Sub-Indicator: *Mysis*

Overall Assessment

Status: Good

10-Year Trend (2013-2023): Unchanging

Long-term Trend (1990/2005 to 2023, time frame varies by lake): Unchanging

Rationale: The *Mysis* sub-indicator is based on *Mysis diluviana* abundance (#/m^2) in whole water column net hauls taken at night between August and early November at stations deeper than 60 m. Note that the abundance values presented here only refer to the deeper part of the lakes. Available data span years 1990 to 2023 with starting year varying among lakes. Expected mysid abundance varies among lakes due to differences in bathymetry and productivity. The status is based on comparing the last 5 years (2019 – 2023) with data from 2000 to 2015. With this criterion, the status of the *Mysis* population is classified as Good in lakes Superior, Huron, Erie and Ontario, and as Poor in Lake Michigan. However, only Lake Superior shows no declining 10-year or long-term trends. Lake Ontario and Lake Huron show no significant 10-year (2013-2023) trend but have significant long-term declining trends. Lake Michigan has both a declining 10-year and long-term (1995-2023) trend. The population in Lake Huron is classified as Good partly because only one year of data was available prior to 2004 to assess the baseline densities. However, mysid densities in 2019-2023 are only 30-50% of the densities in 2000-2004 in both lakes Huron and Michigan. Data from Lake Erie are too limited to assess trends.

Data for this report was provided by the US Environmental Protection Agency Great Lakes National Program Office (EPA-GLNPO), United States Geological Survey Great Lakes Science Center (USGS-GLSC), National Oceanographic and Atmospheric Agency Great Lakes Environmental Research Laboratory (NOAA-GLERL), EPA Office of Research and Development (EPA-ORD) and Department of Fisheries and Oceans Canada (DFO).

Lake-by-Lake Assessment

Lake Superior

Status: Good

10-Year Trend (2013-2023): Unchanging

Long-term Trend (2005 to 2023): Unchanging

Rationale: *Mysis* population densities in Lake Superior averaged 173/m^2 in recent years (2019-2023) and showed no significant trends over the recent 10-years or the entire data series, with densities averaging 192/m^2 (SE 23, N 11) in 2000-2015 (Table 1, Figure 1 & 2). Mysid densities in Lake Superior vary substantially with location but change less with bottom depth compared to the other lakes. Data are based on annual EPA-GLNPO sampling in August and additional stations sampled by EPA-ORD and USGS-GLSC in September some years (2005, 2006, 2011, 2022). The number of stations sampled are between 6 and 10 per year except for 2011 (60 sites) and 2022 (46 sites). Lake Superior was not sampled in 2020. Data from a larger survey in 2016 are not yet available for inclusion in this analysis.

Lake Michigan

Status: Poor

10-Year Trend (2013-2023): Deteriorating

Long-term Trend (1995 to 2023): Deteriorating

Rationale: The status of mysids in Lake Michigan is classified as Poor as densities in 2019-2023 averaged 74/m^2. Densities in this lake have declined significantly to ~30% of values in the early 2000s. The average for 2019-2023 excludes 2020 when only one station was sampled. Current Lake Michigan mysid abundance is only slightly higher than the current average densities in Lake Huron (Table 1, Figure 1 & 2). The average for 2000-2015 were 174/m^2 (SE 17, N 14), similar to the average in Lake Superior. Data from 1995 through 2002 are limited to the Muskegon area of the lake sampled by NOAA-GLERL; time trends in that area were analyzed by Pothoven et al. (2017). Since 2005, mysids have been collected by EPA-GLNPO, USGS-GLSC, and NOAA-GLERL at 6 to 21 locations per year in August and September with additional samples at one site by Muskegon in October and November.

Lake Huron

Status: Good

10-Year Trend (2013-2023): Unchanging

Long-term Trend (2002-2023): Deteriorating

Rationale: Recent (2019-2023) *Mysis* densities at 51/m^2 are low for a deep lake, but the proportion of deep-water habitat (over 100m) is lower in Lake Huron than in the other deep lakes. Mysids declined in Lake Huron in 2003-2004 at the same time as other zooplankton (Holda et al. 2023). Sampling with mysid nets was conducted by DFO in August and October 2002 , confirming higher abundance at that time (161/m^2), and the long-term decrease is significant (Table 1, Figure 1 & 2). More continuous sampling with mysid nets did not start until 2005 by USGS-GLSC and 2006 by EPA-GLNPO with sampling in August, September and October, and there has been no further significant decline since then. This results in a status assignment of Good even though the population has declined since the early 2000s. The number of stations sampled ranged from 6 to 26 per year. Mysids were not as abundant as in the other three deep lakes even in earlier years, likely due to lower productivity and shallower depths of Lake Huron. Average density 2000-2015 was 59/m^2 (SE 10, N 12).

Lake Erie

Status: Good

10-Year Trend (2013-2023): Undetermined

Long-term Trend (2006 to 2023): Undetermined

Rationale: *Mysis diluviana* is expected to be rare in Lake Erie due to the shallow depth of this lake. They are only found in the deeper parts of the Eastern Basin, where only one station deeper than 60 m was sampled for mysids in some years by EPA-GLNPO, with typical catches less than 4/m^2 (Table 1, Figure 1). Data are too limited for an accurate assessment of trends, with samples available for only 8 years since 2006. Low densities are likely the result of a lack of a daytime low light refuge from fish predation (Holda et al. 2023). The proportion of this lake with water depth deeper than 60 m is small and mysids are not an important component of the Lake Erie ecosystem.

Lake Ontario

Status: Good

10-Year Trend (2013-2023): Unchanging

Long-term Trend (1990 to 2023): Deteriorating

Rationale: Lake Ontario currently has the highest densities of *Mysis* of any of the Great Lakes at 193/m^2, but densities are quite variable among years. The long-term trend (1990-2023) is decreasing (P=0.03, Table 1, Figure 1) but the 10-year trend is Unchanging (Table 1, Figure 2). DFO's Fall surveys of 25 to 50 stations since 2002 in October-November provide excellent spatial coverage of mysid sampling stations in Lake Ontario, although this survey is not conducted each year (missing in 2010, 2015, 2019, 2020, 2023). The EPA-GLNPO sampling available most years since 2007 is limited to less than 5 stations per year sampled in August. Additional samples were available from USGS-GLSC for years 2018 and 2022 and from Cooperative Science and Monitoring Initiative sampling efforts in 2018 and 2023. DFO calculates hypsographically corrected mysid densities from their Fall surveys, and those have averaged around 170 /m^2 in the last decades, or about half the densities found in the 1990s. The 2000-2015 densities calculated from this data set without hypsographic corrections was 225 /m2 (SE 26, N 14).

Status Assessment Definitions

We define the status of the mysid populations by comparing data from the last five years (2019-2023) with available observations between year 2000 and year 2015 in each lake (Figure 2). We assume this time period to represent the expected mysid densities under current ecological conditions in each lake that includes the presence of quagga mussels. Densities more than 1 standard deviation (SD) below the average in 2000-2015 are considered Fair, and more than 2 SD below the 2000-2015 average are considered Poor. Annual values for assessing expected mysid densities are available from 2005 to 2015 in Lake Superior, 2002 and 2005-2015 in Lake Huron, 2000-2002 and 2005-2015 in Lake Michigan, 2007, 2008, 2012, and 2013 in Lake Erie and 2002-2015 in Lake Ontario. Averages and SD were calculated based on $\log_e$ transformed values, back transformed to numbers per m^2 and rounded. These assumptions result in the lake-specific definitions for the status criteria below. Note that if more pre-2005 data from Huron were available, the limits calculated with this method for Lake Huron would increase and Huron mysids may be considered to have a status of Fair.

Lake Superior:	Good > 125 /m^2,	Fair 85-125/m^2,	Poor < 85/m^2
Lake Huron:	Good > 35 /m^2,	Fair 20-35/m^2,	Poor < 20/m^2
Lake Michigan:	Good > 115 /m^2,	Fair 80-115/m^2,	Poor < 80/m^2
Lake Erie:	Good > 0.7 /m^2,	Fair 0.4-0.7/m^2, Poor < 0.4/m^2	
Lake Ontario:	Good > 125 /m^2,	Fair 80-125/m^2,	Poor < 80/m^2

Trend Assessment Definitions

Improving: Recovery to densities observed in 2000-2015.

Unchanging: No significant changes in density, generally a good thing unless in restoration process.

No trend: Data for a 10-year or longer trend are available, but the data show conflicting trends or the trend is not significantly Improving or Deteriorating due to high variability in the data.

Deteriorating: Mysid densities declining.

Undetermined: Data are not available to report on a trend.

Endpoints and/or Targets

Mysid populations will vary with lake productivity, fish abundance, and lake bathymetry, leading to different target densities among lakes. We consider the average of samples collected from 2000 to 2015 to represent the expected density for each lake under current ecological conditions and use those values to set criteria for the current status of the mysid populations in each lake. The years 2000-2015 represents years with lowered offshore productivity and with quagga mussels present in deep waters. Since there are no actions currently available to eliminate dreissenids, we believe trends in mysids are best evaluated against a baseline that includes these ecosystem changes. Note that the densities refer only to water deeper than 60 m in each lake.

Sub-Indicator Purpose

The offshore mysid sub-indicator assesses the density of mysid shrimps in the Great Lakes over time in water deeper than 60 m. The unit is number of individuals per m^2.

This sub-indicator contributes to the assessment of food web structure and the efficiency at transferring algal production to fish. Changes in mysid densities reflect influences from both bottom-up (phytoplankton and zooplankton production) and top-down (fish predation) mechanisms. Mysids are important prey for many fish species in the Great Lakes because of their large size and high energy density. As mysids migrate from the bottom to the thermocline each night, they also contribute to the coupling of benthic and pelagic habitats.

Ecosystem Objective

Mysis diluviana is native to the Great Lakes and represents an important lipid rich prey and, due to their long life for a zooplankton (2 years), are available to fish year-round. We consider a mysid population similar to densities in the first 15 years of this century to be a reasonable goal for each of the Great Lakes.

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.” Further, this sub-indicator supports the objective to maintain and support a healthy and diverse fishery of native fish species adapted to feeding on mysids.

Methods

Both U.S. and Canadian agencies conduct mysid monitoring programs and sampling methods are comparable (Holda et al. 2023). Mysid nets are either a square net or a round net with a net opening of 0.7 to 1 m^2 and mesh sizes in the net and bucket are between 250 to 1000 µm. Samples are collected from 2 to 5 m above the bottom to the surface at night with vessels operating with red deck lights to minimize mysid’s avoidance of light. The nets are retrieved at speeds between 0.3 and 0.5 m/sec. Here we combined data from four agencies (EPA, NOAA, USGS, DFO) collected with several different research vessels. Details are in Holda et al. (2023).

For this indicator, we use samples collected between August and early November. *Mysis diluviana* is long-lived (2 years) with low daily mortality rates. Because most of the release of young occur in late winter to spring, samples collected in August-November will be dominated by the cohort released that year, thus making each year’s data largely independent. We present densities of animals larger than 3 mm, the size of juvenile mysids when leaving

the brood pouch (Holda et al. 2023). By using densities rather than biomass, we limit effects associated with the length-weight regressions used.

Number of stations sampled varies among years and depend on when ships are at a station at night. Day time samples are not included in this assessment. Only samples from stations deeper than 60 m are included as *Mysis diluviana* are rare at shallower depth. Thus, densities reported here are limited to water deeper than 60 m.

Discussion

The mysid shrimp *Mysis diluviana*, also known as the opossum shrimp, is an important component of the Great Lakes food web and can contribute up to 30% of the total biomass of crustacean zooplankton (Jude et al. 2018). Mysids mature at age 1 or 2 and produce one brood of 10-30 young that are carried in a brood pouch, hence the common name opossum shrimp. When the young mysids are about 3 mm long, they are released from the brood pouch as animals looking like adult mysids. Only one species resides in the deeper waters of the Great Lakes – *Mysis diluviana*, previously known as *Mysis relicta* (Audzijonyte and Väinölä 2005). The only other mysid species in the Great Lakes is a relatively new invader, *Hemimysis anomala*, that is only found in shallow water (Walsh et al. 2012). *Mysis diluviana* migrates from the bottom or deep hypolimnetic waters to the thermocline at night. Their upwards migration is limited by light and temperature (Boscarino et al. 2009). This daily migration couples benthic and pelagic habitats as mysids are omnivores and feed on zooplankton and phytoplankton in the water column as well as benthic invertebrates and detritus on the bottom (Johannsson et al. 2001, Sierszen et al. 2011, O'Malley et al. 2017). Their benthic ecology has received limited attention compared to their ecological role in the open water (Stockwell et al. 2020).

Mysis diluviana is native to the Great Lakes and is an important prey for both benthic and pelagic fish (Isaac et al. 2012). Pelagic fishes in the Great Lakes migrate with the mysid daily movements to feed on them (Jensen et al. 2006, Eshenroder et al. 1998). The importance of mysids for fish has likely increased with the decline in the other larger lipid-rich deepwater crustaceans – *Diporeia* sp. – in all Laurentian Great Lakes except Lake Superior. Mysids are predators on other zooplankton and are associated with lower densities of herbivorous cladocerans as revealed by comparing Canadian Shield lakes with and without native mysids (Nero and Sprules 1986, Almond et al. 1996). When introduced to new water bodies, they have had large negative effects on fish production in both the western US and Scandinavia (Lasenby et al. 1986, Spencer et al. 1999, Koksvik et al. 2009).

Mysid populations are influenced by the production of zooplankton and phytoplankton (Holda et al. 2023). Mysids declined in Lake Huron in 2003-2004 at the same time as the well documented decline in *Daphnia* and Alewife, and the continuing decline in Lake Michigan mirrors declines in productivity of that lake (Barbiero et al. 2019, Holda et al. 2023). However, mysid densities are similar in lakes Ontario and Superior even though Lake Ontario is more productive, suggesting that other factors are also important. Mysids are sensitive to increased mortality rates due to slow growth and low fecundity (Johansson et al. 2003; Holda et al. 2023) and therefore are sensitive to changes in predation rates. Mysids require sufficiently dark daytime refugia to minimize fish predation and the mysid declines in lakes Huron and Michigan could be due to increased light penetration associated with lower chlorophyll levels in addition to declines in productivity.

Although four lakes show mysid densities similar to values in 2000-2015 and thus are assigned a status of Good, there is concern about the decline in mysids in Lake Michigan. This lake's mysid population is assigned the status Poor. We hypothesize that this is related to both declining productivity and increased water clarity in this lake. Preliminary data indicate that mysid densities in Lake Michigan are still high in the northern deep basin where the water is sufficiently deep to provide mysids with a dark daytime refuge from fish predation (authors' pers. obs.), but

they have declined to low levels in the shallower southern basin. Lake Erie has consistently low mysid densities, likely because of high fish predation and very limited deep-water habitat. Mysids in Lake Erie grow fast enough to mature in one year, indicating that food resources are less limiting to mysid growth in Lake Erie than in the other lakes (Holda et al. 2023). Mysids in the other lakes mature in 2 years, although some individuals matured at 1.5 years of age in the past (Johannsson et al. 1994).

Mysis diluviana is a glacial relict species and does not survive long in water temperatures over 16 ˚C (Rudstam et al. 1999), but cold-water habitat will be available below the thermocline throughout the year in all the Great Lakes for the foreseeable future, even if warming of surface water temperatures accelerates. However, changes in nutrient loading, degraded water quality, or altered lake productivity could affect the populations.

Linkages

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

- Other Habitat and Species sub-indicators (phytoplankton, benthic community, *Diporeia*, and prey fish diversity). Mysids are omnivores that consume phytoplankton, zooplankton, benthic invertebrates, and detritus and respond to phytoplankton and zooplankton biomass. Because mysids are both part of the pelagic and benthic subsystems, they influence prey fish in both habitats. Mysid populations also respond to changes in their fish predators in both habitats.
- Nutrients in Lakes (open water) – phosphorus levels regulate primary productivity of phytoplankton and thus impact food availability for zooplankton and mysids.
- 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 mysids that reside below the thermocline during the night. Water clarity also affects forage fish predation success during the day and the availability of low-light daytime refuge is likely critical for maintaining high mysid densities.

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	This indicator is based on data from several sources and can be requested. The EPA-GLNPO data are available on the web, see below.		

Notes on Accessing Data

Mysid data collected by EPA-GLNPO biomonitoring program are publicly available on the EPA GLENDA database at the cdx website (https://cdx.epa.gov/), which requires registration to access. The mysid data are available as a RTD (Ready-to-Download) file that includes density and biomass from 2006/07 to 2022. A ReadMe table includes sampling metadata and defines data fields for this dataset. Data from USGS-GLSC are available on USGS Science Data (https://data.usgs.gov/). Data from DFO Canada are available by request from Warren Currie, data from NOAA-GLERL by request from Stephen Pothoven and data from EPA-ORD by request from Joel Hoffman.

Data Limitations

Mysid samples are collected at a limited number of stations each year and the number of dates and stations sampled each year varies (5-46 in Lake Superior, 6-26 in Lake Huron, 2-21 in Lake Michigan, and 3-49 in Lake Ontario). Only one station deeper than 60 m is sampled in Lake Erie. During the Covid-19 year (2020), sampling was limited to one station in Lake Michigan and 7 stations in Lake Huron; the other lakes were not sampled in 2020. The year 2020 was therefore only included in trend analyses for Lake Huron. Because mysids tend to be more abundant at deeper stations, the actual depths sampled will affect density estimates and stations are not the same each year. This will contribute to observed variability among years. Mysids that remain on or close to the bottom at night are not included in the net tows and not part of the density estimates.

Additional Information

Mysids can also be assessed with hydroacoustics (Rudstam et al. 2008, Watkins et al. 2015) as part of fisheries acoustics surveys or with uncrewed surface drones. This technique can allow for better spatial coverage than net hauls. However, there are still some methodological difficulties with estimating absolute abundance with acoustics associated with the target strengths estimates. Uncertainty in target strength is the largest component of current uncertainty in mysid estimates with hydroacoustics (Sullivan and Rudstam 2016).

Some mysids may stay on the bottom during the night and are then not available to water column net sampling (Shea and Makarewicz 1989, Stockwell et al. 2020). This would underestimate mysid densities obtained with nets and acoustics and, if this proportion changes over time, will affect observed time trends. Although a large proportion of the mysid population has been found on the bottom during the night in Lake Champlain (O'Malley et al 2018), this proportion may be smaller in the Great Lakes, and in deep enough water, all mysids do not migrate to the bottom during the day and stay in the water column both day and night (Robertson et al. 1968, Chapina et al. 2025).

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List of Tables

Table 1: Significance of time trends in mysid densities in the five Great Lakes. Analyses of the 10-year trends and of trends in the complete available data set are presented. Time period is given as start and end year and in parenthesis the number of years included in the analysis. Statistics include R^2 and P values. Statistically significant trends (p-value <0.05) are in bold font. Data sources are EPA Great Lakes National Program Office (all lakes), EPA Office of Research Development (Superior), USGS-Great Lakes Science Center (all lakes except Erie), NOAA-Great Lakes Environmental Research Laboratory (Michigan), and Fisheries and Oceans Canada (Ontario and Huron). Trends are the slope of the regressions in #/m^2 per year. Significant trends are in bold font.

List of Figures

Figure 1. Average mysid densities (#/m^2) in whole water column mysid net tows collected between August and October in each of the Great Lakes at night. Only stations deeper than 60 m are included. Data sources are listed in Table 1. Much of the data up to 2019 are presented in Holda et al. (2023) although additional data were added for this report. The lines represent the Spline Fit with a lambda of 3.7 for all five Great Lakes and the shaded areas the confidence limits for these lines based on annual averages. The Spline Fit was calculated using Jmp version 16.0 (SAS 2021).

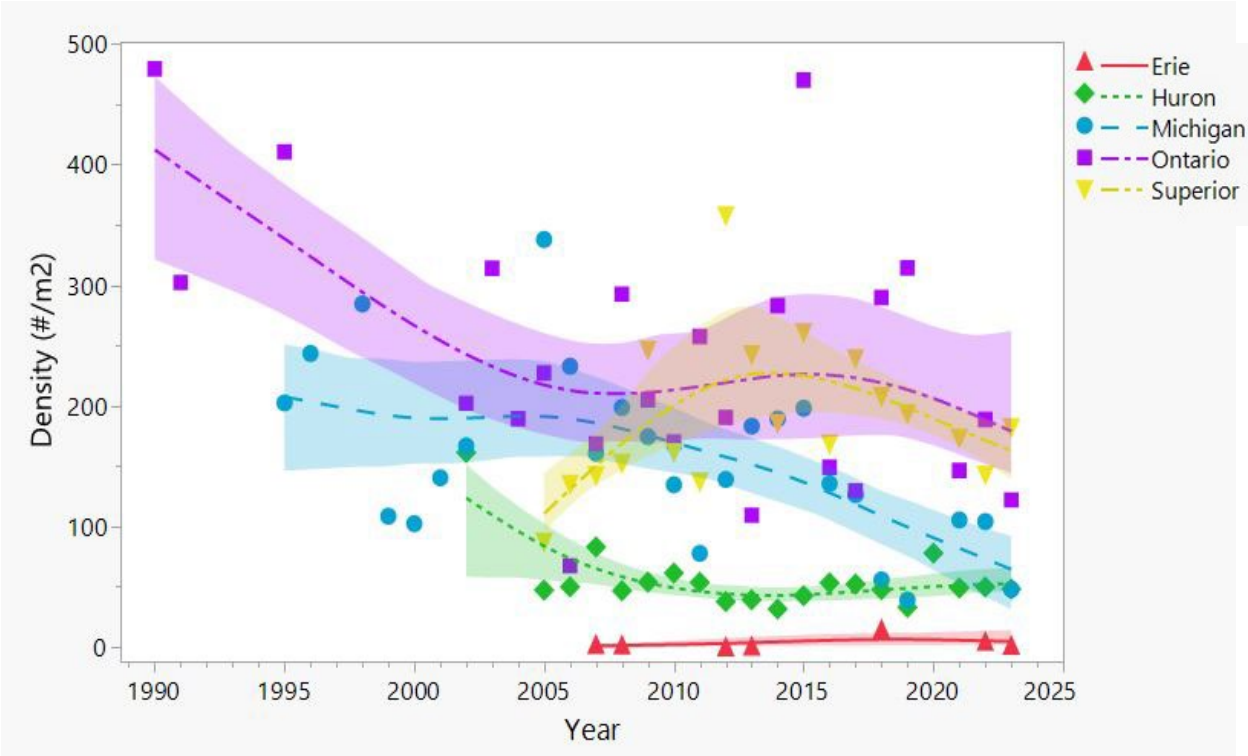
Figure 2. Comparison of average annual mysid densities in the four deeper Great Lakes for the period 2000 to 2015 (baseline) and the current years 2019-2023. Bars indicate 1 SE based on annual averages. Lake Erie is not included. Number of years included in the averages are above the bars. Data sources: Data Sources: U.S. EPA Great Lakes National Program Office, Cornell University.

Last Updated

State of the Great Lakes 2025 Report

Table 1: Significance of time trends in mysid densities in the five Great Lakes. Analyses of the 10-year trends and of trends in the complete available data set are presented. Time period is given as start and end year and in parenthesis the number of years included in the analysis. Statistics include R^2 and P values. Statistically significant trends (p-value <0.05) are in bold font. Data sources are EPA Great Lakes National Program Office (all lakes), EPA Office of Research Development (Superior), USGS-Great Lakes Science Center (all lakes except Erie), NOAA-Great Lakes Environmental Research Laboratory (Michigan), and Fisheries and Oceans Canada (Ontario and Huron). Trends are the slope of the regressions in #/m^2 per year. Significant trends are in bold font.

Lake	Long-term trends			10-year trends		
	Years	Trend	Stats R^2 (P)	Years	Trend	Stats R^2 (P)
Superior	2005-2023 (N=18)	2.3	0.04 (P=0.41)	2013-2023 (N=10)	-6.8	0.39 (P=0.054)
Michigan	**1995-2023 (N=25)**	**-4.8**	**0.31 (P=0.004)**	**2013-2023 (N=10)**	**-13.4**	**0.60 (P=0.008)**
Huron	**2002-2023 (N=20)**	**-2.0**	**0.20 (P=0.049)**	2013-2023 (N=11)	1.5	0.16 (P=0.22)
Erie	2007-2023 (N=7)	0.3	0.11 (P=0.47)	2013-2023 (N=4)	0	0.00 (P=0.99)
Ontario	**1990-2023 (N=24)**	**-5.3**	**0.20 (P=0.029)**	2013-2023 (N=10)	-12.7	0.07 (P=0.46)



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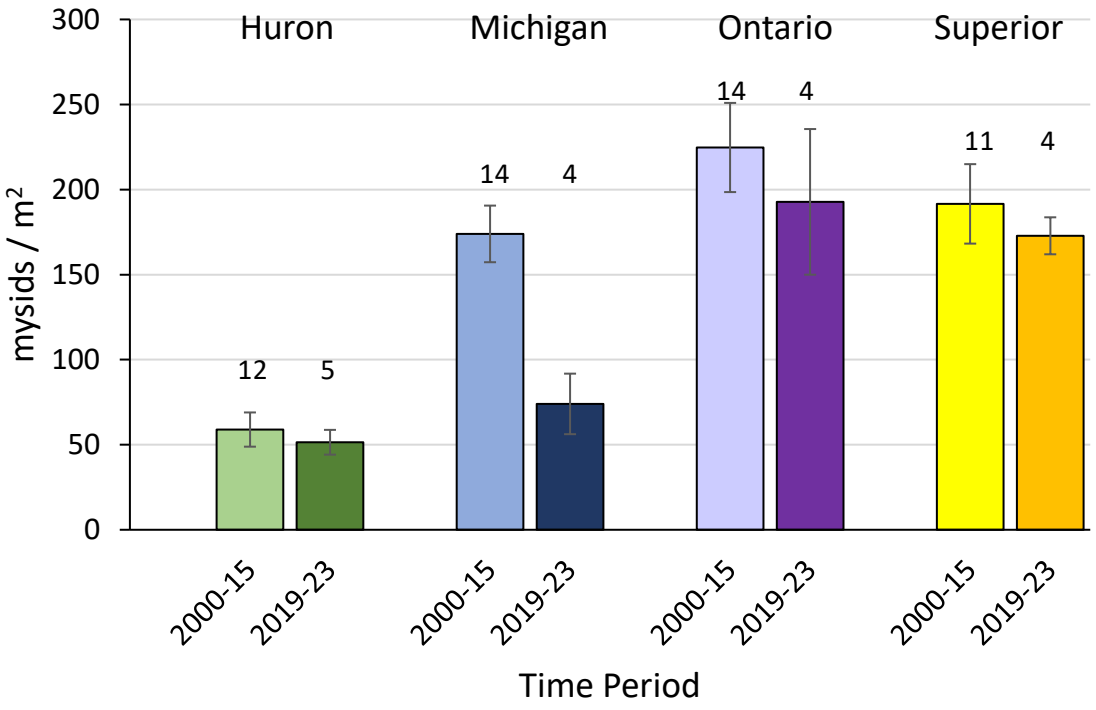

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