meters (m) |
| Depth_Smp | Depth below surface from which sample was collected | meters (m) |

| | | |
|---|---|---|
| Ht | Height above lake bottom | centimeters (cm) |
| SRP | Soluble Reactive Phosphorus; resolution = 0.01; accuracy = ±5%; detection limit = 0.5 | micrograms per liter (ug/L) |
| TDP | Total Dissolved Phosphorus; resolution = 0.01; accuracy = ±5%; detection limit = 1 | micrograms per liter (ug/L) |
| PP | Particulate Phosphorus; resolution = 0.01; accuracy = ±5%; detection limit = 0.5 | micrograms per liter (ug/L) |
| Chl | Chlorophyll a; resolution = 0.01; accuracy = 0.1; detection limit = 0.5 | micrograms per liter (ug/L) |
| PC | Particulate Carbon; resolution = 0.1; accuracy = 1; detection limit = 0.5 | micrograms per liter (ug/L) |
| PN | Particulate Nitrogen; resolution = 0.01; accuracy = 0.1; detection limit = 0.1 | micrograms per liter (ug/L) |
| d13C | Delta 13C, representing the ratio of 13C to 12C of suspended particulate material, calculated as d13C = ((Rsmp/Rstd)-1) X 1000, where R = 13C/12C, smp = sample, std = PDB carbonate standard. resolution = 0.01; accuracy = 0.05 ‰ | per mil (‰) |
| d15N | Delta 15N, representing the ratio of 15N to 14N of suspended particulate material, calculated as d15N = ((Rsmp/Rstd)-1) X 1000, where R = 15C/14C, smp = sample, std = air. resolution = 0.01; accuracy = 0.1 ‰ | per mil (‰) |
| CO2 | Carbon dioxide; resolution = 0.1 umol/L; accuracy = ±3% | micromoles per liter (umol/L) |
| DIC | Dissolved Inorganic Carbon (carbon dioxide + carbonic acid + bicarbonate + carbonate); resolution = 1 umol/L; accuracy = ±3% | micromoles per liter (umol/L) |
| DOC | Dissolved organic carbon; resolution = 0.1; accuracy = 5; detection limit=5 | micromoles per liter (umol/L) |

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## Instruments

| | |
|---|---|
| **Dataset-specific Instrument Name** | Li-Cor Li-820 |
| **Generic Instrument Name** | CO2 Analyzer |
| **Dataset-specific Description** | As part of the continuous CO2 monitoring system, reverse-flow air from the equilibrator is pumped through desiccant, after which it flows through an infrared gas analyzer (Li-Cor Li-820) which measures the partial pressure of CO2 normalized to 1 atmosphere. |
| **Generic Instrument Description** | Measures atmospheric carbon dioxide (CO2) concentration. |

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|---|---|
| **Dataset-specific Instrument Name** | Campbell CR1000 Controller / Datalogger |
| **Generic Instrument Name** | Data Logger |
| **Dataset-specific Description** | The continuous CO2 monitoring system is controlled by a Campbell CR1000 Controller / Datalogger. |
| **Generic Instrument Description** | Electronic devices that record data over time or in relation to location either with a built-in instrument or sensor or via external instruments and sensors. |

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|---|---|
| **Dataset-specific Instrument Name** | WETLabs flow-through fluorometer |
| **Generic Instrument Name** | Fluorometer |
| **Dataset-specific Description** | The continuous CO2 monitoring system includes a WETLabs flow-through fluorometer. |
| **Generic Instrument Description** | A fluorometer or fluorimeter is a device used to measure parameters of fluorescence: its intensity and wavelength distribution of emission spectrum after excitation by a certain spectrum of light. The instrument is designed to measure the amount of stimulated electromagnetic radiation produced by pulses of electromagnetic radiation emitted into a water sample or in situ. |

| | |
|---|---|
| **Dataset-specific Instrument Name** | SRI 8610C Gas chromatograph |
| **Generic Instrument Name** | Gas Chromatograph |
| **Dataset-specific Description** | SRI 8610C Gas chromatograph. This instrument was used to measured the CO2 and DIC concentration in water samples. The instrument was calibrated against CO2 standards with an accuracy of +/- 3%. |
| **Generic Instrument Description** | Instrument separating gases, volatile substances, or substances dissolved in a volatile solvent by transporting an inert gas through a column packed with a sorbent to a detector for assay. (from SeaDataNet, BODC) |

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|---|---|
| **Dataset-specific Instrument Name** | Finnigan MAT delta S stable isotope ratio mass spectrometer |
| **Generic Instrument Name** | Isotope-ratio Mass Spectrometer |
| **Dataset-specific Description** | Finnigan MAT delta S stable isotope ratio mass spectrometer with elemental analyzer front end and ConFlo II interface; Thermo Fisher Scientific, Waltham, MA, USA. This instrument was used to measure carbon and nitrogen stable isotope ratios. After every 12th sample, an acetanilide control was run to ensure instrument calibration. Instrument precision was 0.2 per mil for both C and N isotopes based upon acetanilide controls. |
| **Generic Instrument Description** | The Isotope-ratio Mass Spectrometer is a particular type of mass spectrometer used to measure the relative abundance of isotopes in a given sample (e.g. VG Prism II Isotope Ratio Mass-Spectrometer). |

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| **Dataset-specific Instrument Name** | ASI-5000 auto sampler |
| **Generic Instrument Name** | Laboratory Autosampler |
| **Dataset-specific Description** | The Shimadzu TOC-L analyzer is equipped with an ASI-5000 auto sampler. |
| **Generic Instrument Description** | Laboratory apparatus that automatically introduces one or more samples with a predetermined volume or mass into an analytical instrument. |

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| **Dataset-specific Instrument Name** | Niskin bottles |
| **Generic Instrument Name** | Niskin bottle |
| **Dataset-specific Description** | 5 L Niskin bottles. Lake water samples were collected with a 5-liter Niskin bottle fitted with MasterFlex tubing (to minimize potential toxicity from latex rubber and heavy metals). |
| **Generic Instrument Description** | A Niskin bottle (a next generation water sampler based on the Nansen bottle) is a cylindrical, non-metallic water collection device with stoppers at both ends. The bottles can be attached individually on a hydrowire or deployed in 12, 24, or 36 bottle Rosette systems mounted on a frame and combined with a CTD. Niskin bottles are used to collect discrete water samples for a range of measurements including pigments, nutrients, plankton, etc. |

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|---|---|
| **Dataset-specific Instrument Name** | peristaltic pump |
| **Generic Instrument Name** | Pump |
| **Dataset-specific Description** | The components of the continuous CO2 monitoring system include a peristaltic pump that forces water through an air-water equilibrator. |
| **Generic Instrument Description** | A pump is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action. Pumps can be classified into three major groups according to the method they use to move the fluid: direct lift, displacement, and gravity pumps |

| | |
|---|---|
| **Dataset-specific Instrument Name** | Shimadzu TOC-L total organic carbon analyzer |
| **Generic Instrument Name** | Shimadzu TOC-L Analyzer |
| **Dataset-specific Description** | Shimadzu TOC-L total organic carbon analyzer. This instrument was used for measuring dissolved organic carbon in filtered water samples. The analyzer was calibrated with a dilution series of reagent grade potassium hydrogen phthalate in 0.3 molar hydrochloric acid. |
| **Generic Instrument Description** | A Shimadzu TOC-L Analyzer measures DOC by high temperature combustion method. Developed by Shimadzu, the 680 degree C combustion catalytic oxidation method is now used worldwide. One of its most important features is the capacity to efficiently oxidize hard-to-decompose organic compounds, including insoluble and macromolecular organic compounds. The 680 degree C combustion catalytic oxidation method has been adopted for the TOC-L series. http://www.shimadzu.com/an/toc/lab/toc-l2.html |

| | |
|---|---|
| **Dataset-specific Instrument Name** | Varian Cary 50 UV-Vis spectrophotometer |
| **Generic Instrument Name** | Spectrophotomer-Varian Cary 50UV |
| **Dataset-specific Description** | Varian Cary 50 UV-Vis spectrophotometer. All phosphorus measurements were made using this spectrophotometer. Soluble reactive phosphorus and total dissolved phosphorus were measured using a 10-cm cuvette, and particulate phosphorus was measured using a 1-cm cuvetter. |
| **Generic Instrument Description** | The Varian Cary 50 UV-Visible Spectrophotometer has a xenon flash lamp and a 1.5nm slit width for measurement of total particulate absorption spectra. |

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| **Dataset-specific Instrument Name** | Turner Designs benchtop fluorometer model 10-000 |
| **Generic Instrument Name** | Turner Designs Fluorometer-10 |
| **Dataset-specific Description** | Turner Designs benchtop fluorometer model 10-000. This fluorometer was used for all chlorophyll a measurements. The instrument was calibrated annually using spinach leaf extract calibrated following the trichromatic method as described by Stainton et al. (1977). |
| **Generic Instrument Description** | The Turner Designs Model 10 fluorometer (manufactured by Turner Designs, turnerdesigns.com, Sunnyvale, CA, USA) is used to measure Chlorophyll fluorescence. No information could be found for this specific model. |

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|---|---|
| **Dataset-specific Instrument Name** | temperature sensor |
| **Generic Instrument Name** | Water Temperature Sensor |
| **Dataset-specific Description** | The continuous CO2 monitoring system includes a temperature sensor. |
| **Generic Instrument Description** | General term for an instrument that measures the temperature of the water with which it is in contact (thermometer). |

| | |
|---|---|
| **Dataset-specific Instrument Name** | temperature sensor |
| **Generic Instrument Name** | Water Temperature Sensor |
| **Dataset-specific Description** | The continuous CO2 monitoring system includes a temperature sensor. |
| **Generic Instrument Description** | General term for an instrument that measures the temperature of the water with which it is in contact (thermometer). |

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## Deployments

**Neeskay_Cruises_2017-2020**

| | |
|---|---|
| **Website** | https://www.bco-dmo.org/deployment/730830 |
| **Platform** | R/V Neeskay |
| **Start Date** | 2017-05-11 |
| **End Date** | 2020-07-10 |
| **Description** | Cruises associated with project "Collaborative Research: Regulation of plankton and nutrient dynamics by hydrodynamics and profundal filter feeders" (https://www.bco-dmo.org/project/670679) Multiple deployments of the small research vessel, R/V Osprey, in Lake Michigan at three locations northeast of Milwaukee Harbor, with bottom depths of 15 m (43.09577 N, 87.8611 W), 45 m (43.097983 N, 87.784033 W), and 75 m (43.097917 N, 87.7187 W). The vessel returned to port at end of each day. Both R/V/ Neeskay and R/V Osprey were used for sampling on this project. Sampling dates are as follows: 2017 Dates: May 11, 26; June 1, 8, 13, 23, 30; July 11, 18, 25; Aug. 1, 2, 9, 10, 16, 29; Sep. 12; Oct. 5, 9, 23; Nov. 13. 2018 Dates: May 10, June 12, June 27, July 17, July 19, July 31, Aug. 6, Aug. 23, Sep. 11, Sep. 13, Sep. 25, Oct. 18, Oct. 25. 2019 Dates: May 2, 14; June 5; July 1, 25; Aug. 19, 27; Sep. 11, 20, 23; Oct. 14; Nov. 4 2020 Dates: July 10. |

**Osprey_Lake_Michigan_2017-2020**

| | |
|---|---|
| **Website** | https://www.bco-dmo.org/deployment/737338 |
| **Platform** | R/V Osprey |
| **Start Date** | 2017-05-11 |
| **End Date** | 2020-07-10 |
| **Description** | Cruises associated with project "Collaborative Research: Regulation of plankton and nutrient dynamics by hydrodynamics and profundal filter feeders" (https://www.bco-dmo.org/project/670679) Multiple deployments of the small research vessel, R/V Osprey, in Lake Michigan at three locations northeast of Milwaukee Harbor, with bottom depths of 15 m (43.09577 N, 87.8611 W), 45 m (43.097983 N, 87.784033 W), and 75 m (43.097917 N, 87.7187 W). The vessel returned to port at end of each day. Both R/V/ Neeskay and R/V Osprey were used for sampling on this project. Sampling dates are as follows: 2017 Dates: May 11, 26; June 1, 8, 13, 23, 30; July 11, 18, 25; Aug. 1, 2, 9, 10, 16, 29; Sep. 12; Oct. 5, 9, 23; Nov. 13. 2018 Dates: May 10, June 12, June 27, July 17, July 19, July 31, Aug. 6, Aug. 23, Sep. 11, Sep. 13, Sep. 25, Oct. 18, Oct. 25. 2019 Dates: May 2, 14; June 5; July 1, 25; Aug. 19, 27; Sep. 11, 20, 23; Oct. 14; Nov. 4 2020 Dates: July 10. |

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## Project Information

## Collaborative Research: Regulation of plankton and nutrient dynamics by hydrodynamics and profundal filter feeders (Filter Feeders Physics and Phosphorus)

**Coverage**: Lake Michigan

*Overview:*
While benthic filter feeders are known to influence plankton and nutrient dynamics in shallow marine and freshwater systems, their role is generally considered to be minor in large, deep systems. However, recent evidence indicates that profundal quagga mussels (Dreissena rostriformis bugensis) have dramatically altered energy flow and nutrient cycling in the Laurentian Great Lakes and other larges aquatic systems, so that conventional nutrient-plankton paradigms no longer apply. Observed rates of phosphorus grazing by profundal quagga mussels in Lake Michigan exceed the passive settling rates by nearly an order of magnitude, even under stably stratified conditions. We hypothesize that the apparently enhanced particle deliver rate to the lake bottom results from high filtration capacity combined with vertical mixing processes that advect phytoplankton from the euphotic zone to the near-bottom layer. However, the role of hydrodynamics is unclear, because these processes are poorly characterized both within the hypolimnion as a whole and within the near-bottom layer. In addition, the implications for phytoplankton and nutrient dynamics are unclear, as mussels are also important nutrient recyclers. In the proposed interdisciplinary research project, state-of-the-art instruments and analytical tools will be deployed in Lake Michigan to quantify these critical dynamic processes, including boundary layer turbulence, mussel grazing, excretion and egestion, and benthic fluxes of carbon and phosphorus. Empirical data will be used to calibrate a 3D hydrodynamic-biogeochemical model to test our hypotheses.

*Intellectual Merit:*
This collaborative biophysical project is structured around two primary questions: 1) What role do profundal dreissenid mussels play in large lake carbon and nutrient cycles? 2) How are mussel grazing and the fate of nutrients recycled by mussels modulated by hydrodynamics at scales ranging from mm (benthic boundary layer) to meters (entire water column)? The project will improve the ability to model nutrient and carbon dynamics in coastal and lacustrine waters where benthic filter-feeders are a significant portion of the biota. By so doing, it will address the overarching question of how plankton and nutrient dynamics in large, deep lakes with abundant profundal filter feeders differ from the conventional paradigm described by previous models. Additionally, the project will quantify and characterize boundary layer turbulence for benthic boundary layers in large, deep lakes, including near-bed turbulence produced by benthic filter feeders.

*Broader Impacts:*
The project will provide new insight into the impacts of invasive dreissenid mussels, which are now threatening many large lakes and reservoirs across the United States. Dreissenid mussels appear to be responsible for a number of major changes that have occurred in the Great Lakes, including declines of pelagic plankton populations, declines in fish populations, and, ironically, nuisance algal blooms in the nearshore zone. As a result, conventional management models no longer apply, and managers are uncertain about appropriate nutrient loading targets and fish stocking levels. The data and models resulting from this project will help to guide those decisions. Additionally, the project will provide insight to bottom boundary layer physics, with applicability to other large lakes, atidal coastal seas, and the deep ocean. The project will leverage the collaboration and promote interdisciplinary education for undergraduate and graduate students from two universities (UW-Milwaukee and Purdue). The project will support 3 Ph.D. students and provide structured research experiences to undergraduates through a summer research program. The project will also promote education of future aquatic scientists by hosting a Biophysical Coupling Workshop for graduate students who participate in the annual IAGLR conferences, and the workshop lectures will be published for general access through ASLO e-Lectures and on an open-access project website.

*Background publications are available at:*
http://onlinelibrary.wiley.com/doi/10.1002/2014JC010506/full
http://link.springer.com/article/10.1007/s00348-012-1265-9
http://aslo.net/lomethods/free/2009/0169.pdf
http://www.sciencedirect.com/science/article/pii/S0380133015001458

*Note:* This is an NSF Collaborative Research Project.

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## Funding

| Funding Source | Award |
|---|---|
| NSF Division of Ocean Sciences (NSF OCE) | OCE-1658390 |

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