Sub-Indicator: Zooplankton

Overall Assessment

Status: Good

Trends:

10-Year Trend: Unchanging

Long-term Trend (1997-2019): Undetermined

Rationale: The oligotrophic zooplankton community of Lake Superior did not change from 1997 to 2019. Lake Huron experienced a well-documented decrease in zooplankton biomass in 2003, particularly for cladocerans. Similar but smaller decreases in biomass and community shifts occurred at this time for Lakes Michigan and Ontario. Lake Erie zooplankton biomass has been highly variable over the time series but recently (since 2013) biomass increased in the Central and Eastern basins including *Daphnia*.

Lake-by-Lake Assessment

Lake Superior

Status: Good

10-Year Trend: Unchanging

Long-term Trend (1997-2019): Unchanging

Rationale: Consistent oligotrophic zooplankton community dominated by calanoid copepods and maintenance of low but sustained zooplankton biomass near 2-3 g m^{-2}

Lake Michigan

Status: Good

10-Year Trend: Unchanging

Long-term Trend (1997-2019): Deteriorating

Rationale: The oligotrophic zooplankton community has been dominated by calanoid copepods since the early 2000s. Decreases in zooplankton biomass with loss of cladocerans was evident in 2004.

Lake Huron (including St. Marys River)

Status: Fair

10-Year Trend: Unchanging

Long-term Trend (1997-2019): Deteriorating

Rationale: The decrease in zooplankton biomass in 2003, particularly of cladocerans, to levels below that of Lake Superior (< 2 g m^{-2}) was sudden and likely represents levels limiting to forage fish. The decadal status has not changed, although the long-term trend remains of concern.

Lake Erie (including St. Clair-Detroit River Ecosystem)

Status: Good

10-Year Trend: Improving

Long-term Trend (1997-2019): Unchanging

Rationale: Zooplankton biomass has steadily increased, including important *Daphnia* in the Central Basin and the Eastern Basin, since 2013.

Lake Ontario (including Niagara River and International section of the St. Lawrence River)

Status: Good

10-Year Trend: Unchanging

Long-term Trend (1997-2019): Unchanging

Rationale: Over the past decade, overall zooplankton biomass and community structure has been unchanging. Over the entire time series, biomass has decreased slightly over time and the community has shifted toward calanoid copepods, with losses of cyclopoid copepods and variable abundance of cladocerans. The decrease in biomass has not reached levels of concern for forage fish.

Status Assessment Definitions

The current available GLNPO time series is 1997-2019. New data added in this report is for 2017-2019.

Good: Zooplankton biomass and community structure consistent with target TP concentrations of specific deep lakes (higher than 2 g m^{-2} in Lakes Superior, Huron and Michigan, 3 g m^{-2} in Lake Ontario). For shallow Lake Erie, 2 g m^{-2} in Eastern and Central Lake Erie, and 1 g m^{-2} in Western Lake Erie.

Fair: Evidence of change in biomass, average size, or community structure away from the desired lake-specific goals.

Poor: Offshore zooplankton biomass below 1 g m^{-2} in Lakes Superior, Huron and Michigan and 2 g m^{-2} in Lake Ontario. For Lake Erie, below 1 g m^{-2} in Eastern and Central Basin and 0.5 g m^{-2} in the Western Basin. Such low values may limit forage fish populations.

Undetermined: data are not available or are insufficient to assess condition of the ecosystem components.

Trend Assessment Definitions

Improving: recovery to sustaining levels of biomass and return to original native community composition.

Unchanging: no significant changes in biomass or composition, generally a good thing unless in restoration process.

Deteriorating: zooplankton biomass declining well below goals, low prevalence of large *Daphnia* species (and perhaps small overall average size) due to high fish predation, high prevalence of non-native species such as predatory cladocerans.

Undetermined: metrics do not indicate a clear overall trend, or data are not available to report on a trend.

Endpoints and/or Targets

Due to the bottom-up connection of nutrients (Total Phosphorus - TP) with algal concentration (Chl a) and zooplankton carrying capacity, targets for areal zooplankton biomass (measured in dry weight) should reflect the International Joint Commission (IJC) goals for spring total phosphorus concentrations (Chapra and Dolan 2012). Thus, lakes with lower target TP concentrations (e.g. Lake Superior and Huron at phosphorus concentrations of 5 μg l^{-1} and Lake Michigan at 7 μg l^{-1}) will have a lower target zooplankton biomass (2 g m^{-2}) than lakes with higher target TP concentrations (e.g. Lake Ontario at 10 μg P l^{-1}) which will have a target offshore zooplankton biomass of 3 g m^{-2}. Although Lake Erie has a similar TP target as Lake Ontario, it is a much shallower lake. Therefore goals set for whole water column zooplankton biomass are lower with 2 g m^{-2} for the Eastern (40 m) and Central Basin (20 m) and 1 g m^{-2} for the Western Basin (10 m).

Sub-Indicator Purpose

The offshore zooplankton biomass sub-indicator assesses the standing stock and community composition of zooplankton in the Great Lakes over time and space.

Changes in the offshore zooplankton biomass sub-indicator reflect influences from both bottom-up (primary production) and top-down (vertebrate or invertebrate predation) mechanisms as well as energy transfer across trophic levels. The purpose of this sub-indicator is to contribute to the measurement of the stepwise trophic efficiency of the food web at transferring algal production to fish. Zooplankton biomass has often been used to explain deviations in the relationship between nutrients (total phosphorus, TP) and phytoplankton biomass (Chl a) (Taylor and Carter 1997).

Ecosystem Objective

Maintain and support a healthy and diverse fishery; maintain trophic states consistent with the lake-specific goals – oligotrophic Lakes Superior, Huron, Michigan, and Ontario, and mesotrophic Lake Erie. Zooplankton represent an important trophic link from primary production to fish and thus abundant zooplankton tend to improve water quality and produce more fish.

This sub-indicator best supports work towards General Objective #5 of the 2012 Great Lakes Water Quality Agreement that states that the Waters of the Great Lakes should "support healthy and productive wetlands and other habitats to sustain resilient populations of native species."

Measure

The primary offshore zooplankton index is average lakewide or basinwide areal biomass (g dry weight/m^2). This value can be expressed as summer mean biomass (July-August) or as growing season mean biomass (e.g. April 1-October 31) if more frequent sampling is available. Standard U.S. EPA Great Lakes National Program Office (GLNPO) collection protocols call for vertical net tows from 2 m above the bottom or the top 100 m, whichever is less, with a metered 0.5-m diameter mouth net and 153-μm mesh (U.S. EPA GLNPO LG 402). Zooplankton dry weight biomass is estimated using length measurements in standard sets of length-dry weight equations available for each taxa (U.S. EPA GLNPO LG 403). Within the "Additional Information" section of this report, we propose the future addition of a mysid indicator. GLNPO samples for analysis of mysids were collected at stations > 30 m that are visited during night (1 hour after sunset to 30 min before sunrise) using whole water column tows with a 1-m diameter net with 500 µm mesh at the top and 250µm mesh at the bottom and cod end. Mysid areal dry weight biomass is reported herein as additional context, although it is not explicitly included in the indicator assessment.

Several Canadian/US state/provincial and federal agencies routinely collect offshore zooplankton samples in each Great Lake. U.S. EPA GLNPO collects offshore samples for all five Great Lakes in April and August. GLNPO samples at eight to twenty offshore stations in each lake using the same method and has been the preferred data source for this sub-indicator. Data are now available for the period 1997-2019.

Ecological Condition

Summer biomass of crustacean zooplankton communities in the offshore waters of Lake Superior has remained at a relatively low but stable level near 2-3 g m^{-2} since at least 1997 (Figure 1). The plankton community is dominated by large calanoid copepods (*Leptodiaptomus sicilis* and *Limnocalanus macrurus*) that are characteristic of oligotrophic, coldwater ecosystems.

Changes observed in the zooplankton communities of Lakes Huron and Michigan, and to a lesser extent Lake Ontario (Figures 2, 3 and 4), are consistent with expected responses to the reductions in nutrient levels seen in all three lakes. These changes could represent a consequence of nutrient reduction activities, perhaps compounded by effects of dreissenid mussels. The reductions in cladocerans in Lakes Huron and Michigan, along with continued declines in populations of the benthic amphipod *Diporeia*, could represent a decreasing food base for forage fish. However, exact mechanisms of these declines, and the relative strength of bottom-up versus top-down forcing, have yet to be determined.

Over time, zooplankton indicators of Lakes Huron and Michigan have converged towards Lake Superior in terms of biomass levels and community composition (Barbiero et al. 2012 and 2019). The community shift towards dominance by calanoid copepods is consistent with increased oligotrophication (Gannon and Stemberger ,1978). In 2003, zooplankton biomass in Lake Huron fell below that of ultra-oligotrophic Lake Superior (Barbiero et al. 2011). Bunnell et al. (2014) highlighted this decline as a potential explanation for the concurrent collapse of alewife and reduced growth of salmonids (Riley et al. 2008). Here we show that there has been little additional change since 2003 in Lake Huron.

Lake Ontario has not experienced recent declines in primary production, suggesting that top-down control may better explain the observed zooplankton community shifts in this lake. There has also been a change away from a long-term community of cyclopoid copepods and *Daphnia retrocurva* to a community composed of calanoid copepods and *Daphnia mendotae*, which may be related to low alewife abundance and a rise in invertebrate predation by the predatory cladoceran *Bythotrephes* (Barbiero et al. 2014, Rudstam et al. 2015).

The zooplankton community of Lake Erie is taxonomically diverse and rich in native and non-native cladoceran species (Figures 5-7). The low abundance of deep dwelling calanoid *Limnocalanus macrurus*, and the overall maintenance of cladocerans relative to calanoids in Lake Erie, can be attributed to the shallow bathymetry as well as the lake's mesotrophic state. Zooplankton biomass has been highly variable among years in all three basins, although there have been recent increases in biomass in the central and eastern basins.

Linkages

Linkages to other sub-indicators in the indicator suite include:

- Other Habitat and Species sub-indicators (phytoplankton, benthic community, and prey fish diversity). Zooplankton consume phytoplankton, and thus respond to changes in algal biomass. Zooplankton also respond to changes in their predators that include both fish and invertebrates. Both zooplankton and benthic invertebrate community structure influences the prey fish community biomass and composition.
- Nutrients in Lakes (open water) – phosphorus levels regulate primary productivity by phytoplankton and thus impact food availability for zooplankton.
- Increased water clarity shifts primary production to deeper depths in the form of deep chlorophyll layers (DCL, Scofield et al. 2020), which affects food availability for zooplankton.
- Interannual changes in water temperatures and ice cover associated with climate change could lead to impacts on the distribution of cold-water fauna such as large bodied calanoid copepods that have become increasingly prevalent in the upper Great Lakes. Water levels and changes in precipitation are less likely to affect zooplankton.

Assessing Data Quality

Data Characteristics	Agree	Neutral or Unknown	Disagree	Not Applicable
Data are documented, validated, or quality-assured by a recognized agency or organization	X			
Data are from a known, reliable and respected generator of data and are traceable to original sources	X			
Geographic coverage and scale of data are appropriate to the Great Lakes Basin	X			
Data obtained from sources within the U.S. are comparable to those from Canada	X			
Uncertainty and variability in the data are documented and within acceptable limits for this sub-indicator report	X			
Data used in assessment are openly available and accessible	Yes	Data can be found here: https://cdx.epa.gov/		

Data Limitations

Both U.S. and Canadian agencies conduct zooplankton monitoring programs. Note that sampling and analysis methodologies and biomass calculations differ, highlighting the importance in consolidating efforts across agencies to increase the ability for data sharing in the future.

Many historic time series are based only on epilimnetic sampling that miss deeper dwelling zooplankton, particularly for increasingly oligotrophic offshore settings and in lakes with higher water clarity that have zooplankton residing in deep water during the day and migrating to surface water during the night. Those data are not being utilized in this assessment; only deeper net tow data were used (100 m or 2-m off the bottom, whichever is shallower), which limits the time series to years with deep tow data.

Several taxa-based ratios (e.g. calanoids to cyclopoids+cladocerans) have been proposed but are not always consistently presented (i.e. by density or biomass). Several of the proposed indices have not been fully tested for Great Lakes or in long term datasets across many lakes, and thus are not appropriate to use at this time; such alternate indices may be used in the future if additional validation suggests they would add value to this assessment.

The biomass of dreissenid mussel larvae (veligers) in the zooplankton community can vary dramatically in time and space. Many current monitoring programs focus only on crustacean zooplankton. The small size of veliger larvae requires sampling with a 64 micron net to place this additional biomass in the context of the rest of the zooplankton community.

Additional Information

Note that we use areal biomass (g m^{-2}) rather than volumetric (g m^{-3}) units to better evaluate the overall standing biomass of these lakes for connecting to fish production potential (Bunnell et al. 2014). A change to using areal units as indicators was done in 2015. Whole water column (in this case maximum of 100 m) tows in deep lakes include large strata of hypolimnion that have few zooplankton. Volumetric biomass estimates from 100 m net tows are thus “diluted” relative to shallower lakes that have less hypolimnion. Areal biomass represents the zooplankton biomass found within a one meter square water column. Note that for Lakes Superior, Michigan, and Ontario, most offshore GLNPO sites are > 100 m but many of the sites for Lake Huron are < 100 m. In Lake Erie, depths range from 10 m in the Western to 20 m in the Central to 50 m in the Eastern basins.

More information could be included in this sub-indicator in the future. Including a sub-indicator based on crustacean zooplankton community structure, focusing on calanoid copepods, would be useful. Mean body size and species composition of zooplankton are also sensitive indicators of predatory pressure by planktivorous fish and large invertebrates (*Mysis* and predatory cladocerans). Nearshore measures for the Zooplankton sub-indicator have also been proposed. Several long-term nearshore biomonitoring programs that focus on zooplankton exist (e.g. Lakes Erie and Ontario) and time series have detected changes that can complement offshore trends in biomass and community composition. For example, the Lake Ontario Biomonitoring Effort (NY DEC Regional Offices, USGS, USFWS and Cornell) collects nearshore (10 m depth) samples biweekly throughout the growing season at several sites along the south shore of Lake Ontario (Holeck et al. 2020).

A future *Mysis* sub-indicator could be supported using the GLNPO time series but need further development. Mysids represent a large proportion of overall zooplankton biomass and thus represent an important prey of planktivorous fish. For example, mysids can represent up to 30% of the total crustacean zooplankton biomass in Lake Ontario, 15% in Lake Superior, 10% in Lake Michigan, 3% in Lake Huron, and less than 1% in Lake Erie (Jude et al. 2018). These animals reside on the bottom during the day and therefore are not sampled with daytime net tows. Existing monitoring programs for mysids are based on night net collection and have only been conducted consistently since 2006 or 2007, depending on the lake (Jude et al. 2018). U.S. EPA GLNPO mysid data for 2006 to 2019 are shown in Figure 8, although these data are not directly incorporated into this zooplankton indicator assessment.

An important threat to the zooplankton communities of the Great Lakes is posed by invasive species. The continued proliferation of dreissenid populations can be expected to impact zooplankton communities through the alteration of the structure and abundance of the phytoplankton community that many zooplankton depend on for food. Predation from the non-native cladocerans *Bythotrephes longimanus* and *Cercopagis pengoi* may also have an impact on zooplankton abundance and community composition. These invasive predatory cladocerans have been shown to have a major impact on zooplankton community structure in the Great Lakes (Lehman 1991; Barbiero and Tuchman 2004; Warner et al. 2006). Four new non-native zooplankton species were recently detected in Western Lake Erie: the rotifer *Brachionus leydigii*, the cyclopoid copepods *Thermocyclops crassus* and *Mesocyclops pehpeiensis*, and the cladoceran *Diaphanosoma fluviatile*. All of these species were detected at very low abundances in at least one year between 2015-2018, but they have not rapidly expanded and thus their potential impacts are not likely to be significant.

Some of the other measures useful for the interpretation of the zooplankton data include: total phosphorus, chlorophyll a, temperature, oxygen (seasonal depletion in upper hypolimnion, including anoxia in central basin of Lake Erie), primary production, and phytoplankton composition and biomass.

Acknowledgments

Authors

James Watkins, Cornell University, jmw237@cornell.edu
Anne Scofield, Great Lakes National Program Office (U.S. EPA) Chicago, IL, Scofield.Anne@epa.gov
Lars Rudstam, Cornell University, lgr1@cornell.edu

Data Source:
U.S. EPA Great Lakes National Program Office
Anne Scofield, Great Lakes National Program Office (U.S. EPA), Chicago, IL
James Watkins and Lars Rudstam, Cornell University

Information Sources

Barbiero, R. P., Tuchman, M. L. 2004. Changes in the crustacean communities of Lakes Michigan, Huron, and Erie following the invasion of the predatory cladoceran *Bythotrephes longimanus*. Can. J. Fish. Aquat. Sci. 61:2111-2125.

Barbiero, R.P., Lesht, B.M., Warren, G.J. 2011. Evidence for bottom-up control of recent shifts in the pelagic food web of Lake Huron. *J. Great Lakes Res.* 37:78-85.

Barbiero, R. P., Lesht, B. M., Warren, G. J. 2012. Convergence of trophic state and the lower food web in Lakes Huron, Michigan and Superior. J. Great Lakes Res. 38:368–380.

Barbiero, R. P., Lesht, B. M., Warren, G. J., 2014. Recent changes in the crustacean zooplankton community of Lake Ontario. J. Great Lakes Res. 40:898–910.

Barbiero, R.P., L.G. Rudstam, J.M. Watkins and B. Lesht. 2019. A cross-lake comparison of

crustacean zooplankton communities in the Great Lakes 1997-2016. J. Great Lakes Res. 45:672-690.

Bunnell, D. B., R. P. Barbiero, S. A. Ludsin, C. P. Madenjian, G. J. Warren, D. M. Dolan, T.O. Brenden, R. Briland, O.T. Gorman, J. X. He, T. H. Johengen, B. F. Lantry, T. F. Nalepa, S. C. Riley, C. M. Riseng, T. J. Treska, I. Tsehaye, M. G.

Walsh, D. M. Warner, and B. C. Weidel. 2014. Changing ecosystem dynamics in the Laurentian Great Lakes: bottom-up and top-down regulation. BioScience 64: 26-39.

Chapra, S.C and Dolan, D.M. 2012. Great Lakes total phosphorus revisited: 2. Mass balance modeling. J. Great Lakes Res. 38:741-754.

Gannon, J.E. and Stemberger, R.S. 1978. Zooplankton (Especially Crustaceans and Rotifers) as indicators of water quality. Trans. Amer. Micros. Soc. 97: 16–35.

Holeck, K. T., L. G. Rudstam, C. Hotaling, D. Lemon, W. Pearsall, J. Lantry, M. Connerton, C. Legard, S. LaPan, Z. Biesinger, B. Lantry, B. Weidel, and B. P. O'Malley. 2020. 2019 Status of the Lake Ontario lower trophic levels. NYSDEC Lake Ontario Annual Report 2019 **Section 3**:1-28.

Jude, D.J., Rudstam, L.G., Holda, T.J., Watkins, J.M., Euclide, P.T., Balcer, M.D., 2018. Trends in *Mysis diluviana* abundance in the Great Lakes, 2006–2016. J. Great Lakes Res. 44:590-599.

Lehman, J. T. 1991. Causes and consequences of cladoceran dynamics in Lake Michigan: implications of species invasion by *Bythotrephes*. J. Great Lakes Res. **17**:437-445.

Riley, S. C., Roseman, E. F., Nichols, S. J., O'Brien, T. P.,Kiley, C. S., Schaeffer, J. S., 2008. Deepwater demersal fish community collapse in Lake Huron. Trans. Am. Fish. Soc. 137: 1879–1890.

Rudstam, L. G., Holeck, K. T., Bowen, K. L., Watkins, J.M., Weidel, B. C., and Luckey, F. J., 2015. Lake Ontario zooplankton in 2003 and 2008: Community changes and vertical redistribution. Aquat. Ecosyst. Health Mgmt. 18: 43–62.

Scofield, A. E., J. M. Watkins, E. Osantowski, and L. G. Rudstam. 2020. Deep chlorophyll maxima across a productivity gradient: A case study in the Laurentian Great Lakes. Limnology and Oceanography **64**:2460–2484.

Taylor, W.D., and Carter, J.C.H. 1997. Zooplankton size and its relationship to trophic status in deep Ontario lakes. Can. J. Fish. Aquat. Sci. 54: 2691–2699.

U.S. EPA Great Lakes National Program Office, 2017. LG 402. Standard Operating Procedure for Zooplankton Sample Collection and Preservation and Secchi Depth Measurement Field Procedures. Revision 12, February 2017.

U.S. EPA Great Lakes National Program Office, 2017. LG 403. Standard Operating Procedure for Zooplankton Analysis. Revision 8, February 2017.

U.S. EPA Great Lakes National Program Office. 2017. LG 408. Standard Operating Procedure for mysid analysis. Revision 2.

Warner, D. M., Rudstam, L.G., Benoît, H. Johannsson, O.E. and Mills. E.L. 2006. Changes in seasonal nearshore zooplankton abundance patterns in Lake Ontario following establishment of the exotic predator *Cercopagis pengoi*. J. Great Lakes Res. 32:531-542.

List of Figures

Figure 1. Areal biomass (g m^{-2}) calculated from U.S. EPA's GLNPO summer survey D100 tows (towed from 100 m depth or 2 m above bottom for shallower sites to the surface) 153-µm tows for Lake Superior. Length-weight coefficients used are listed in EPA SOP LG 403. Data Sources: U.S. EPA Great Lakes National Program Office, Cornell University

Figure 2. Areal biomass (g m^{-2}) calculated from U.S. EPA's GLNPO summer survey D100 tows (towed from 100 m depth or 2 m above bottom for shallower sites to the surface) 153-µm tows for Lake Huron. Length-weight coefficients used are listed in EPA SOP LG 403. Data Sources: U.S. EPA Great Lakes National Program Office, Cornell University

Figure 3. Areal biomass (g m^{-2}) calculated from U.S. EPA's GLNPO summer survey D100 tows (towed from 100 m depth or 2 m above bottom for shallower sites to the surface) 153-µm tows for Lake Michigan. Length-weight coefficients used are listed in EPA SOP LG 403. Data Sources: U.S. EPA Great Lakes National Program Office, Cornell University

Figure 4. Areal biomass (g m^{-2}) calculated from U.S. EPA's GLNPO summer survey D100 tows (towed from 100 m depth or 2 m above bottom for shallower sites to the surface) 153-µm tows for Lake Ontario. Length-weight coefficients used are listed in EPA SOP LG 403. Data Sources: U.S. EPA Great Lakes National Program Office, Cornell University

Figure 5. Areal biomass (g m^{-2}) calculated from U.S. EPA's GLNPO summer survey D100 tows (towed from 100 m depth or 2 m above bottom for shallower sites to the surface) 153-µm tows for Western Lake Erie. Length-weight coefficients used are listed in EPA SOP LG 403. Data Sources: U.S. EPA Great Lakes National Program Office, Cornell University

Figure 6. Areal biomass (g m^{-2}) calculated from U.S. EPA's GLNPO summer survey D100 tows (towed from 100 m depth or 2 m above bottom for shallower sites to the surface) 153-µm tows for Central Lake Erie. Length-weight coefficients used are listed in EPA SOP LG 403. Data Sources: U.S. EPA Great Lakes National Program Office, Cornell University

Figure 7. Areal biomass (g m^{-2}) calculated from U.S. EPA's GLNPO summer survey D100 tows (towed from 100 m depth or 2 m above bottom for shallower sites to the surface) 153-µm tows for Eastern Lake Erie. Length-weight coefficients used are listed in EPA SOP LG 403. Data Sources: U.S. EPA Great Lakes National Program Office, Cornell University

Figure 8. Areal biomass (g m^{-2}) calculated from U.S. EPA's GLNPO spring and summer survey mysid tows (whole water column, average of spring and summer shown) for each lake. Length-weight coefficients used are listed in EPA SOP LG 408. Data for 2008 Lake Ontario uncertain due to low sample size. Data Sources: U.S. EPA Great Lakes National Program Office, Cornell University

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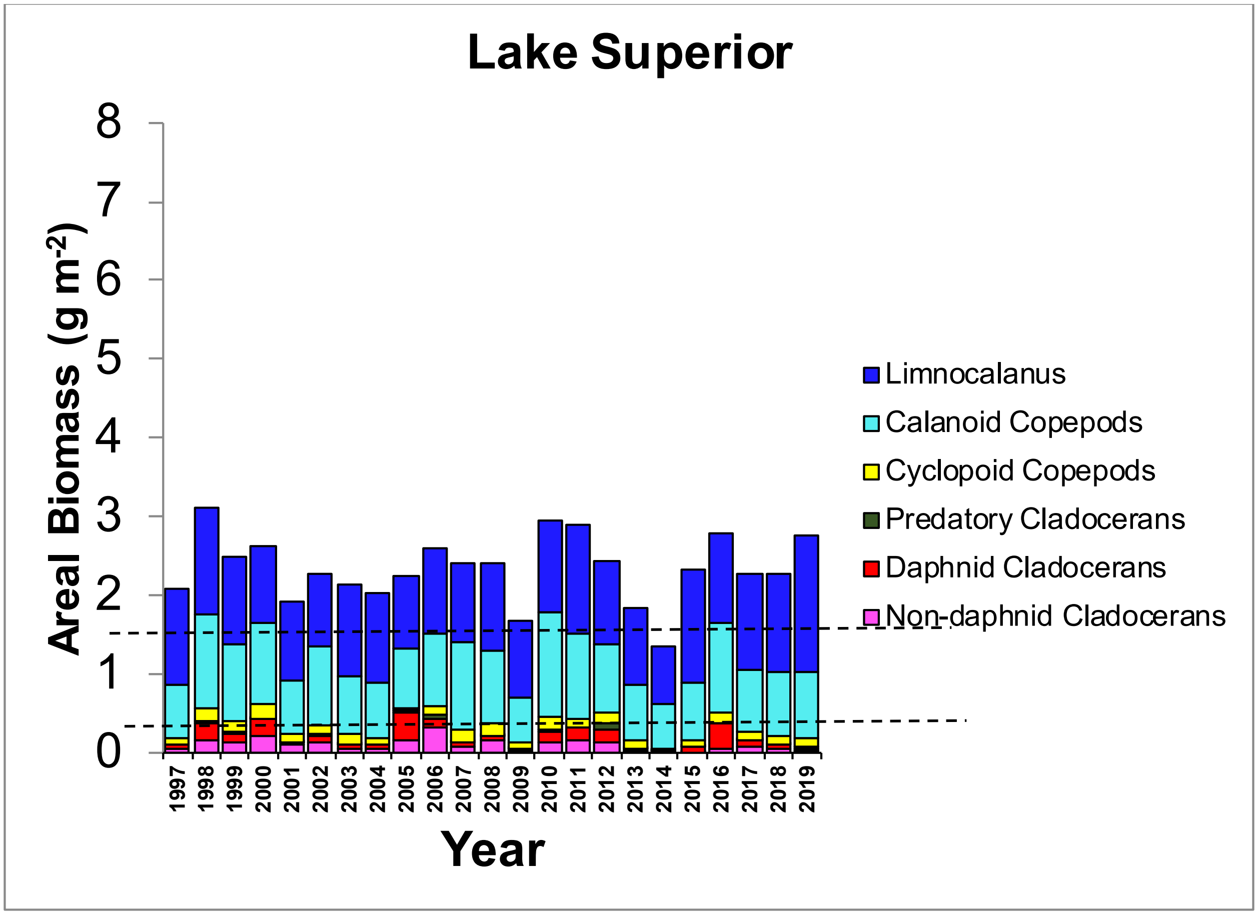

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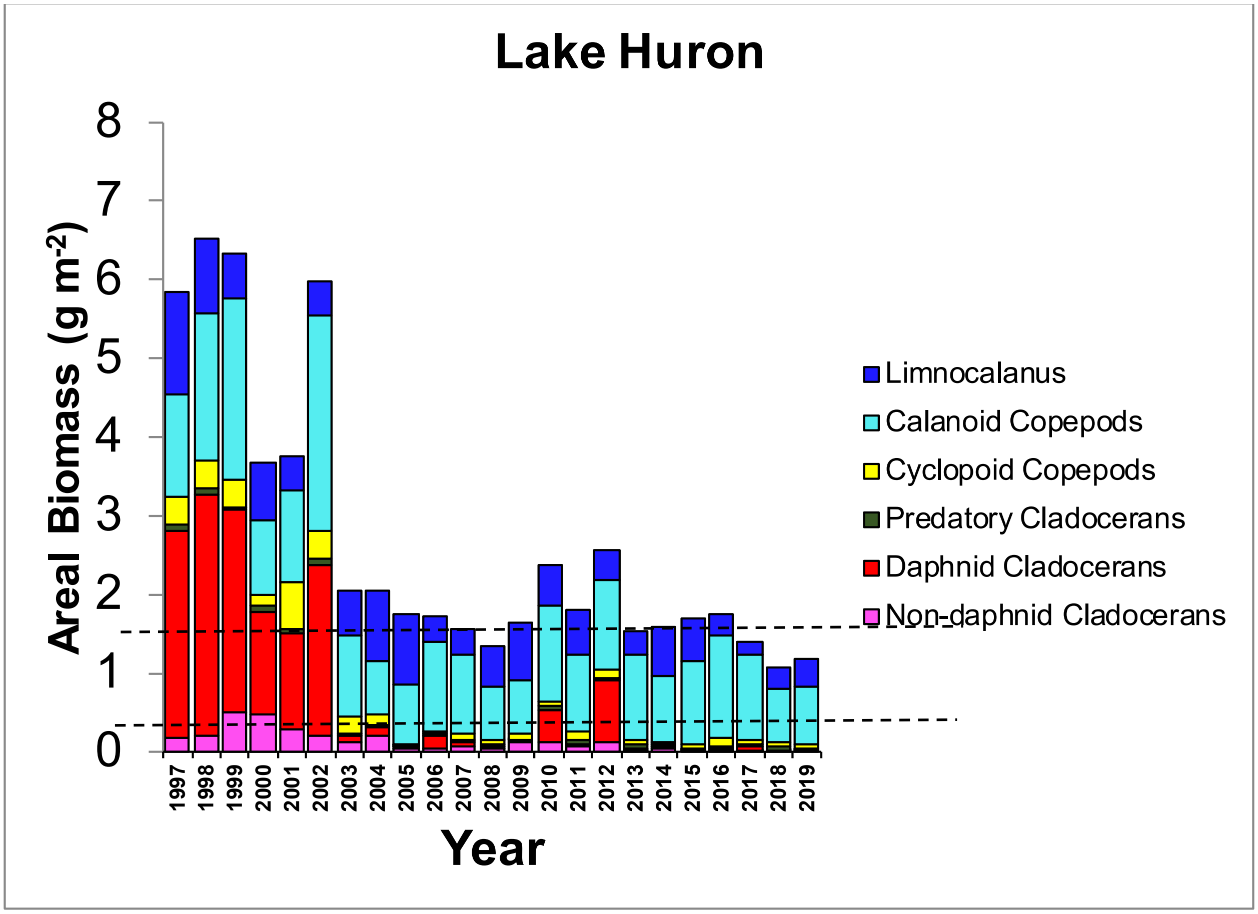
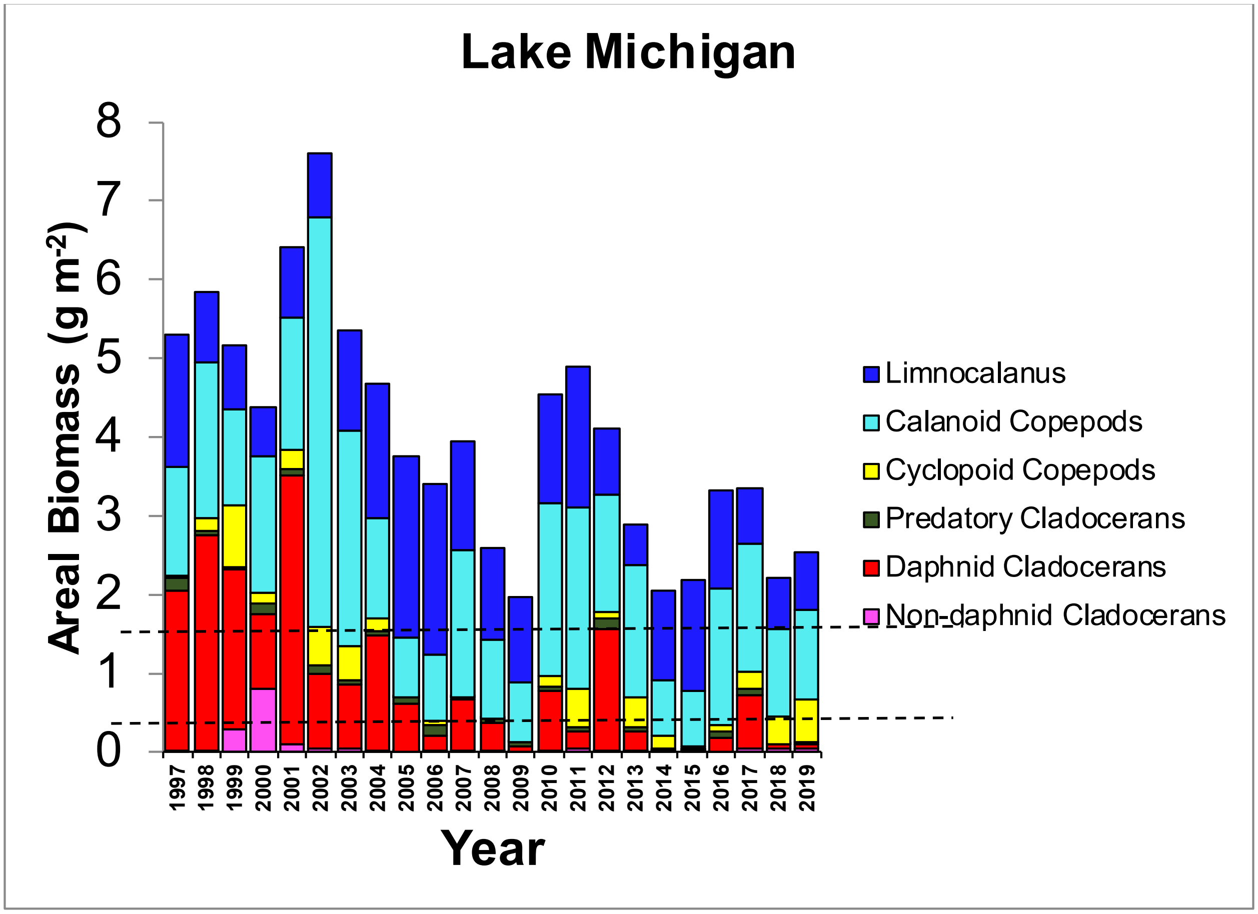


Figure 2. Areal biomass (g m^{-2}) calculated from U.S. EPA's GLNPO summer survey D100 tows (towed from 100 m depth or 2 m above bottom for shallower sites to the surface) 153-µm tows for Lake Huron. Length-weight coefficients used are listed in EPA SOP LG 403. "Good" and "Poor" thresholds are identified by dashed lines. Conditions are assessed as "Fair" when total biomass falls between the dashed lines. Data Sources: U.S. EPA Great Lakes National Program Office, Cornell University.



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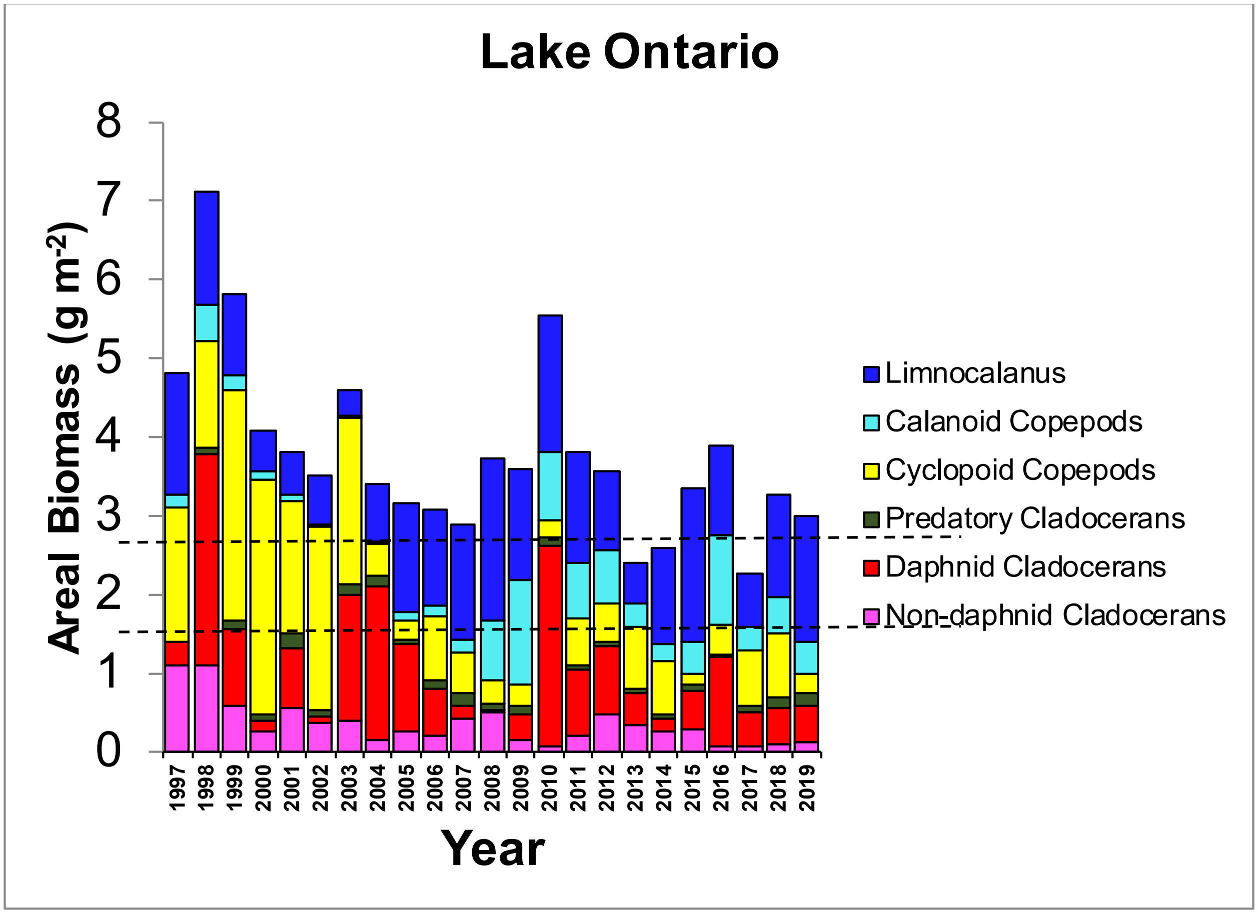

Figure 4. Areal biomass (g m^{-2}) calculated from U.S. EPA's GLNPO summer survey D100 tows (towed from 100 m depth or 2 m above bottom for shallower sites to the surface) 153-µm tows for Lake Ontario. Length-weight coefficients used are listed in EPA SOP LG 403. "Good" and "Poor" thresholds are identified by dashed lines. Conditions are assessed as "Fair" when total biomass falls between the dashed lines. Data Sources: U.S. EPA Great Lakes National Program Office, Cornell University.

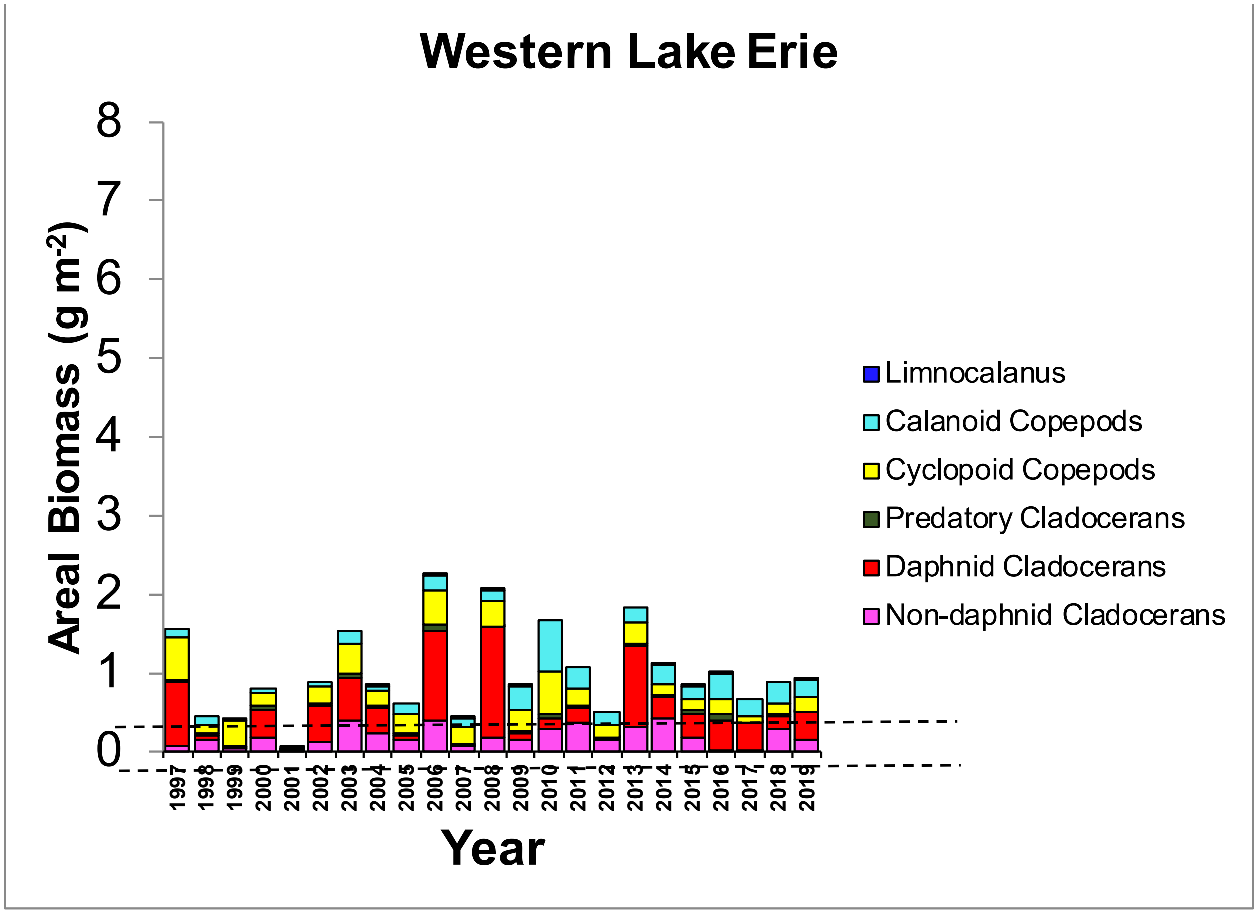

Figure 5. Areal biomass (g m^{-2}) calculated from U.S. EPA's GLNPO summer survey D100 tows (towed from 100 m depth or 2 m above bottom for shallower sites to the surface) 153-µm tows for Western Lake Erie. Length-weight coefficients used are listed in EPA SOP LG 403. "Good" and "Poor" thresholds are identified by dashed lines. Conditions are assessed as "Fair" when total biomass falls between the dashed lines. Data Sources: U.S. EPA Great Lakes National Program Office, Cornell University.

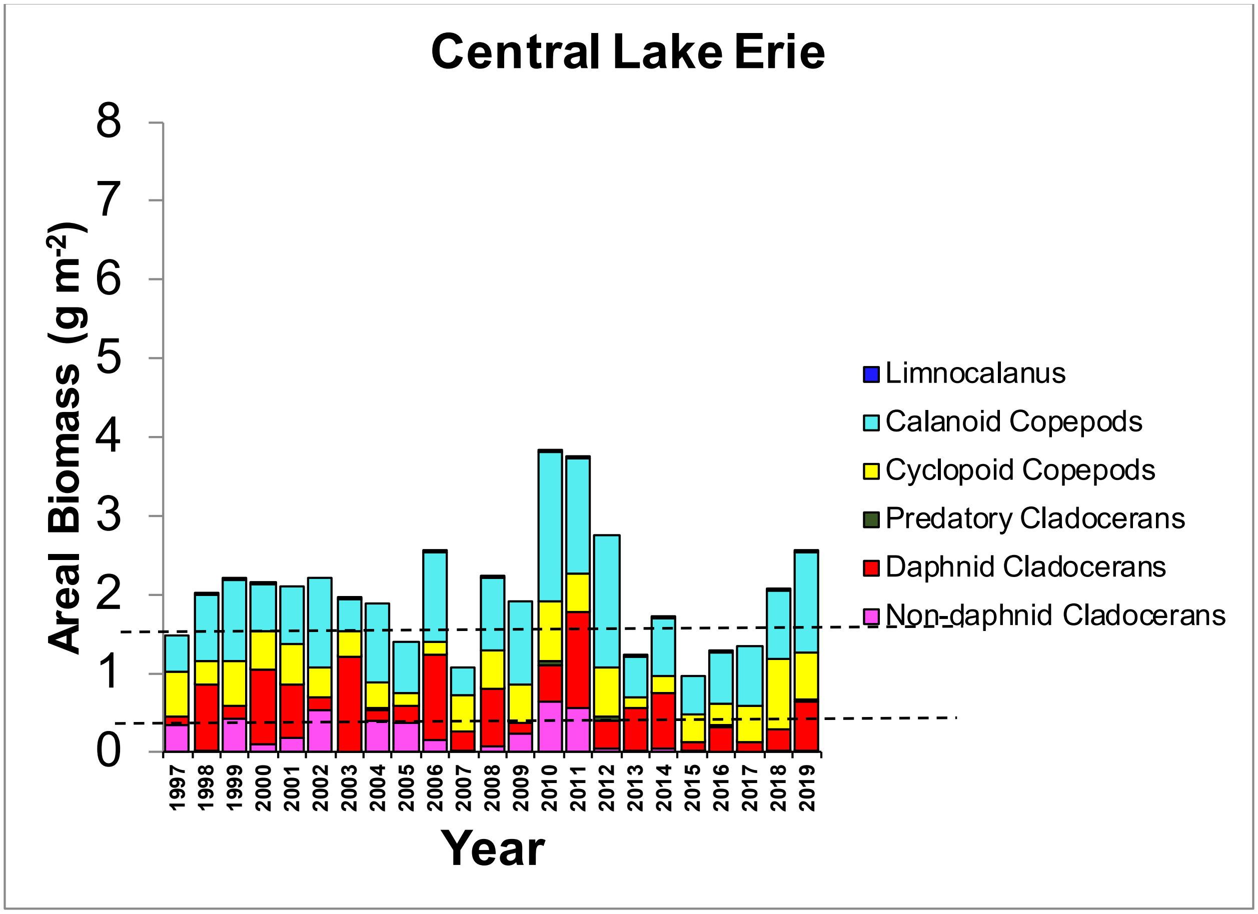

Figure 6. Areal biomass (g m^{-2}) calculated from U.S. EPA's GLNPO summer survey D100 tows (towed from 100 m depth or 2 m above bottom for shallower sites to the surface) 153-µm tows for Central Lake Erie. Length-weight coefficients used are listed in EPA SOP LG 403. "Good" and "Poor" thresholds are identified by dashed lines for each figure. Conditions are assessed as "Fair" when total biomass falls between the dashed lines. Data Sources: U.S. EPA Great Lakes National Program Office, Cornell University.

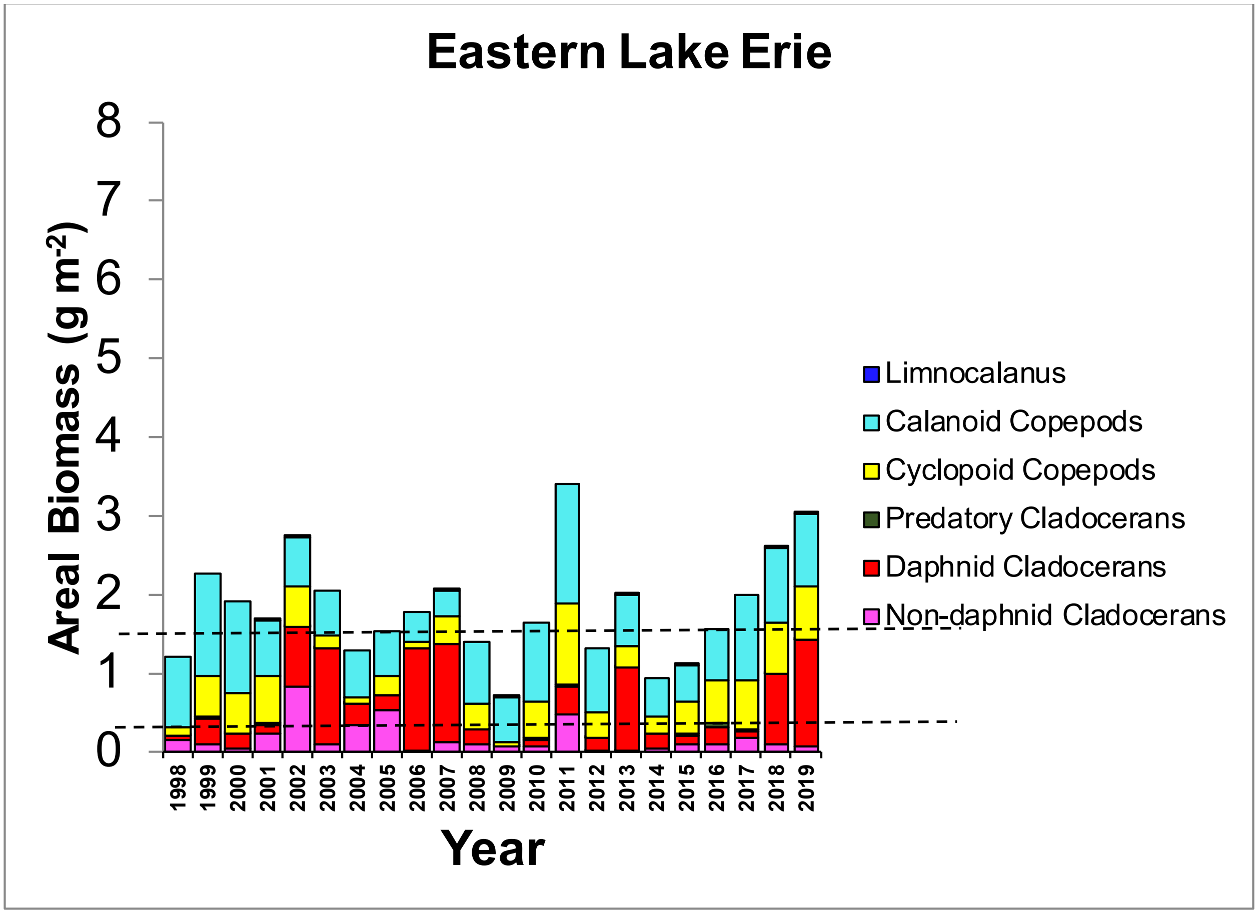

Figure 7. Areal biomass (g m^{-2}) calculated from U.S. EPA's GLNPO summer survey D100 tows (towed from 100 m depth or 2 m above bottom for shallower sites to the surface) 153-µm tows for Eastern Lake Erie. Length-weight coefficients used are listed in EPA SOP LG 403. "Good" and "Poor" thresholds are identified by dashed lines. Conditions are assessed as "Fair" when total biomass falls between the dashed lines. Data Sources: U.S. EPA Great Lakes National Program Office, Cornell University.

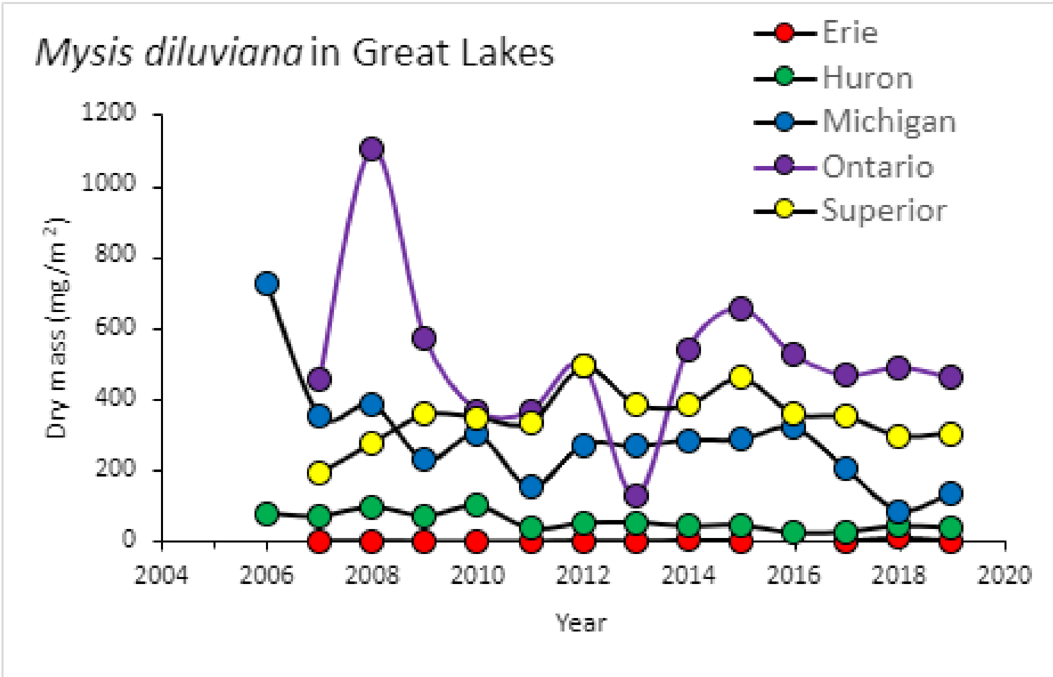

Figure 8. Areal biomass (g m^{-2}) calculated from U.S. EPA's GLNPO spring and summer survey mysid tows (whole water column, average of spring and summer shown) for each lake. Length-weight coefficients used are listed in EPA SOP LG 408. Data for 2008 Lake Ontario uncertain due to low sample size. Data Sources: U.S. EPA Great Lakes National Program Office, Cornell University.