Sub-Indicator: Diporeia

Overall Assessment

Status: Poor

Trends:

10-Year Trend: Deteriorating

Long-term Trend (1972-2020): Deteriorating

Rationale: *Diporeia* spp. was once the dominant benthic invertebrate in the Great Lakes, but their populations experienced rapid declines starting in the 1990s. Since then, their declines have continued and densities remain low in Lakes Michigan, Huron, and Ontario. Abundances in Lake Superior are variable over time, with an overall trend of decline in the nearshore, but populations remain at good levels in the offshore and lake-wide. *Diporeia* is currently extremely rare in Lake Erie and is possibly close to extirpation. In all the lakes where *Diporeia* has declined, lower abundances first became apparent a few years after dreissenid mussels became established, though a causal link between *Dreissena* and the declines in *Diporeia* has been difficult to establish. The data presented here are primarily based on lake-wide surveys conducted over time by the US Environmental Protection Agency (EPA) and National Oceanic and Atmospheric Administration (NOAA), and the Canadian Department of Fisheries and Oceans (DFO). Since 2002, lake-wide benthic surveys have been a part of the Cooperative Science and Monitoring Initiative (CSMI), which occurs every 5 years for each lake on a rotating cycle. New to this reporting cycle are data from regional assessments and the Canadian Ontario Ministry of the Environment, Conservation and Parks (MECP) Nearshore Great Lakes Monitoring Network from 1992-2016 (https://data.ontario.ca/dataset/benthic-invertebrate-community-great-lakes-nearshore-areas).

Lake-by-Lake Assessment

Lake Superior

Status: Good

10-Year Trend (2006-2016): Unchanging

Long-term Trend (1973-2016): Unchanging

Rationale: Long-term monitoring and studies of distribution patterns indicate substantial temporal variability, with a trend of decreasing density at some U.S. nearshore stations between 1994-2016 (Figure 1). However, the population is not considered to be "Deteriorating" despite the observed declines because the density of *Diporeia* both nearshore (defined in this case as ≤100 m depth) and offshore remain above the level recommended by the 1978 Great Lakes Water Quality Agreement. Canadian nearshore monitoring in 1992, 1999, 2005, and 2011 measured consistently high *Diporeia* densities (ranging between 950-1885/m^2; MECP), which are comparable to densities shown from 1994-2003 (Figure 1). *Diporeia* are consistently found throughout the lake and remain the dominant benthic organism (Mehler et al. 2018). Further, the observed changes between 2006, 2011, and 2016 may be within the range of natural population variability for *Diporeia*, but more monitoring of the population is needed (Scharold and Corry 2019). The next lake-wide CSMI benthic survey is scheduled for 2021.

Lake Michigan

Status: Poor

10-Year Trend (2005-2015): Deteriorating

Long-term Trend (1981-2020): Deteriorating

Rationale: *Diporeia* abundances continue to decline in Lake Michigan. A lake-wide survey in 2015 indicated that *Diporeia* is still extremely rare at depths <90 m over the entire lake (Figure 2). At depths > 90 m, abundances were 58% lower compared to abundances found in 2005, and similar to 2010 levels (Figure 3). Recent annual surveys (2010-2020) conducted in just the southern region of Lake Michigan reveal *Diporeia* densities to be essentially absent <90 m and low and variable >90 m (Figures 4 and 5; Nalepa et al. 2014, 2020). No *Diporeia* were found in 2019 or 2020 at the one site (depth = 129 m) in southern Lake Michigan where they have been consistently found in the past. The next lake-wide CSMI benthic survey is scheduled for 2021.

Lake Huron (including St. Marys River)

Status: Poor

10-Year Trend (2007-2017): Deteriorating

Long-term Trend (1972-2017): Deteriorating

Rationale: *Diporeia* abundances continue to decline in Lake Huron. The most recent lake-wide survey occurred in 2017, and abundances showed further declines compared to a similar survey in 2012 (Figures 2, 3 and 6). Average density for the main basin in 2017 was 3/m^2 at depths 31-90 m and 161/m^2 at depths >90 m (Karatayev et al. 2020). Canadian nearshore monitoring within the main basin last reported *Diporeia* in 2002 (630/m^2), with no observations since in 2009 or 2015 (MECP). In 2017, the average density of *Diporeia* in the North Channel was 175/m^2, comparable to that observed at >90 m depths in the main basin, but densities at 51-90 m in Georgian Bay (2/m^2) were much lower (Karatayev et al. 2020). Canadian data showed moderate *Diporeia* densities in the nearshore of Georgian Bay (ranging between 158/m^2 in 1996 to 395/m^2 in 2015), declines in the nearshore of North Channel from 2563/m^2 in 1996 to 4/m^2 in 2011, and no *Diporeia* in St. Marys River with the exception of a few specimens collected at one site in 1999 (MECP). The next lake-wide CSMI benthic survey is scheduled for 2022.

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

Status: Poor

10-Year Trend (2009-2019): Unchanging

Long-term Trend (1978-2019): Deteriorating

Rationale: Because of shallow, warm waters, *Diporeia* are naturally not present in the western basin and most of the central basin. *Diporeia* declined in the eastern basin beginning in the early 1990s (Dermott and Kerec 1997) and have not been found in that basin since 1998 according to one study (Barbiero et al. 2011). Canadian nearshore monitoring found a single specimen in 2010 in north central Lake Erie, but none before or since that time and no *Diporeia* have been found in the St. Clair River, Lake St. Clair, or the Detroit River (MECP). This trend is confirmed by no *Diporeia* found in the 2014 (Burlakova et al., 2017; Schloesser et al., 2017) or 2019 (Burlakova unpub. data) lake-wide surveys. The next lake-wide CSMI benthic survey is scheduled for 2024.

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

Status: Poor

10-Year Trend (2008-2018): Unchanging

Long-term Trend (1994-2018): Deteriorating

Rationale: *Diporeia* abundances remain at low densities in Lake Ontario (Figures 2 and 3). The 2013 and 2018 lake-wide surveys in Lake Ontario produced only a single individual in each year (found at site depths >150 m) out of the 45-55 sites sampled (Nalepa and Baldridge 2016, Karatayev et al. 2021). Canadian nearshore surveys reported low densities of *Diporeia* (<30/m^2) at four sites across Lake Ontario in 1994, a few individuals at one site in 1997, and no *Diporeia* since then (MECP). Further, no *Diporeia* have been found in nearshore surveys of Hamilton Harbour, Bay of Quinte, or the St. Lawrence River (MECP). Additional benthic monitoring by USGS has identified a deep site (95 m) in western Lake Ontario with low but persistent numbers of *Diporeia* (B. Weidel, pers. comm.) Also, low numbers of *Diporeia* were found during EPA Long-term Monitoring surveys in 2018 (one individual at one station >90 m) and 2019 (31 total at two stations >90 m; GLNPO). The next lake-wide CSMI benthic survey is scheduled for 2023.

Status Assessment Definitions

Good: The following recommendation applies to Lake Superior only. Densities of *Diporeia* remain above 220-320/m^2 in nearshore waters (<100 m) and 30-160/m^2 in offshore waters (>100 m; 1978 GLWQA recommendations for Lake Superior; The Government of Canada and the Government of the United States of America 1978) and are found at sites well-distributed throughout the lake. For the other Great Lakes, the criteria are for *Diporeia* to be at moderate to high densities and also be the dominant non-dreissenid benthic organism.

Fair: Lake Superior: Densities of *Diporeia* remain above the GLWQA recommendations, but are only found at a few locations. Other Lakes: *Diporeia* are found in moderate to low densities.

Poor: Lake Superior: Densities of *Diporeia* are below the GLWQA recommendations. Other Lakes: *Diporeia* are found in low densities or are absent.

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

Trend Assessment Definitions

Target values are provided to evaluate abundances on a historic basis. Trends over time provide a means to assess indicator direction. On a more direct basis, if target values are met, the system can be assumed to be healthy; if the values are not met there is health impairment. Causative agents of impairment are not addressed by the sub-indicator.

Improving: Increase in *Diporeia* densities and/or the number of stations with *Diporeia*.

Unchanging: Minor changes in *Diporeia* densities and the number of stations that have *Diporeia*.

Deteriorating: Decrease in *Diporeia* densities and/or the number of stations with *Diporeia*.

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

Endpoints and/or Targets

In Lake Superior, *Diporeia* should be maintained throughout the lake at abundances of >220-320/m^2 at depths <100 m and >30-160/m^2 at depths >100 m as per the 1978 GLWQA. In the other Great Lakes, for *Diporeia* to be the dominant non-dreissenid benthic organism and to be found at a majority of offshore locations.

Sub-Indicator Purpose

The purpose of this sub-indicator is to show the status and trends in *Diporeia* populations, and to infer the basic structure of cold-water benthic communities and the general health of the Great Lakes ecosystem.

Ecosystem Objective

The cold, deep-water regions of the Great Lakes should be maintained as a balanced, stable, and productive oligotrophic ecosystem with *Diporeia* as one of the key organisms in the food chain.

This sub-indicator best supports work towards General Objective #5 of the 2012 Great Lakes Water Quality Agreement (GLWQA) which 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

This sub-indicator will measure the density (number/m^2) of *Diporeia* in the Great Lakes. The recent lake-wide trends presented here are based on extensive, lake-wide surveys (nearshore and offshore) that are conducted in each of the lakes every 5 years as a part of the CSMI cycle. Additional lake-wide surveys conducted by EPA, NOAA, and DFO provide longer frames of reference for *Diporeia* population dynamics. Also presented are data collected during the annual NOAA Great Lakes Environmental Research Laboratory benthic survey of the southern basin of Lake Michigan. New to this round is the inclusion of data from the MECP Nearshore Great Lakes Monitoring Network, which includes benthic data collected from the 1990s – 2016 in nearshore regions and connecting waterways in Canadian waters across the Great Lakes basin.

The U.S. EPA Great Lakes National Program Office (GLNPO) long-term monitoring program assesses abundances of *Diporeia* (and other benthos) in offshore regions of each of the lakes on an annual basis. In CSMI years, data from some of the GLNPO stations are included in with the lake-wide survey results. Otherwise, some GLNPO data are included anecdotally here (e.g., the few *Diporeia* observations in Lake Ontario), but are not included in the figures. GLNPO data generally follows similar trends within each lake and are accessible by request from the GLNPO data portal GLENDA.

Ecological Condition

This glacial-marine relic was once the most abundant benthic organism in cold waters greater than 30 m deep in each of the lakes. It was present, although less abundant in nearshore regions of the open lake basins, but it was naturally absent from shallow, warm bays, basins, and river mouths. *Diporeia* occurs in the upper few centimetres of bottom sediment and feed on algal material that freshly settles to the bottom from the water column (i.e., mostly diatoms). In turn, it is fed upon by most species of Great Lakes fish; including many forage fish species that themselves serve as prey for the larger piscivores such as trout and salmon. For example, sculpin feed almost exclusively upon *Diporeia*, and sculpin are eaten by lake trout. Also, lake whitefish, an important commercial species, feeds heavily on *Diporeia*. Thus, *Diporeia* was an important pathway by which energy was cycled through the ecosystem, and a key component in the food web of offshore regions.

To some degree, *Diporeia* abundances are affected by the amount of phytoplankton food settling to the bottom, and population trends may reflect the food conditions (Dermott 2001). Abundances can also vary somewhat relative to shifts in predation pressure from changing fish populations (Dermott 2001). In nearshore regions, this species is sensitive to local sources of pollution (Gossiaux et al. 1993; Maity et al. 2013), but because of varying conditions such as temperature fluctuations, substrate heterogeneity, and wave-induced turbulence, it can be difficult to assess population trends in this region.

Nearshore/offshore comparisons reveal that MECP nearshore data trends tend to match the offshore trends reported by the CSMI lake-wide surveys for most waterbodies (e.g., Lake Erie, Lake Huron main basin, Lake Ontario, and Lake Superior); however, the patterns observed in the two datasets diverge in North Channel and Georgian Bay. This could be due to the *Diporeia* populations in these regions exhibiting high levels of spatial and temporal variation. Also, the two surveys are often not conducted in the same years and have different sampling locations and numbers of stations. Lake Superior is the only lake to exhibit consistently higher *Diporeia* densities in the nearshore (here, Canadian and U.S. waters <100 m deep) than in the offshore (waters >100 m deep) (MECP; Mehler et al. 2018).

Diporeia populations have undergone dramatic declines with no signs of recovery in all the lakes except Lake Superior (Figures 1, 2 and 3). Based on the most recent surveys, *Diporeia* is present but continues to decline in Lakes Michigan and Huron, while it is nearing extirpation in Lake Erie and possibly Lake Ontario as well. The population in Lake Superior is highly variable and had exhibited declines in the nearshore zone since 1994 and 2003 (Figure 1). However, *Diporeia* is still found distributed throughout the lake, and densities remain relatively high. Declines in *Diporeia* within all lower Great Lakes were observed after zebra mussels (*Dreissena polymorpha*) or quagga mussel (*Dreissena rostriformis bugensis*) first became established (Dermott et al. 2005). It is worth noting that in some regions of Lake Ontario, *Diporeia* exhibited high population variability in the 1980s prior to the introduction of dreissenid mussels, as attributed to fish predation and/or reductions in productivity (Dermott 2001). Reasons for the negative response of *Diporeia* to these mussel species are not entirely clear and several hypotheses have been proposed (Watkins et al. 2007). One hypothesis is that dreissenid mussels are out-competing *Diporeia* for available food. That is, large mussel populations filter food material before it reaches the bottom, thereby decreasing amounts available to *Diporeia*. *Diporeia* declines in the early 1990s in nearshore Lake Ontario appear to correspond with grazing effects from mussels, but later declines in the offshore do not (Watkins et al. 2013). Edlund et al. (2021) suggested that reductions in preferred, more nutritious diatom prey in Lake Michigan exacerbated *Diporeia* declines. However, the reason for widespread reductions in *Diporeia* populations is more complex than a simple decline in food because *Diporeia* have completely disappeared from areas where food is still settling to the bottom and where there are no local populations of mussels. Also, individual *Diporeia* show no signs of starvation before or during population declines. Further, *Diporeia* and *Dreissena* coexist in some lakes outside of the Great Lakes (i.e., Finger Lakes in New York). Some empirical (Cave and Strychar 2015) and modeling (McKenna et al. 2017) studies suggest that the decline in *Diporeia* could be related to disease/parasites, but further work is needed in this area.

Linkages

Linkages of this sub-indicator to other sub-indicators include:

- Benthos (open water) – *Diporeia* is the dominant benthic species in Lake Superior deep-water habitats, where dreissenid mussels are absent. In the other Great Lakes, oligochaetes are now the most abundant non-dreissenid taxa.
- Prey fish – *Diporeia* is an important food source for several prey species. When abundant, *Diporeia* served as an important pathway to transfer energy from primary producers to higher trophic levels.
- Phytoplankton - The primary food source for *Diporeia* is phytoplankton that settles to the bottom of the lake.
- Impacts of Aquatic Invasive Species and Dreissenid Mussels – The rapid decline of *Diporeia* has coincided with the proliferation of invasive dreissenid mussels in multiple lakes (see Ecological Condition section above for more details).
- Toxic Chemicals in Sediment – *Diporeia* are a pollution-sensitive species and are absent or occur in low numbers in areas with elevated levels of contaminants (Nalepa and Thomas 1976).

This sub-indicator also links directly to the other sub-indicators in the Habitat and Species indicator, particularly lake trout, as lake trout are among the fish species that are energetically linked to *Diporeia*. Young lake trout feed on *Diporeia* directly, while adult lake trout feed on sculpin, and sculpin feed heavily on *Diporeia* (Hudson et al. 1995). Lake trout are a top predator in the deep-water habitat, and therefore assessments of both *Diporeia* and lake trout provide an evaluation of lower and upper trophic levels in the cold, deep-water habitat.

Diporeia may face mild to moderate impacts of changing climate trends. Being a cold-water stenotherm, *Diporeia* could potentially decline in the nearshore zones of Lake Superior as water temperatures increase, but a substantial cold-water refuge will remain in deeper waters. Climate-induced disruptions to preferred diatom food sources is another potential way in which *Diporeia* could be negatively affected.

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: **Lake Michigan Data**: NOAA GLERL Technical Memo 164 (1994-2010) and NOAA GLERL Technical Memo 175 (2015). **Lake Huron Data:** NOAA GLERL Technical Memo 140 (1972, 2000-2003); NOAA GLERL Technical Memo 172 (2006-2012), **Lake Ontario Data:** Burlakova et al. Accepted 2021. *Ecology* Data Paper (1964-2018). Compilation of Canadian and U.S. data. https://esajournals.onlinelibrary.wiley.com/doi/10.1002/ecy.3528 **MECP Canadian Nearshore Data:** https://data.ontario.ca/dataset/benthic-invertebrate-community-great-lakes-nearshore-areas		

Data Limitations

This sub-indicator is of greatest value in assessing ecosystem health in the cold, open-water portions of the Great Lakes. It may also be useful when assessing long term trends within a specific lake region in the nearshore (< 30 m), but its value is questionable if widely applied to nearshore areas over all the lakes. Because this sub-indicator consists of only one taxon, it may not reliably diagnose causes of degraded ecosystem health. A number of lake-wide surveys and assessments of benthic invertebrate communities have been made over the past several decades in the Great Lakes and the current status of *Diporeia* populations is generally known, and an understanding of the changes related to the dreissenid mussel invasion is emerging. The available U.S. and Canadian data sources are comparable over time because both countries have performed whole-lake benthic surveys. In more recent years, the data sources are more complementary than comparable because they cover different depth zones and sampling locations. The benthic monitoring program conducted by MECP primarily covers nearshore areas (typically <3 km from shore) and DFO no longer conducts long-term offshore monitoring. However, the CSMI lake-wide benthic surveys include data from both U.S. and Canadian waters, with site depths ranging from ~10 m to >200 m, depending on the lake.

Additional Information

The historical dominance of *Diporeia* in cold, deep-water habitats in all of the Great Lakes provides a good basis for a basin-wide evaluation of ecosystem health.

The continuing decline of *Diporeia* has strong implications to the Great Lakes food web. As noted, many fish species rely on *Diporeia* as a major prey item, and the loss of *Diporeia* has impacted many of these species. Fish responses include changes in diet, movement to areas with more food, or a reduction in weight or energy content. Implications to fish populations include changes in distribution, abundance, growth, recruitment, and condition. Recent evidence suggests that fish are already being affected. Studies have shown that populations of lake whitefish, an important commercial species, have been affected, as well as fish species that serve as prey for salmon and lake trout such as alewife, sculpin, and bloater (Owens and Dittman 2003).

Because of the rapid rate at which *Diporeia* has declined in many areas, and its significance to the food web, documenting trends and reporting data needs to be completed in a timely manner. The population decline has a defined natural pattern, and studies of food web impacts should be spatially well coordinated. Also, studies to define the cause of the negative response of *Diporeia* to *Dreissena* should continue and build upon existing information. Potential areas of study are physiological and biochemical responses of *Diporeia* to *Dreissena*, and influence of potential pathogens, including bacteria and viruses. With a better understanding of why *Diporeia* populations have declined, one can better assess the potential for population recovery if dreissenid populations significantly decline.

Methods for estimating abundances of *Diporeia* are generally similar across the Great Lakes. Samples of bottom substrates are collected with a Ponar grab and contents are washed through a screen (or net mesh) of 0.5-mm openings (0.6-mm for the MECP Nearshore surveys). All *Diporeia* retained on the screen are immediately preserved, and later counted and identified. Densities are reported as numbers per square metre. Nalepa et al. (2009) provides additional details on sampling methods and laboratory analysis, which are largely consistent with the US EPA Standard Operating Procedure for Benthic Invertebrate Field Sampling Procedure

(SOP LG406, Revision 12, March 2018), and the US EPA Standard Operating Procedure for Benthic Invertebrate Laboratory Analysis (SOP LG407, Revision 09, April 2015). Given the decline and disappearance of *Diporeia* in nearshore regions, and very low abundances of *Diporeia* in offshore regions in each of the lakes except Lake Superior, the present monitoring programs are adequate to detect population changes.

Acknowledgments

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State of the Great Lakes 2022 Report

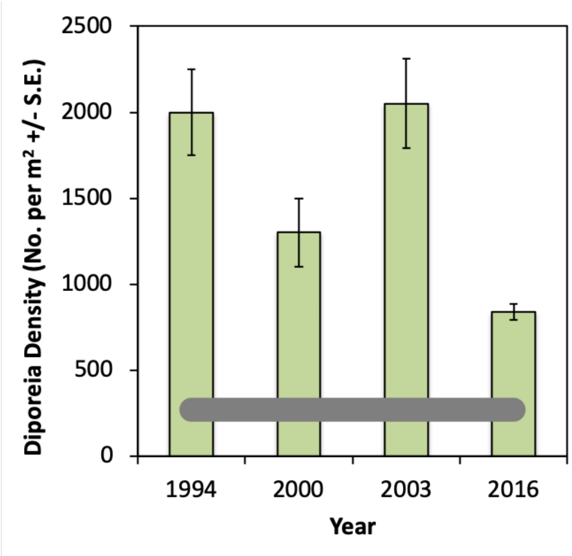

Figure 1. Mean density (number per square metre ± S.E.) of the amphipod *Diporeia* spp. from 25 stations in the U.S. nearshore waters (defined here as ≤100 m depth) of southern Lake Superior that were sampled in 1994, 2000, 2003, and 2016. The horizontal grey line indicates the GLWQA recommendation threshold of 220-320/m² in nearshore waters. Data Sources: Great Lakes Center, SUNY Buffalo; Mehler et al. 2018; Scharold et al. 2009.

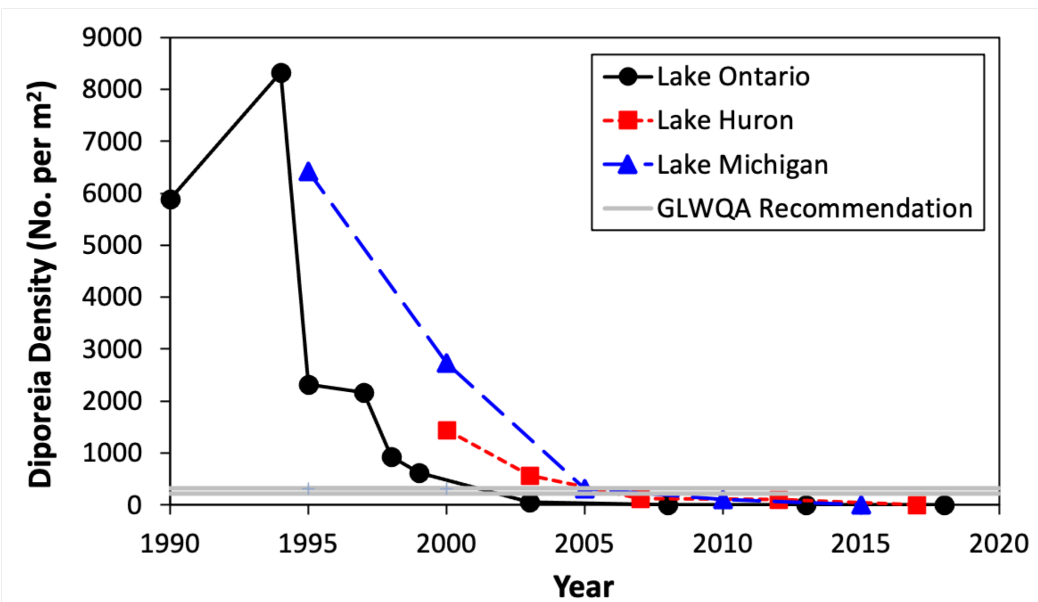

Figure 2. Mean densities (number per square metre) of the amphipod *Diporeia* spp. from sites at 31-90 m in lakes Michigan, Huron, and Ontario, 1995 – 2018. Data are from lake-wide surveys conducted mostly at 5-year intervals. Lake Michigan = triangles, long-dashed line (blue); Lake Huron = squares, short-dashed line (red); Lake Ontario = circles, solid line (black). The horizontal grey lines indicate the GLWQA recommendation threshold of 220-320/m² in nearshore waters, for comparison. Data Sources: Great Lakes Environmental Research Lab, NOAA; Great Lakes Center, SUNY Buffalo; Dermott and Geminiuc 2003; Lozano et al. 2001; Watkins et al. 2007; Birkett et al. 2015; Nalepa et al. 2014, 2018, 2020; Karatayev et al. 2020 and 2021; Burlakova et al. 2021.

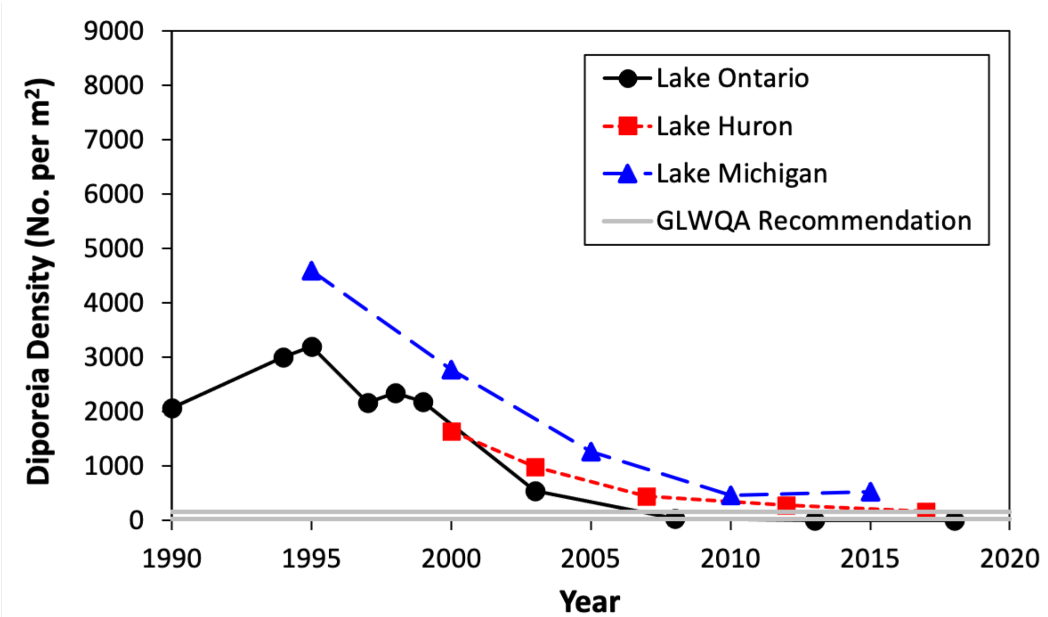

Figure 3. Mean densities (number per square metre) of the amphipod *Diporeia* spp. from sites at > 90 m in lakes Michigan, Huron, and Ontario, 1995 - 2018. Data are from lake-wide surveys conducted mostly at 5-year intervals. Lake Michigan = triangles, long-dashed line (blue); Lake Huron = squares, short-dashed line (red); Lake Ontario = circles, solid line (black). The horizontal grey lines indicate the GLWQA recommendation threshold of 30-160/m^2 in offshore waters, for comparison. Data Sources: Great Lakes Environmental Research Lab, NOAA; Great Lakes Center, SUNY Buffalo; Dermott and Geminiuc 2003; Lozano et al. 2001; Watkins et al. 2007; Birkett et al. 2015; Nalepa et al. 2014, 2018, 2020; Karatayev et al. 2020 and 2021; Burlakova et al. 2021.

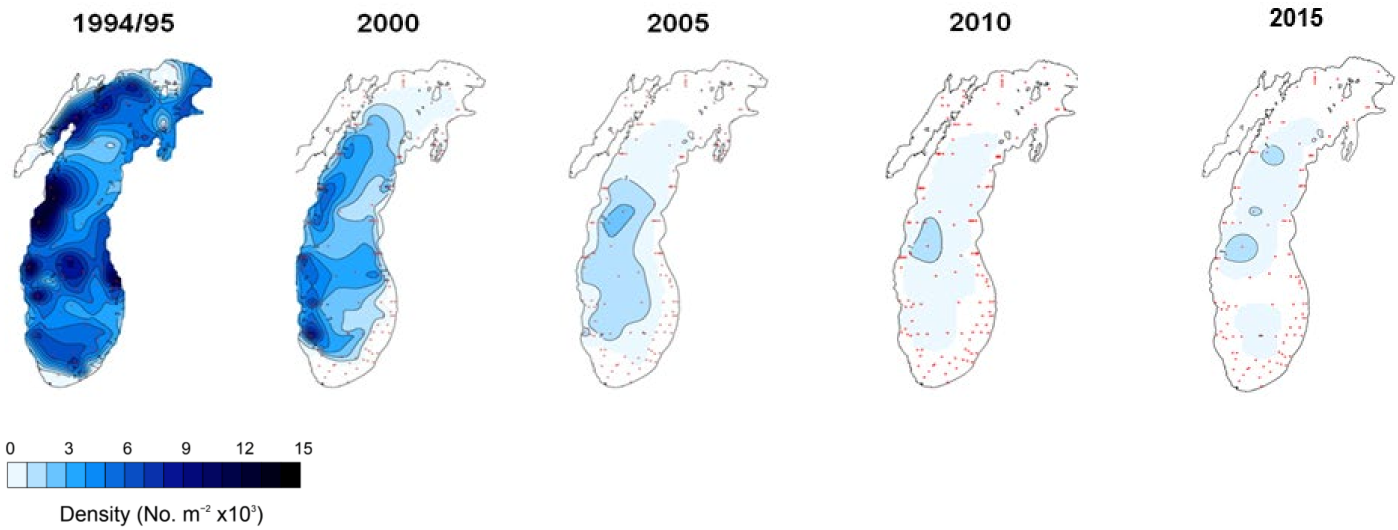

Figure 4. *Diporeia* population density (number x 10^3 per square metre) declines in Lake Michigan, 1994/5– 2015. Small red dots indicate location of sampling sites. Data Source: Great Lakes Environmental Research Lab, NOAA; Nalepa et al. 2014, 2020.

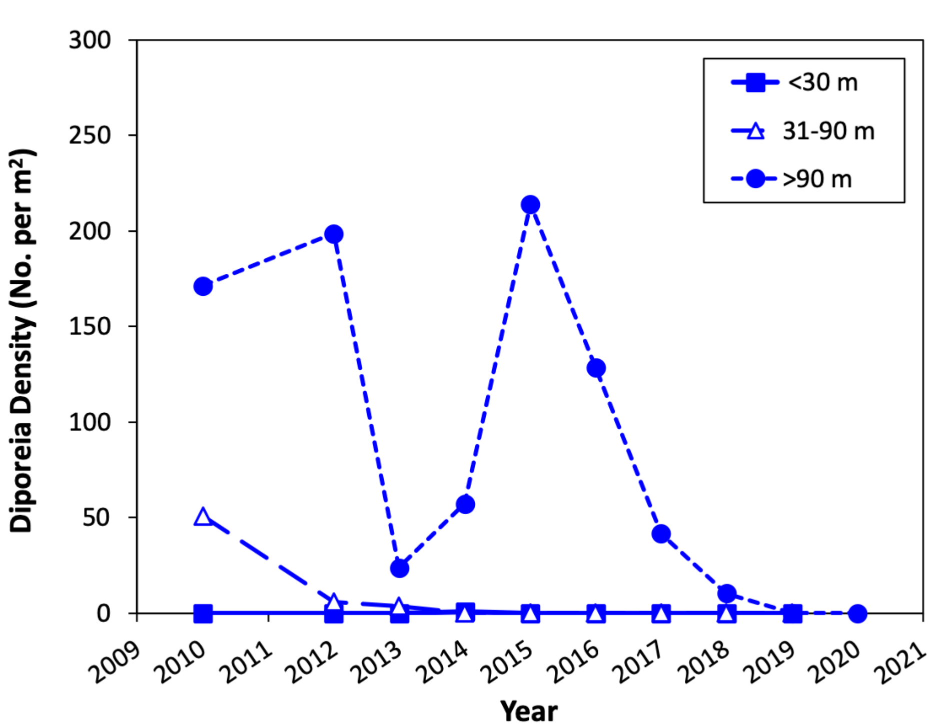

Figure 5. Mean densities (number per square metre) of the amphipod *Diporeia* spp. in southern Lake Michigan, reported by depth: < 30 m (squares, solid line); 31-90 m (triangles, long-dashed line); and > 90 m (circles, short-dashed line), 2010-2020. In 2020, only one station (the one southern site to consistently have *Diporeia* in previous years) was sampled due to survey limitations. Note that the axis scale is greatly reduced compared to Figures 2 and 3. Data Source: Great Lakes Environmental Research Lab, NOAA.

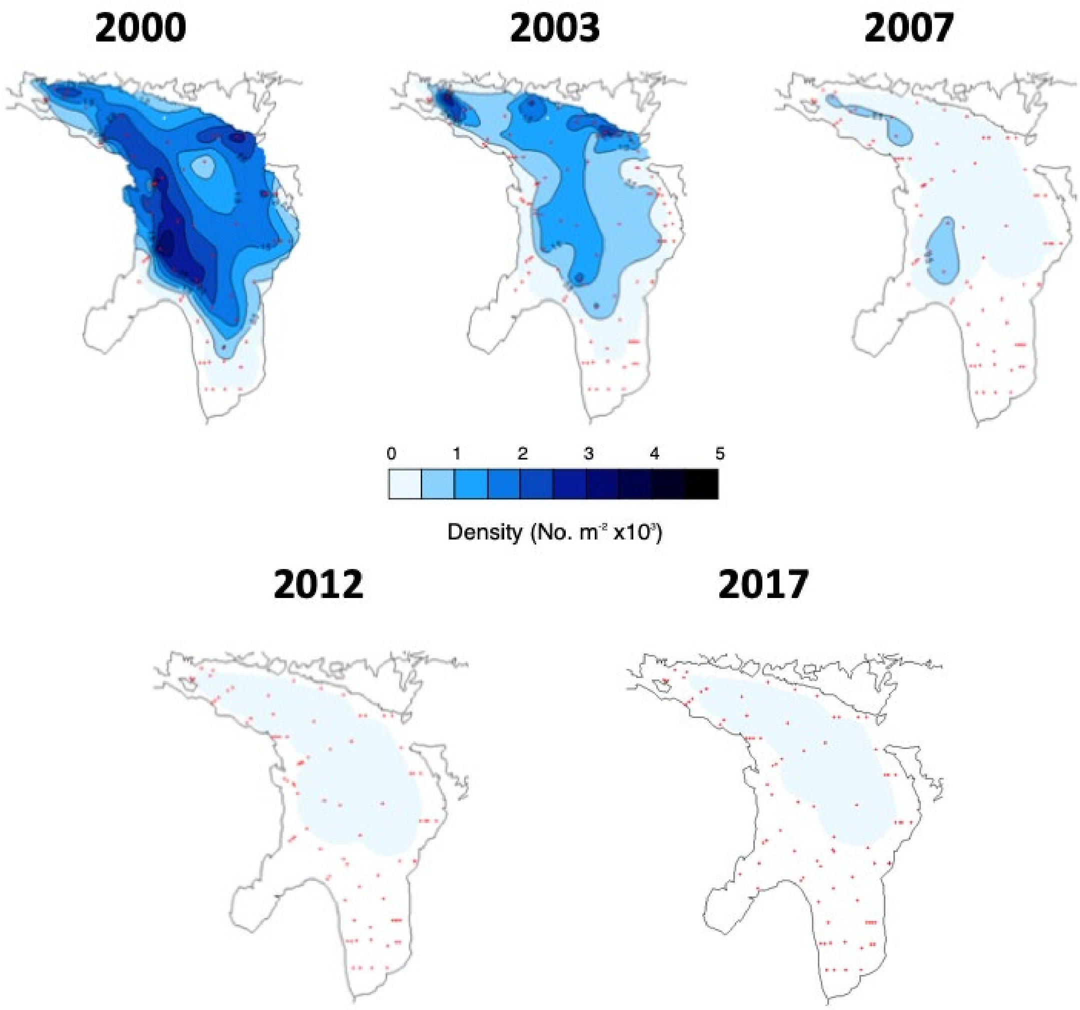

Figure 6. *Diporeia* population density (number x 10^3 per square metre) declines in Lake Huron, 2000 – 2017. Small red dots indicate location of sampling sites. Data Source: Great Lakes Environmental Research Lab, NOAA; Nalepa et al. 2018, Karatayev et al. 2020.