# Sub-Indicator: *Cladophora*

## Executive Summary

The Overall and Lake-by-Lake assessment sections at the top of this report provide a high-level Executive Summary of the status and trend of *Cladophora* in the Great Lakes. The definitions and date ranges for status and trend assessments are described immediately below this assessment section as are the endpoints from which these definitions are derived. Additional detail about the methods used to evaluate data are provided in the Methods section, and the Discussion section provides more detail on the status and trend assessments including references to the figures and data as well as important context for these conclusions.

## Overall Assessment

**Status:** Poor

**Trends:**

**10-Year Trend (2014-2023):** Undetermined

**Long-term Trend (1995-2023):** Undetermined

**Rationale:** *Cladophora* is distributed across broad regions of the littoral (nearshore) zones of Lakes Ontario and Michigan and the eastern basin of Lake Erie. Nuisance conditions in Lake Huron are limited to isolated locations. There is no evidence of nuisance algal fouling by *Cladophora* in Lake Superior. Temporal trends for all lakes are difficult to determine because of natural variability and a lack of consistent long-term data across the lakes, resulting in an Undetermined long-term trend.

## Lake-by-Lake Assessment

### Lake Superior

**Status:** Good

**10-Year Trend:** Unchanging

**Long-term Trend (based on anecdotal information):** Unchanging

**Rationale:** Recent systematic data are not available for Lake Superior, however, fouling of shorelines by *Cladophora* has not historically been an issue in Lake Superior, nor have nuisance levels of *Cladophora* been observed growing in the nearshore, potentially due to lower phosphorus loading and re-suspension, lower water temperatures relative to the other Great Lakes, and a lack of invasive dreissenid mussels in Lake Superior.

### Lake Michigan

**Status:** Poor

**10-Year Trend (2014-2023):** No Trend

**Long-term Trend (2004-2023):** No Trend

**Rationale:** *Cladophora* grows at nuisance levels (tentatively defined as > 50 g dry weight (DW) per square meter ($DW/m^2$)) over large areas of the Lake Michigan nearshore zone. Long-term *Cladophora* monitoring has been conducted at two primary sites: offshore of Atwater Beach (north of Milwaukee, Wisconsin (WI)) and Good Harbor Bay (in the Sleeping Bear Dunes National Lakeshore region of northwest Lower Michigan (MI)). Maximum recorded *Cladophora* biomass at both sites is variable from year-to-year, ranging from < 50 g $DW/m^2$ at the Atwater site in 2010 to > 250 g $DW/m^2$ at the same site in 2011 and 2016 (Depew et al., 2022). Peak biomass in Good Harbor Bay was variable but frequently above 100 g $DW/m^2$ from 2010-2023. Since 2019, an additional site has been sampled south of Waukegan, Illinois (IL) and maximum standing crop in-lake biomass > 50 g $DW/m^2$ has been observed at this site in three of five observation years. Prior to 2004 there was no formal *Cladophora* monitoring program in Lake Michigan. However, earlier qualitative reports (Herbst 1969) indicate *Cladophora* nuisance conditions occurred in the Milwaukee region from the late 1950s to the 1970s. Satellite imagery time series indicates areal coverage of submerged vegetation was relatively low from 1974 to 1990 and resurged in the 1990s (Brooks et al. 2015), coincident with the establishment of invasive dreissenid mussels.

## Lake Huron

**Status:** Fair

**10-Year Trend (2014-2023):** Undetermined

**Long-term Trend (2006-2023):** Undetermined

**Rationale:** *Cladophora* biomass approaches nuisance levels in localized areas that coincide with points of nutrient input on the Canadian shores of the main Lake Huron basin. Field-based monitoring has been limited but indicates that *Cladophora* biomass is generally low and below nuisance levels. Nonetheless, there is periodic fouling of shorelines by mixtures of algae comprised of macroalgae (charophytes and *Cladophora*) and diatom periphyton. Similarly, *Cladophora* is part of a cosmopolitan assemblage of benthic macroalgae linked to episodic fouling of beaches in Saginaw Bay on the United States (U.S.) side of Lake Huron. At U.S. sampling sites outside of Saginaw Bay, nuisance levels of growth have been observed outside the mouth of Thunder Bay but not within Thunder Bay or Hammond Bay. *Cladophora* is not found at macroscopically visible levels in the nearshore of eastern Georgian Bay nor has it been reported to foul shorelines in Georgian Bay, except in enclosed harbors. Temporal trends are difficult to determine because of high natural variability and a lack of consistent long-term data, resulting in an Undetermined 10-year and long-term trend.

## Lake Erie

**Status:** Poor

**10-Year Trend (2014-2023):** No Trend

**Long-term Trend (1995-2023):** Undetermined

**Rationale:** *Cladophora* remains broadly distributed along much of the north shore of the eastern basin of Lake Erie, as well as along offshore shoals with sufficient hard substrate for *Cladophora* attachment. Monitoring of three to five transects between Port Dover, Ontario (ON) and Port Colborne, ON since 2012 has shown high variability in biomass from year-to-year, although peak biomass is often at, or above, nuisance conditions at most sampling locations. Both offshore and local phosphorus supplies are implicated in this high growth. There is no indication of trends improving or worsening from 2007-2023 in Lake Erie as interannual variation is large. Prior to the initiation of monitoring in 2012, assessment of *Cladophora* in eastern Lake Erie was done on an ad-hoc basis from 1995 to

2010 as exploratory monitoring and research and in response to regional concerns. Surveys conducted in 1995 and 2002 on the north shore of the lake found *Cladophora* abundant and widely distributed over hard substrate in shallow water. Nuisance levels of biomass were measured near the mouth of the Grand River in 2010. On the U.S. side of Lake Erie, sampling sites established since 2018 have recorded nuisance levels of growth at sites east of Erie, Pennsylvania (PA) and Dunkirk, New York (NY). Temporal trends are difficult to determine because of high natural variability and a lack of consistent long-term data, resulting in an Undetermined long-term trend.

### Lake Ontario

**Status:** Poor

**10-Year Trend (2014-2023):** No Trend

**Long-term Trend (1998-2023):** Undetermined

**Rationale:** *Cladophora* is widely distributed in Lake Ontario. Monitoring surveys and research studies dating back to 2005 indicate peak biomass often exceeds 75 g DW/$m^2$ where hard substrate dominates, both in the vicinity of point source inputs and in regions remote from any direct sources. Monitoring of the Canadian shoreline since 2018 shows that biomass > 50 g DW/$m^2$ occurs consistently at Scarborough, though more sporadically at other locations (Oakville, Cobourg). High variability and a limited time horizon make a trend difficult to discern. Previous studies of *Cladophora* on the Canadian shoreline near Welland Canal and along the north shore also point to biomass of > 50 g DW/$m^2$ being reached on a consistent basis. In U.S. nearshore areas, sites in the western portion of the lake have maximum standing crop in-lake biomass > 50 g DW/$m^2$ in both ad-hoc surveys and at a station near Olcott, NY that has been assessed since 2018 but not at sites further to the east. Inter-annual variability is comparable to that observed in Lakes Erie and Michigan and the lack of a long-term monitoring record hinders assessment of trends. Temporal trends are difficult to determine because of high natural variability and a lack of consistent long-term data, resulting in an Undetermined long-term trend.

## Status Assessment Definitions

**Good:** maximum observed standing crop in-lake biomass < 50g DW/$m^2$

**Fair:** maximum observed standing crop in-lake biomass > 50g and < 75g DW/$m^2$

**Poor:** maximum observed standing crop in-lake biomass > 75g DW/$m^2$

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

Note: Refer to “Endpoints and Targets” section below for qualification of the above thresholds.

## Trend Assessment Definitions

**Improving:** In-lake *Cladophora* biomass shows a statistically significant change toward more acceptable conditions.

**Unchanging:** In-lake *Cladophora* biomass shows no statistically significant change with low interannual variability.

**No Trend:** The trend is not statistically Improving or Deteriorating due to high variability in the data. No Trend is

different from Unchanging (which would be used when the trend is not statistically significant and has low variability (*i.e.*, stable)).

**Deteriorating:** In-lake *Cladophora* biomass shows a statistically significant change away from acceptable conditions.

**Undetermined:** Sufficient data are not available to report on a trend.

Note: Long-term, greater than 10-year, trend date ranges are determined based on the dates of available data.

## Endpoints and/or Targets

Previous observational and modeling studies in Lake Huron noted substantial reductions in quantity of sloughed biomass and shore fouling by *Cladophora* when the standing crop was reduced to ~ 50 g DW/$m^2$ after improvements to local phosphorus loads (Canale and Auer 1982). While a definitive threshold for "nuisance" conditions does not yet exist, the 50 g DW/$m^2$ has often been used in this context. However, there may be a need to revisit this target because *Cladophora* now extends to greater depths and is not confined to locations near point sources, as it was when Canale and Auer conducted their studies on Lake Huron. Lower biomass spread over larger areas of the lakebed may still result in beach fouling, intake clogging, and other negative impacts. Alternatively, in areas with sparse rocky substrate, a standing crop of more than 50 g DW/$m^2$ on individual rocks may result in minimal impacts. Studies documenting shoreline accumulations and linking in-lake biomass and transport with this washup would be informative to determine whether targets linking in-lake growth could be established. Additional work is required to determine if this target needs to be revised, and if different targets may be appropriate for different regions. In setting these targets, several points should be considered: 1) Ideally, targets would be set at a level below which the negative impacts of nuisance benthic algae are minimal. This is the criterion for the putative 50 g DW/$m^2$ target. 2) While eliminating the negative effects of excessive benthic algae is an optimal goal, the reality is that nutrient cycling in all the lakes except Superior have been dramatically altered by dreissenid mussels (Li et al., 2021; Ozersky et al., 2009; Ozersky and Barton, 2013), indicating potential for benthic algae to grow to nuisance levels despite total phosphorus concentrations in most of the lakes below target levels specified in the Great Lakes Water Quality Agreement. (GLWQA). In areas with high water clarity and dreissenid densities, it may be that maintaining benthic algal biomass at levels below 50 g DW/$m^2$ is unobtainable through management of external nutrient loads. 3) At shallow depths (Katona et al. 2023) or when biomass is high (Higgins et al. 2008b), algal sloughing may be substantial, so that biomass is not correlated to production at a given location. Because negative impacts such as beach fouling are likely related to algal production, it is important to have a better understanding of the relationship between biomass and production if biomass is to be used as the management target.

## Sub-Indicator Purpose

The purpose of this sub-indicator is to evaluate biomass of *Cladophora* in the Great Lakes. Data can be used to infer the amount of *Cladophora* to be transported to the lake shore by currents, wind and waves where it may foul beaches and clog water intakes, as well as potentially contribute to other negative impacts on ecosystem integrity such as avian botulism, habitat loss, and food web disruption.

## Ecosystem Objective

*This text includes reference to the applicable General Objective(s) from pages 7-8 of the Great Lakes Water Quality Agreement and any other objectives as appropriate.*

This sub-indicator best supports work towards General Objective #6 of the 2012 GLWQA (Great Lakes Water Quality Protocol, 2012), which states that the waters of the Great Lakes should "be free from nutrients that directly or indirectly enter the water as a result of human activity, in amounts that promote growth of algae and cyanobacteria that interfere with aquatic ecosystem health or human use of the ecosystem." This sub-indicator also supports General Objective #2 of the 2012 GLWQA which states that the waters of the Great Lakes should "allow for swimming and other recreational use, unrestricted by environmental quality concerns." In other words, waters and beaches should be safe for recreational use and be free from nuisance algae which may negatively impact drinking water infrastructure and beach use, pose a threat to human health by harboring pathogens, and contribute to negative impacts on ecosystem health, such as avian botulism and hypoxia.

## Methods

The biomass of the sub-indicator *Cladophora* is reported as standing crop in g DW/$m^2$. Peak biomass is typically achieved in mid-summer, although the exact timing varies between years, lakes, and locations. Quantitative sampling of *Cladophora,* typically by divers, is logistically challenging, method-sensitive, and time consuming but is considered the best approach (Auer et al., 2010). Biomass is typically determined by harvesting of all algal filaments from a defined area of lakebed (often in triplicate), followed by removal of non-target organisms (benthic invertebrates) and debris. The cleaned sample is dried to a constant weight followed by gravimetric determination of dry mass. Methodological differences among agencies and investigators may be a source of uncertainty, and so methods should be standardized where possible. No formal comparison of methods among institutions has been conducted, and so the accuracy with which data can be compared among the lakes remains somewhat uncertain. However, this is not expected to have a substantial effect on the assessment of long-term trends within each lake.

Historically, *Cladophora* biomass was determined on an ad-hoc basis, often in response to reports of local problematic conditions. The lack of an established and consistent framework for *Cladophora* monitoring has been cited as a major impediment to understanding the status and trends of *Cladophora* in the Great Lakes (Ciborowski 2016). In 2016, an expert workgroup in support of the GLWQA Annex 4 (nutrients), developed a research plan for Great Lakes *Cladophora* modeling, research and monitoring (Ciborowski 2016). The parties, Canada and the United States, are currently implementing monitoring plans that include sentinel site monitoring. Sentinel site monitoring has been conducted at three to five nearshore transects of priority in Lake Erie since 2012 (McCusker et al. 2019) and at three to five transects in Lake Ontario since 2017 (McCusker et al. 2021) by Environment and Climate Change Canada (ECCC) in collaboration with the Ontario Ministry of Environment, Conservation and Parks (MECP). The U. S. Environmental Protection Agency (USEPA) and U.S. Geological Survey (USGS) initiated ongoing monitoring in the four lower lakes beginning in 2018. Since 2018, the USGS has monitored eight to 12 sites in the lower four Great Lakes (Nevers and Evans 2021), including two transects in each lake (northern and southern Lake Michigan, sites on the western shore of northern Lake Huron, and sites along the southern shores of Lakes Erie and Ontario). Additionally, in Lake Michigan, long-term monitoring of *Cladophora* is conducted within the context of academic research programs at two locations (near Milwaukee, WI and near Sleeping Bear Dunes National Park, MI). Sentinel, long-term, monitoring transects have been selected by each sampling agency to be representative of broad scale trends in environmental conditions but also to reflect local influences; as such, the monitoring results

should be considered in the context of light availability (i.e., depth and turbidity) and proximity to shoreline inputs (e.g., tributaries), amongst other factors. Attention needs to be given to the prevailing direction of alongshore currents, as nutrient and light conditions can vary over relatively small spatial scales (< 2 km) depending on whether sites are up-current or down-current of any shoreline inputs (McCusker et al. 2023). Variability in substrate type may also influence monitoring results given the requirement for hard and stable substrate in the inherently high energy environment where *Cladophora* is abundant. While these efforts have produced valuable data, comparison among lakes must also consider exposure to wave action and near-bottom shear stress that affect sloughing.

# Discussion

## Background

Algae, both planktonic and benthic, occur naturally in freshwater systems. They are essential to the aquatic food web and healthy ecosystems. However, too much or too little algae can result in negative impacts to water quality, the ecosystem or human health.

*Cladophora* is a filamentous green alga that grows on hard substrates in all the Great Lakes. The fouling of shorelines by rotting mats of filamentous algae (primarily *Cladophora sp.*) in the summer months was a common phenomenon in the lower Great Lakes as far back as the mid-20$^{th}$ century (Herbst 1969; Taft and Kishler 1973). Generally attributed to excess phosphorus (P) pollution, these blooms elicited public outcry and were identified as an emerging issue under the 1978 GLWQA (Agreement on Great Lakes Water Quality. 1978). Targeted research in the late 1970s generally concluded that P load reductions implemented under the GLWQA would contribute to a reduction of nuisance *Cladophora* growth (Auer and Canale 1982). A small number of documented (Canale and Auer 1982, Painter and Kamaitis 1987) and anecdotal reports (e.g., Painter and McCabe 1987) indicated some success of P control programs in reducing *Cladophora* growth, but systematic monitoring was not conducted. By the mid-1990s, reports of shore fouling began to increase in Lake Erie (Howell 1998) and by the early 2000s, had also increased in Lakes Ontario (DeJong 2000, Malkin et al. 2008) and Michigan (Bootsma et al. 2005). A retrospective analysis of Landsat remote sensing data from 1975 through c. 2010 showed variable submerged aquatic vegetation (SAV) percent cover at focal areas in Lakes Michigan, Ontario, Erie, and Huron through 1990, followed by steep increases in percent cover at sites in Lakes Michigan and Ontario (Brooks et al 2015). Between 2013 and 2019, there was interannual variability but no directional change in SAV percent cover at sites assessed using Landsat imagery (Shuchman et al 2021). With the recent resurgence of the nearshore algal problem in some areas and with other changes in the ecosystem (caused by invasive species including dreissenid mussels as well as land use change, warmer temperatures, increased rainfall, and more intense rain events), the problem has become more complicated. A more detailed and considered history of *Cladophora* in the Great Lakes is provided in Higgins et al. (2008a) and Auer and Bootsma (2009). Modeling studies of *Cladophora* growth in response to light, temperature and dissolved phosphorus concentration (Tomlinson et al. 2010; Kuczynski et al. 2020), and historical data for these variables (Higgins et al. 2008a, Auer et al. 2010, Brooks et al. 2015), implicate invasive dreissenid mussels in the resurgence of *Cladophora,* mussel filter feeding increases light and nutrient availability (Auer et al. 2010; Bootsma and Liao 2014). In some areas, local inputs of allochthonous phosphorus have also been implicated in *Cladophora* growth (Auer et al. 2021). Despite many negative attributes, *Cladophora* algae are natural substrate for many aquatic biological communities from microbes to small fish species (e.g., Byappanahalli et al. 2019; Dodds and Gudder 1992).

The negative economic, aesthetic and recreational use impacts of excessive *Cladophora* growth and biomass are well documented and include the fouling of beaches and residential shorelines, clogging of municipal and industrial water intakes, unpleasant aesthetics, and potential pathogen accumulation associated with mats of decaying algae along the lake shore (Higgins et al. 2008a, Peller et al. 2014, Ishii et al. 2006, Chun et al. 2017, Whitman et al. 2003). The ecological impacts of excessive *Cladophora* growth and biomass are not as well understood but may nonetheless be important. Expansive standing crops may represent a substantial (albeit perhaps temporary) nutrient sink over much of the growing season (Higgins et al. 2005). *Cladophora* is generally considered to be a poor food resource for grazers (Dodds and Gudder 1992), though it can be associated with higher quality epiphytes, such as diatoms that provide energy to upper trophic levels via invertebrates and the round goby (*Neogobius melanostomus*) (Tarsa 2021). Growing *Cladophora* can sequester synthetic microfibers (Peller et al. 2021) with unknown effects on food web transfer of these fibers. Accumulation of attached or drifting mats can result in transient hypoxic conditions in shallow littoral regions (Gubelit and Berezina, 2010) and deeper depressions (Tyner 2013); this may have deleterious impacts on invertebrate communities (Berezina and Golubkov 2008) and create an environment conducive to the development of botulism (*Clostridium botulinum*) and other pathogens (i.e., *Escherichia coli*), thus creating a risk for fish and wildlife (Chun et al. 2015).

## Current conditions

Locations affected by excessive *Cladophora* biomass continue to be found across much of Lake Ontario and Lake Michigan, as well as eastern Lake Erie. In Lake Huron, reports of excessive biomass are generally restricted to isolated locations along the southeastern shore. *Cladophora* is not currently considered an issue in Lake Superior where there are currently no long-term *Cladophora* monitoring sites (Fig. 1). An assessment of satellite imagery from 2008-2011 indicated that *Cladophora* and other submerged aquatic vegetation cover up to 40% of the nearshore lake bottom, in this case, the area visible to satellites (Lake Huron - 15%, Lake Erie - 23%, Lake Michigan - 28%, Lake Ontario - 40%; Brooks et al. 2015). However, while satellite imagery is useful for monitoring spatial coverage of algae in the nearshore zone, there remains a need to assess the viability of measuring algal biomass using remote imagery. For example, comparison among lakes is confounded by differences in water quality, resulting in satellite sensor mean detection depths ranging from 4 m for Lake Erie to 12 m for Lake Michigan (Brooks et al. 2015).

## Lake Superior

Attached filamentous algae in Lake Superior has not been comprehensively studied since 1969 – 1971 (Parker, 1979). Localized investigations in the 1960s (Herbst 1969), 1970s (Gerloff and Fitzgerald 1976) and 1980s (Auer and Canale 1981, Jackson et al. 1990) identified *Cladophora* at locales adjacent to obvious point source inputs of phosphorus and/or warm water discharges. While quantitative information is generally lacking, these studies report the abundance of *Cladophora* was considered relatively low. It is assumed that the colder temperatures, low phosphorus levels and the lack of dreissenid mussels may limit the extent of *Cladophora* growth in Lake Superior waters.

## Lake Michigan

In Lake Michigan, anecdotal evidence (primarily observations of accumulation on beaches and fouling of water intakes) and historical satellite imagery (Brooks et al. 2015) indicate that *Cladophora* has been growing at nuisance levels since the mid-to late-1990s. Prior to that it was present at high levels in some areas, notably the Milwaukee region, from the late-1950s to the 1970s (Herbst 1969). Quantitative measurements of biomass were made at the

Atwater station, at a depth of 10-11 m, about 7 km north of Milwaukee Harbor from 2004 to 2020. Peak biomass varied from year-to-year, ranging from a high of 283 g DW/$m^2$ in 2016 to a low of 34 g DW/$m^2$ in 2010 (excluding single low measurements in 2018 and 2020), with most years exceeding the status assessment cutoffs for Fair (50 g DW/$m^2$) and Poor (75 g DW/$m^2$) conditions. Data for this location were presented in the 2022 sub-indicator report (Depew et al. 2022) and are not included here as no further monitoring has been conducted at this location since then. However, there continues to be problems with fouling of beaches and water intakes near this location. *Cladophora* biomass and tissue phosphorus content have also been monitored on a shallow reef (10-11 m deep) in Good Harbor Bay, near Sleeping Bear Dunes National Lakeshore, MI since 2010. Much alike the Atwater station, peak biomass in Good Harbor Bay has exceeded the status assessment cutoffs, reaching levels above 100 g DW/$m^2$ in most years (Figs 2 and 3). Phosphorus content occasionally exceeds 1.0 mg P/g DW, though is generally between 0.4 and 0.8 mg P/g DW (Fig. 2), bracketing the value of 0.6 mg P/g DW which is considered the minimum threshold for *Cladophora* growth (Higgins et al., 2005). *Cladophora* biomass at this location regularly exceeds that measured near Milwaukee, despite the absence of any major external nutrient inputs to the Good Harbor Bay area. Since 2019, an additional site has been sampled approximately 20 km south of Waukegan Harbor, IL where peak biomass > 50 g DW/$m^2$ has been observed in three of four observation years with no clear trend across years (Fig 3, MWA; Przybyla-Kelly et al. 2020a and b, 2021, 2023; Giordano et al. 2024).

## Lake Huron

*Cladophora* biomass can reach nuisance conditions in the vicinity of local nutrient inputs in isolated regions along the southeastern shore of Lake Huron. Episodic fouling of beaches has occurred sporadically since 2004 although the degree of shore fouling is considerably less severe than that experienced in Lakes Michigan, Erie, and Ontario. In 2013 and 2014, limited measurements were made at a depth of 1 meter near Goderich, ON (affected by a municipal wastewater treatment plant (WWTP) discharge) and Kincardine, ON (affected by a small inflowing agricultural drain), biomass in 2013 and 2014 at Goderich was 46 g DW/$m^2$ and 49 g DW/$m^2$, respectively, and at Kincardine was 21 g DW/$m^2$ and 33 g DW/$m^2$, respectively (David Depew, Environment and Climate Change Canada, written personal communication, 11 December, 2024). Similar observations of localized growth of *Cladophora* directly adjacent to nutrient discharge points have been observed over the coastline in recent years as in the past (Barton et al. 2013; Depew et al. 2022). The spatial extent of growth at these locations was limited. Over broader stretches of the eastern shoreline of this lake, *Cladophora* grows to depths of 20 m, although biomass rarely exceeds 10-20 g DW/$m^2$ (Barton et al. 2013). A 2014 study by the Ontario Ministry of the Environment, Conservation and Parks of 48 sites in eastern Georgian Bay found little *Cladophora* over the hard and mostly bare substrate surveyed (Fig. 1). Stefanoff et al. (2018) reported that dreissenid mussels were the strongest predictor of benthic algae and *Cladophora* percent cover at sites in eastern Lake Huron. *Cladophora* is part of a cosmopolitan assemblage of benthic macroalgae in Saginaw Bay (approximately 43°52'N 83°37'W) linked to episodic fouling of beaches with decaying organic matter (Francoeur et al. 2014). While Saginaw Bay “muck” contains *Cladophora*, it has historically been recognized as a multi-species eutrophication problem (Francoeur et al. 2014). Sampling sites established since 2018 have recorded peak biomass > 50 g DW/$m^2$ outside the mouth of Thunder Bay in three of four years with no clear trend across year (Fig. 3, HAL; Przybyla-Kelly et al. 2020a and b, 2021, 2023; Giordano et al. 2024) but not in Thunder Bay (Przybyla-Kelly et al. 2020a and b, 2021, 2023; Giordano et al. 2024) or Hammond Bay (Fig. 3, HHB; Przybyla-Kelly et al. 2020a and b, 2021, 2023; Giordano et al. 2024).

## Lake Erie

As an indication of historical conditions, in 1979, the mean standing *Cladophora* biomass at Rathfon Point in the

east basin of Lake Erie was measured at 431 g DW/m$^2$ between depths of 0.5-3 m, with peak biomass greater than 900 g DW/m$^2$ (Neil and Jackson, 1982). Nuisance conditions were thought to have largely abated in the 1980s following phosphorus reduction strategies, but then resurged with the dreissenid invasion (Higgins et al. 2008b). Widespread assessments of *Cladophora* along the north shore of Lake Erie's East Basin in 1995 (Howell, 1998), and again in 2001-2002 (Higgins et al. 2005), found biomass to be more than 75 g DW/m$^2$ at many sites within the 0-2 m depth zone, often above 300 g DW/m$^2$. Since 2012, sentinel site monitoring of *Cladophora* biomass has occurred at three to five transects along the north shore of the east basin between ~3-20 m water depth in the vicinity of the Grand River, extending eastward to Port Colborne, ON, by ECCC (points on the north shore of Lake Erie in Fig. 1, Environment and Climate Change Canada. 2024). Inter-annual variation in peak biomass has been relatively high across these sites (with coefficient of variation of approximately 1 at most sites), displaying no temporal trend (Fig. 4, Environment and Climate Change Canada. 2024). Although peak biomass per unit area has tended to be lower in recent decades compared to the 1970s, abundant nuisance algae wash-up continues to occur, possibly due to the greater areal footprint of algae in the lake (McCusker et al. 2023). *Cladophora* growth is promoted by high light and warm temperatures, therefore biomass tends to be higher in years characterized by low river discharge and warm, dry growing periods and lower in years with elevated river discharge and wet, cool growing periods (McCusker et al. 2023). Additional samples collected at depths of 3 and 6 m at an offshore shoal (Nanticoke Shoal; ~ 7 km southwest of Port Dover, ON) in 2016 exceeded 50 g DW/m$^2$, indicating that even areas far removed from obvious nutrient inputs (i.e., wastewater outfalls, tributaries etc.) can experience high algal biomass. Valipour et al. (2016) modeled upwelling of offshore waters and found substantial soluble reactive phosphorus (SRP) supplies to the nearshore in some years, potentially sustaining regional *Cladophora* growth independent of local sources. On the southern shore of the eastern basin of Lake Erie, sampling sites established since 2018 have recorded peak biomass > 50 g DW/m$^2$ at sites east of Erie, PA (Fig. 3, EEP) and Dunkirk, NY (Fig. 3, EDE; Przybyla-Kelly et al. 2020a and b, 2021, 2023; Giordano et al. 2024).

## Lake Ontario

For many years, portions of the shallow lakebed of Lake Ontario have been widely and extensively covered by *Cladophora* (Wilson et al. 2006; Malkin et al. 2008; Higgins et al. 2012). The general long-term trend of nuisance levels of *Cladophora* in the 1960s and 1970s, abatement in the 1980s and 1990s, and resurgence in the past two decades is broadly alike Lakes Erie and Michigan (Higgins et al. 2008a). Surveys conducted in the 1970s documented median biomass per unit area routinely higher than 200 g DW/m$^2$. By the early 1980s, biomass had declined, but peak biomass remained elevated (often between 200-400 g DW/m$^2$) on the north shore of Lake Ontario (Painter and Kamaitis, 1987). Since this time, per unit area biomass has declined markedly (rarely exceeding 100 g DW/m$^2$) but total area of algal coverage has increased (Brooks et al. 2015). Surveys by the Ontario Ministry of the Environment, Conservation and Parks and ECCC in 2012-2013, 2015, and 2017-2023 identified general features of *Cladophora* in Lake Ontario: high surface coverage to the point of blanketing hard substrate; strong attenuation of biomass with depth but persisting cover to depths > 10-20 m; typical co-occurrence with high dreissenid mussel cover; and frequent co-occurrence with other filamentous green algae, notably *Spirogyra* (Howell, 2018; ECCC Open Data Portal). Biomass levels of > 50 g DW/m$^2$ have been observed at sites surveyed on the eastern, central and western shores of the main basin of the lake, however, there are few data on the occurrence of *Cladophora* in the eastern basin of the lake (Fig. 1, Fig. 5, Environment and Climate Change Canada. 2024). Along the U.S. shoreline, biomass > 50 g DW/m$^2$ was observed in two of four years at a site near Olcott, NY and was not observed at a site east of Irondequoit, NY (Fig. 3, OOL, OIR; Przybyla-Kelly et al. 2020a and b, 2021, 2023; Giordano et al. 2024). Spatial and temporal variability in biomass levels make inferences about observed patterns challenging. The finding of Higgins et al. (2012) indicating higher *Cladophora* levels in

areas of urbanized shoreline remains a central and substantial hypothesis influencing the direction of recent studies (e.g., Auer 2014; Howell 2018), signaling the potential for phosphorus management over the developed shoreline of the lake. However, additional studies may be required as a clear association between spatial patterns of phosphorus loading and *Cladophora* biomass has not always been found (Howell and Dove 2017; Howell 2018).

## State of Knowledge

The proximal drivers of *Cladophora* growth are reasonably well understood. Numerical models that are driven primarily by three variables – temperature, irradiance, and SRP concentration – perform moderately well in simulations of *Cladophora* growth (Higgins et al. 2006, Malkin et al. 2008, Tomlinson et al. 2010, Auer et al. 2010). However, there remains uncertainty about the processes that ultimately regulate these drivers. There is strong evidence that dreissenid mussels play an important role in *Cladophora* growth, due both to their ability to clear the water column (and hence increase *in situ* irradiance) by removing particulate material, and their recycling of particulate phosphorus, making dissolved phosphorus more available in the near-bottom layer where *Cladophora* grows (e.g., Ozersky et al. 2009, Martin 2010, Dayton et al. 2014). It is unclear at present if the enhanced phosphorus near the lakebed is derived from excretion of soluble nutrients as metabolic wastes (i.e., Conroy et al. 2005) or as enhanced remineralization of non-edible algae and other detritus that accumulates within mussel beds. The role of dreissenids is highlighted by observations of increased production rates of *Cladophora* in the presence of mussels (e.g., Davies and Hecky 2005) and the presence of high *Cladophora* biomass even in regions where there are no major nutrient inputs (Wilson et al. 2006, Depew et al. 2011). This situation is unlike the 1960s and 1970s, when *Cladophora* was associated primarily with point sources of nutrients. For example, in 2012 *Cladophora* biomass in Good Harbor Bay (near Sleeping Bear Dunes) in Lake Michigan, where there are no major tributary sources of nutrients, peaked at 125 g DW/$m^2$, whereas peak biomass several kilometres north of Milwaukee Harbor, which is a major nutrient source, was 49 g DW/$m^2$. However, in other regions, (e.g., Lake Ontario) there is evidence that local nutrient inputs do indeed have an influence on *Cladophora* biomass (Higgins et al. 2012).

Moving forward, it will be important to establish linkages between the extent and magnitude of in-lake biomass production, transport, and the degree of shore fouling (Shen et al. 2022). There is uncertainty about the degree to which high levels of biomass on the lakebed manifest as shore fouling. At the basin scale, shore fouling concerns align with elevated biomass levels on the lakebed, yet relations are not straightforward at specific locations. For example, Riley et al. (2015) found that structural development of beaches (*i.e.*, breakwalls, jetties and piers) were important predictors of the degree of *Cladophora* fouling on Lake Michigan beaches, and Barton et al. (2013) found that accumulation of algae on Lake Huron beaches was greatest where shoreline features intercepted nearshore currents. There is a need to measure the extent, duration and severity of beach fouling in a consistent way across the lakes and to collectively assess the information. Despite these and other factors affecting *Cladophora* transport and accumulation, the presence of excessive standing crop biomass at a given area is likely to indicate the potential for shore fouling and other negative impacts.

Evaluation of long-term trends of *Cladophora* biomass is confounded by several factors: 1) Small-scale spatial variation is high, resulting in large confidence limits for biomass measurements at a given time and location (e.g. Fig. 2), 2) Large-scale variability makes it difficult to determine how well a small number of sites may represent lake-wide or regional conditions, and 3) There is substantial seasonal variation in biomass (Figs. 2-5), so that annual peaks and means may be affected by sampling dates, and sloughing events may confound the relation between biomass and seasonal productivity.

Further development of methods (e.g., remote sensing, broad spatial surveys, modeling, and alternative imaging

techniques) are required to assess the areal extent of in-lake *Cladophora* beds and their biomass. Synoptic assessments of SAV were conducted in 2010 and 2012 *via* remotely sensed images throughout the nearshore of the Great Lakes (Shuchman et al. 2013). Additional approaches for monitoring *Cladophora* include hydro-acoustic methods (Depew et al. 2009), and *in situ* monitoring using time lapse imagery (Bootsma et al. 2015). Each of these approaches has advantages and disadvantages related to spatial coverage, quantitative accuracy and precision, technical difficulty, and cost. For example, remote imaging and acoustic survey methods offer potential to expand the geographic scope of assessment and subsume some of the variability in biomass induced by processes operating on the metre to sub-kilometre scale (*i.e.*, substrate patchiness, degree of exposure, variation in light conditions), but there are precision and accuracy issues using these methods when estimating biomass. Such approaches, while limited in their ability to determine the quantity of algae present, can be used to address some of the challenges related to spatial variation in habitat and/or manual sampling provided that near shore waters are not overly turbid. Integration of habitat and quantitative biomass information is similarly one way the European Union has begun to address status assessments for coastal waters under the Water Framework Directive (Scanlan et al. 2007). Specific challenges that remain include: 1) determining the accuracy with which areal biomass can be determined with satellite imagery; and 2) development of sampling / measurement methods and approaches that are relatively simple while accounting for spatial and temporal variability.

Currently, there are efforts to evaluate the effectiveness of autonomous under water vehicles (AUV) and remotely operated vehicle (ROV)-mounted optical sensors for determining *Cladophora* biomass and distribution (https://www.usgs.gov/centers/glsc/science/development-and-application-a-robot-assisted-computer-vision-system-map-great?qt-science_center_objects=0#qt-science_center_objects). Although these will not be as synoptic as satellite imagery, they are likely to yield more quantitative data compared to satellite imagery and will allow for greater spatial coverage than conventional grab sampling methods.

## Linkages

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

- Nutrients in Lakes – *Cladophora* is sensitive to levels of soluble reactive phosphorus in the environment.
- Benthos (open water) – benthos diversity and abundance may be correlated with the occurrence levels of *Cladophora* and connected by indirect mechanisms that are poorly understood.
- Dreissenid Mussels – *Cladophora* is substantially influenced by the state of water clarity, and thus light availability, and nutrients in the Great Lakes, which are influenced by dreissenid mussel populations.
- Water Quality in Tributaries – Nutrient loading from tributaries can have both an immediate and long-term effect on *Cladophora* growth. Likewise, tributary loads of suspended sediment and coloured dissolved organic material affect water clarity in the nearshore zone, which in turn affects light availability for *Cladophora* growth.
- Surface Water Temperature – The direct effect of surface water temperatures on *Cladophora* growth is uncertain. Considering that maximum summer surface temperatures in most of the lakes are already above the optimal growth temperatures for *Cladophora*, there may not be a direct positive effect of warming on growth and biomass. However, earlier spring warming can result in earlier maximum growth, altering seasonal patterns. Furthermore, available data indicate that dreissenid nutrient

recycling rates will respond positively to increased temperatures, which will increase nutrient supply to *Cladophora* growing near dreissenids, and so rising temperatures may indirectly lead to higher *Cladophora* growth rates (Bootsma and Liao, 2014).

This sub-indicator also links directly to the other sub-indicators in the Nutrients and Algae indicator. Improved wastewater treatment and sustainable agriculture practices which result in decreased nutrient loadings to the Great Lakes may also result in decreases in *Cladophora* biomass.

## Citizen Science, Traditional Ecological Knowledge (TEK), and other Bodies of Knowledge

In Lake Michigan, the frequency of measurements of *Cladophora* biomass and nearshore water quality in Good Harbor Bay has increased with the help of scuba-certified citizen scientists and support from the National Parks Conservation Association (Zemanski Heis 2014). This effort has resulted in a data set that is complete enough for calibrating and validating *Cladophora* growth models. However, it is important that protocols be in place to ensure the quality of data collected by citizen scientists is high.

In Lake Erie, the Niagara Coastal Community Collaborative (NCCC) has undertaken beach surveys to assess the degree of shore fouling since 2018 and this effort is expanding to Lake Ontario (Ford 2021; https://www.niagaracoastal.ca/).

There is currently limited information on the location, extent, and timing of *Cladophora* accumulation along New York's Great Lakes and connecting river channel shorelines. To promote enhanced management of nearshore areas in New York's Great Lakes basin, the New York State Department of Environmental Conservation recently updated their Shoreline *Cladophora* Survey, and created a web page where additional supporting information may be found (New York State, https://dec.ny.gov/nature/waterbodies/lakes-rivers/great-lakes/management/cladophora). This survey is a participatory science tool that allows users to submit observations of *Cladophora* accumulation (or absence) to be used as screening data by resource managers to identify areas where additional actions may be needed to address the impacts of *Cladophora* accumulation.

## 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 | University of Wisconsin-Milwaukee data: https://uwm.edu/glos/data/<br><br>ECCC Nuisance Benthic Algae Data:<br>https://open.canada.ca/data/en/dataset/a7b59572-5dba-4a34-ba2c-4262b25fa6ea<br><br>Cladophora biomass and supporting data collected in the Great Lakes - ScienceBase-Catalog: https://www.sciencebase.gov/catalog/item/5f6e18ba82ce38aaa2498f3e<br>2018 doi:10.5066/P9E570JS<br>2019 doi:10.5066/P99O4QXB<br>2020 doi:10.5066/P9O9FSTT<br>2021 doi:10.5066/P9449EUF<br>2022 doi:10.5066/P13JDUMH | | |

## Data Limitations

A lack of long-term monitoring means that trends cannot be determined, and recent measurements of *Cladophora* abundance cannot easily be placed in historical context. Most studies of *Cladophora* in the Great Lakes are focused on specific sites with known algae problems and may therefore not be suitable for scaling up or extrapolating to other locations. Additional challenges of discrete sample collection limit data extrapolation, including methods differences among studies, *Cladophora*'s substantial variability in space and time, and difficulty in collecting quantitative samples in areas with particularly high or particularly low biomass. Implementation of improved remote sensing and visualization techniques could permit reporting of regional or lake-wide estimates of algal coverage, but additional research is needed to link these measurements with direct measurements of biomass.

Excessive growth of *Cladophora* was a management challenge in many parts of the Great Lakes in the 1960s and 1970s and was one of the hallmarks of eutrophication. In highly eutrophic regions, such as Lake Erie, *Cladophora*

was relatively widespread, but in less impacted systems, such as Lake Huron, it was associated primarily with phosphorus point sources (Canale et al. 1982). Following the implementation of nutrient management programs that led to reduced phosphorus loading, *Cladophora* biomass declined in the 1980s and early 1990s. But in most of the Great Lakes, with the exception of Lake Superior, there was a resurgence of *Cladophora* growth in the mid-1990s to 2000s (well underway by mid-1995 in eastern Lake Erie) (Higgins et al. 2008a, Auer et al. 2010, Brooks et al. 2015). The application of models that simulate *Cladophora* growth in response to light, temperature and dissolved phosphorus concentration (Tomlinson et al. 2010; Kuczynski et al. 2020), along with historical data for these variables, indicate that the resurgence of *Cladophora* is largely due to increased water clarity caused by the filter feeding of dreissenid mussels, with additional contributing factors being nutrient excretion by mussels (Auer et al. 2010; Bootsma and Liao 2014) and, in some areas, local inputs of allochthonous phosphorus (Auer et al. 2021). While management of nutrient loading remains an important tool for controlling *Cladophora* growth in the Great Lakes, the relationship between nutrient loading and *Cladophora* growth may have changed due to the alteration of internal nutrient dynamics by dreissenid mussels. Indeed, the apparent important role of light indicates that nutrient supply from dreissenids may meet algal nutrient requirements in most light environments, regardless of external nutrient loading rates. Hence there is a renewed need for time-series data and quantitative models to better understand the mechanisms that regulate *Cladophora* growth and how it may respond to specific nutrient management actions (Bootsma et al. 2015). These models will require an improved understanding of the physical and biogeochemical processes that drive nearshore nutrient dynamics.

## Additional Information

*Cladophora* can be measured by both areal extent and by biomass. However, biomass is probably more useful, as percent coverage can remain relatively constant, even if biomass increases or decreases. It is anticipated that biomass of *Cladophora* may decline as nutrient concentrations decrease and algae become nutrient-stressed. Phosphorus control strategies have worked in the past for reducing *Cladophora* but the issue is now complicated by dreissenid-induced increases in water transparency and the conversion of particulate phosphorus to dissolved phosphorus at the lakebed-water interface. The trends provided by this sub-indicator may aid in identifying areas for targeted phosphorus reductions and may also provide guidance regarding any new targets for total phosphorus concentration in the nearshore zone. While the General Objective #6 of the GLWQA is relevant, it is important to recognize that, unlike in the past, the current nuisance algae problem may not be primarily a nutrient loading problem in all areas. For example, *Cladophora* is a problem in Lake Michigan, but total phosphorus concentrations in both the pelagic and nearshore are well below the GLWQA target of 7 µg/L (Great Lakes Water Quality Protocol, 2012).

The tissue phosphorus content (or phosphorus status) of algal filaments has historically been considered a useful metric for assessing the nutritional status of *Cladophora*, its growth potential, and thus the potential for phosphorus management to be effective in controlling growth. Expressed most commonly as the proportion of dry weight (% DW; $Q_P$), $Q_P$ is thought to provide a time-integrated measure of algal exposure to phosphorus that: a) removes uncertainty in phosphorus supply, and b) represents exposure and uptake of phosphorus by the alga in its physical habitat (*i.e.*, at the lakebed). In general, values exceeding 1.6 mg P/g DW (0.16 %) are considered phosphorus saturated, values between 1.6 and 0.6 mg P/g DW (0.16 – 0.06 %) are phosphorus limited, and values below 0.6 mg P/g DW (0.06 %) are critically limiting and insufficient to sustain net positive growth (Higgins et al., 2005). However, phosphorus limitation cannot be inferred from $Q_P$ alone for the simple reason that other factors can affect internal phosphorus levels. In persistently turbid or deep waters, *Cladophora* growth is light limited, and

thus, unable to dilute internal phosphorus stores to minimum cellular quotas. In contrast, higher irradiance in very clear waters and/or shallow areas leads to higher growth rates that may be sufficient to quickly deplete internal phosphorus stores. Such patterns have been demonstrated in Lake Michigan where $Q_P$ content was found to vary more than three-fold and *Cladophora* biomass was negatively correlated with $Q_P$ (Bravo et al. 2019). Similar observations were documented in eastern Lake Erie from 2012-2019, with $Q_P$ increasing (and biomass decreasing) along a gradient toward the Grand River, which is a substantial source of turbidity and nutrients to the Lake Erie nearshore (McCusker et al. 2023). Water quality monitoring conducted in 2013 at the mouth of the Welland Canal in Lake Ontario demonstrated the inverse relationship often seen between phosphorus and light in areas of the nearshore impacted by runoff (Howell and Dove 2017). These observations underscore the important role of light as a regulator of *Cladophora* growth and the importance of considering light conditions when interpreting $Q_P$ and biomass.

*Cladophora* often makes up the majority of nuisance benthic algae that fouls beaches and water intakes in the Great Lakes. However, *Cladophora* is often accompanied by other algae, especially diatoms that grow epiphytically on *Cladophora* filaments (Dodds and Gudder 1992). In some cases, nuisance benthic algae can also consist of other taxa, including the green algae *Chara, Spirogyra, Ulothrix,* and *Oedogonium* (Herbst 1969, Barton et al. 2013, Higgins et al. 2008a, Francoeur et al. 2014). Hence, while the genus *Cladophora* is usually the dominant form of nuisance benthic algae in most regions of the Great Lakes, the term "*Cladophora*" often is used to refer to a conglomeration of benthic algae.

The issue of *Cladophora* in the Great Lakes merits sustained integrated research and monitoring because the symptoms of coastal impairment cannot be easily ignored given the proximity of the problem to recreational, municipal and industrial users. Given the apparent sensitivity of *Cladophora* to very low levels of SRP (Auer et al. 2010), the principal challenge is the better understanding of the relative contributions of nutrient supply from both lake-wide and local sources, as well as the internal processes that regulate phosphorus supply to *Cladophora* growth.

Following a robust binational science-based process and extensive public consultation, Canada and the U.S. have adopted phosphorus reduction targets (compared to a 2008 baseline) for the Western and Central basins of Lake Erie to address algal toxins and low–oxygen (hypoxic) areas (IJC 2016, Objectives and Targets Task Team 2015). For the Eastern Basin, a target has not been recommended to address nuisance algae (*Cladophora*) at this time (Objectives and Targets Task Team 2015). Nonetheless, it is important to note that targets have been recommended for the Western and Central Basins and these work in concert, not in isolation. Because all tributaries to Lake Erie, including the Detroit River and the Huron-Erie Corridor, contribute phosphorus loads to the Eastern Basin, the reductions needed to address algal blooms and hypoxia may lower the phosphorus concentrations in the Eastern Basin as well. This phosphorus load reduction may help address nuisance algal issues in the Eastern Basin, while maintaining enough nutrients to support the fisheries. Work to identify potential targets that will minimize impacts from nuisance algae in the eastern basin of Lake Erie continues.

Evaluating the current status of *Cladophora* is a somewhat subjective exercise, based on measurements of biomass when and where available, the frequency and magnitude of accumulation on beaches, and the fouling of water intakes. Designating a biomass target could support managers in assigning a status to each of the lakes and also in developing management strategies with specific, quantitative objectives, such as nutrient loading targets. As discussed above, and in the commentary by Bootsma et al. (2015), a dry biomass of 50 g/m$^2$, which was suggested as a nuisance threshold for Lake Huron in the early 1980s (Canale and Auer 1982), may now be well above the level that leads to a "nuisance" and beneficial use impairment, because nuisance growth is no longer restricted to

nearshore regions adjacent to point nutrient sources, and the depth range of *Cladophora* has increased due to greater water clarity. Other factors also confound the use of a single biomass target. In nearshore regions with sparse rocky substrate, biomass on rocks may exceed 50 g DW/$m^2$, but spatially averaged biomass may be well below that level, resulting in little accumulation on shore. Also, standing biomass may be a poor indicator of the actual amount of biomass available for accumulation on shorelines because biomass is not necessarily correlated to production. A substantial portion of *Cladophora* production may be lost to sloughing (Canale and Auer 1982; Higgins et al. 2008b; Katona et al. 2023), and in summers when sloughing rates are high (due to wave-induced turbulence or high temperatures), standing biomass may remain low while the availability of *Cladophora* for accumulation on beaches is high. While these conditions might indicate that the frequency and magnitude of accumulation on the shoreline is a more useful measure, shoreline accumulation can also be misleading, as shoreline accumulation is stochastic and subject to the vagaries of nearshore currents and waves. Reliable evaluations of the status of *Cladophora* will depend on measurement of more than one variable, such as biomass. Additional measurements that will support evaluation, and lead to a better understanding of the factors and mechanisms that regulate *Cladophora* include tissue phosphorus content, water clarity (along with solar radiation), and growth rate. Although direct measurement of growth rate is technically more challenging than measurement of biomass, it may be possible to use proxies for growth rate, such as the $^{13}C$:$^{12}C$ ratio of *Cladophora* or variable fluorescence (Katona et al. 2023).

The designation of *Cladophora* as a nuisance is based primarily on its impact on shoreline conditions, which are the most visible to the public. As discussed above, there are a number of less obvious, and less well understood ways in which *Cladophora* affects nutrient and trophic dynamics (Turschak et al. 2014) and contaminant transfer (e.g., Lepak et al. 2015). These processes, as well as the influence of *Cladophora* on dissolved oxygen and microorganisms of concern such as *Escherichia coli* and *Clostridium botulinum*, ultimately influence ecosystem integrity and beneficial uses, so a rigorous assessment of the status of *Cladophora* will require that these factors be increasingly understood.

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## List of Figures

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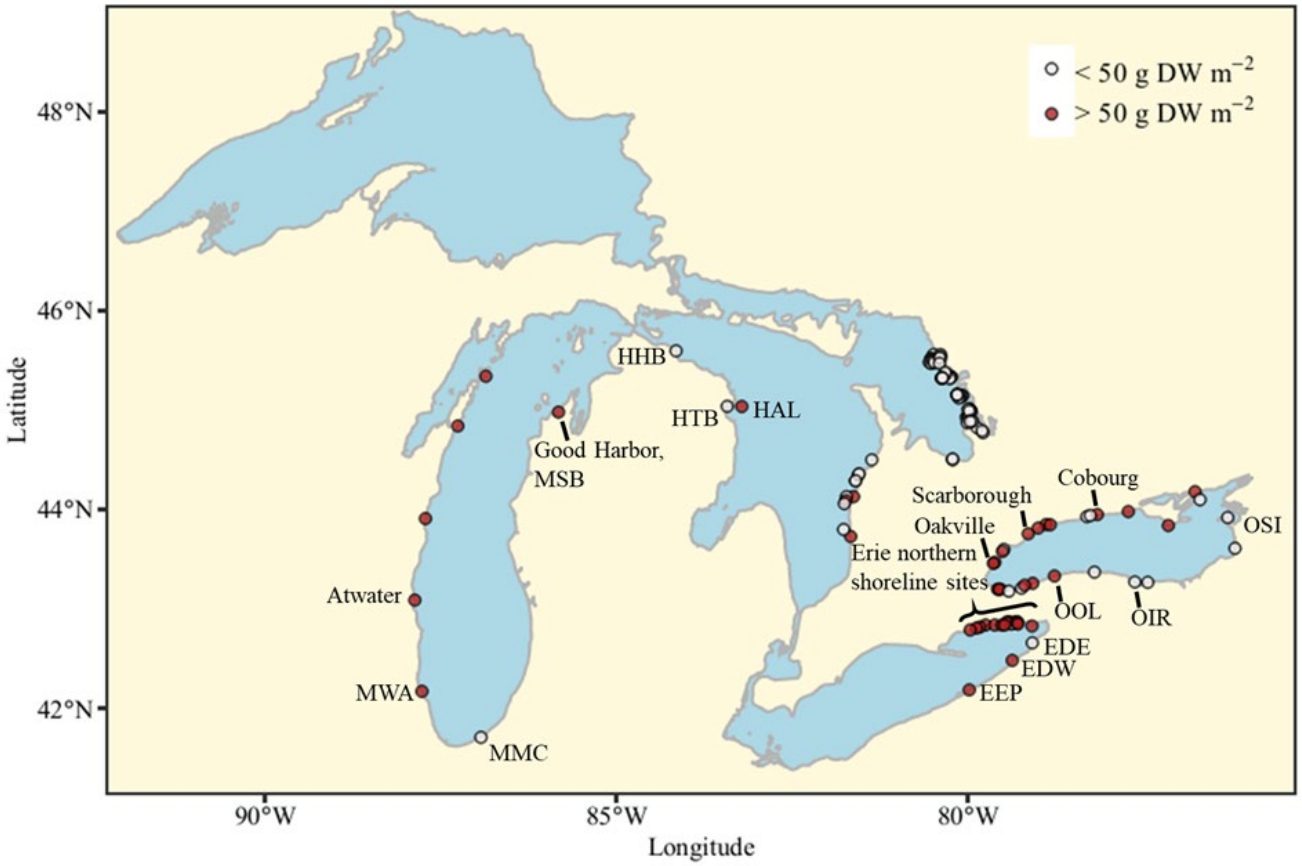
**Last Updated**

*State of the Great Lakes 2025 Report*

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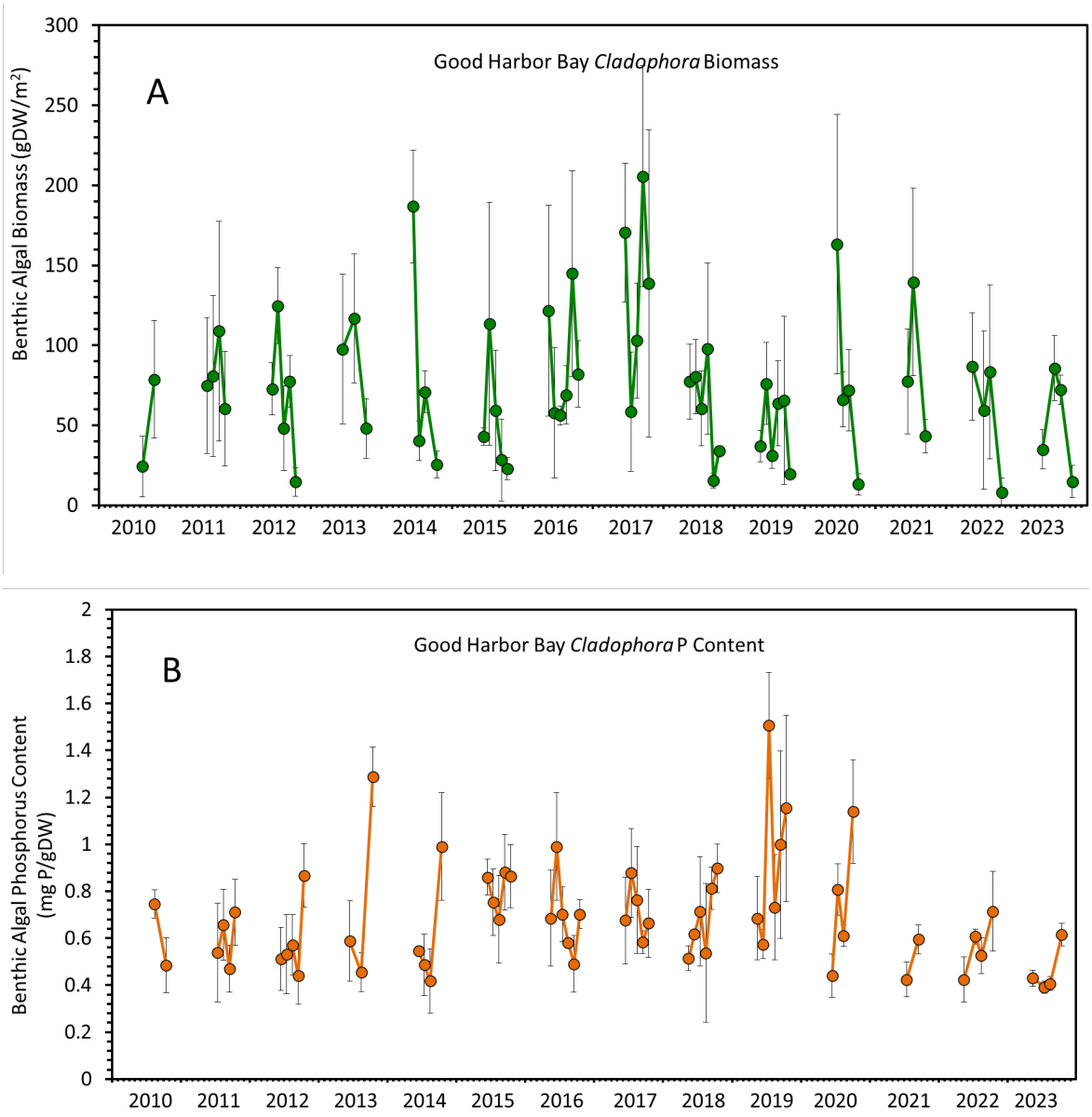


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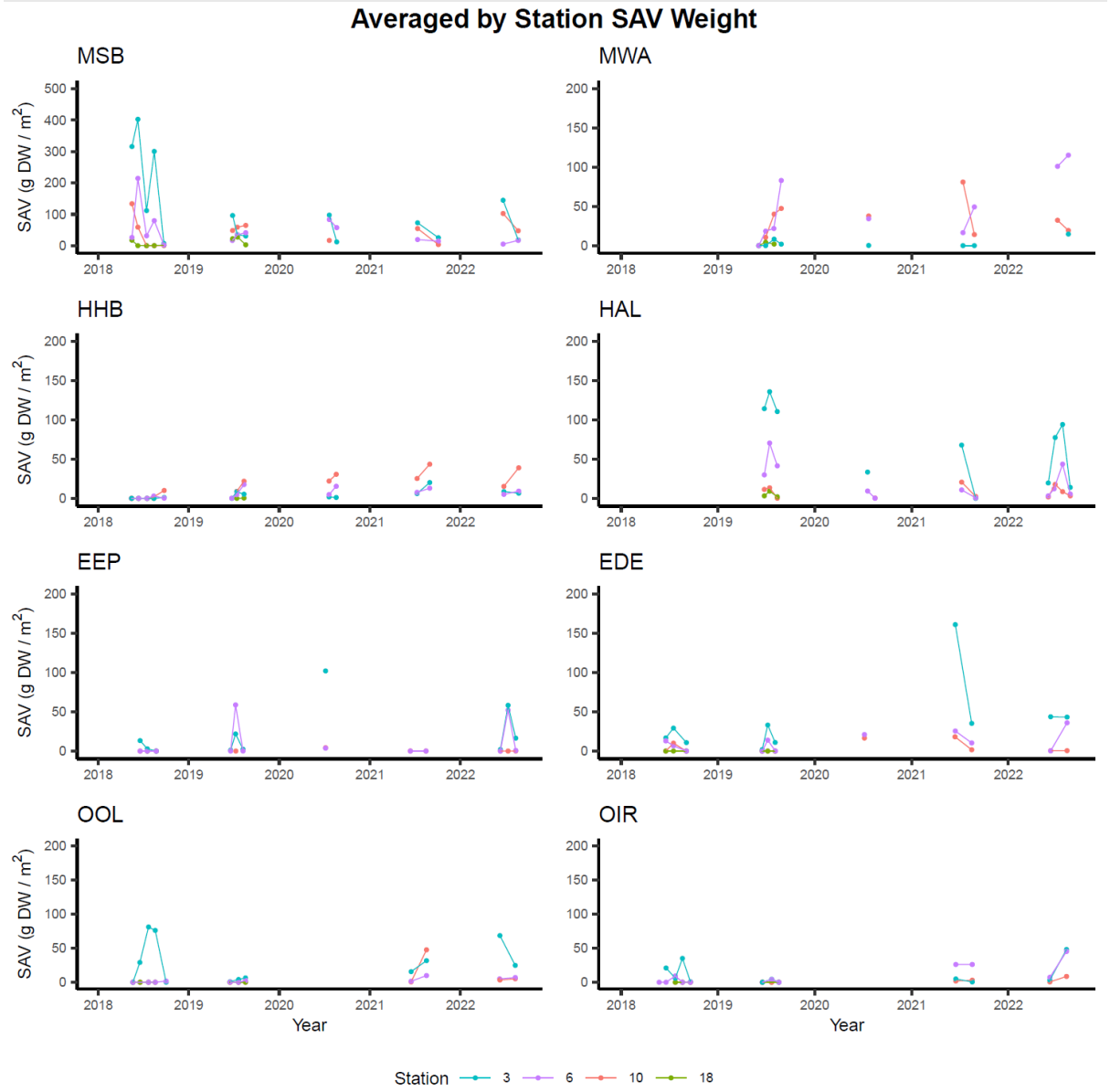


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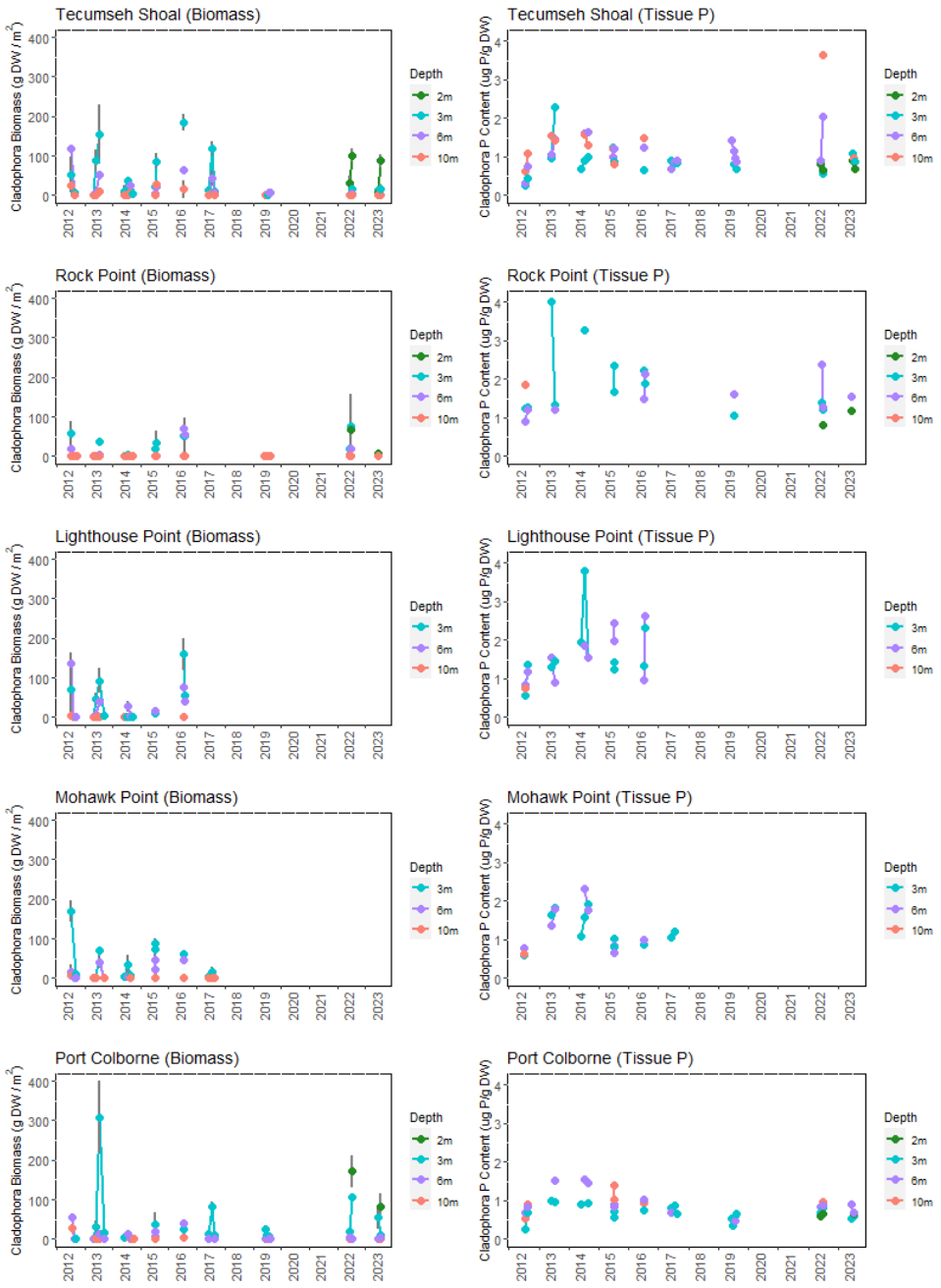


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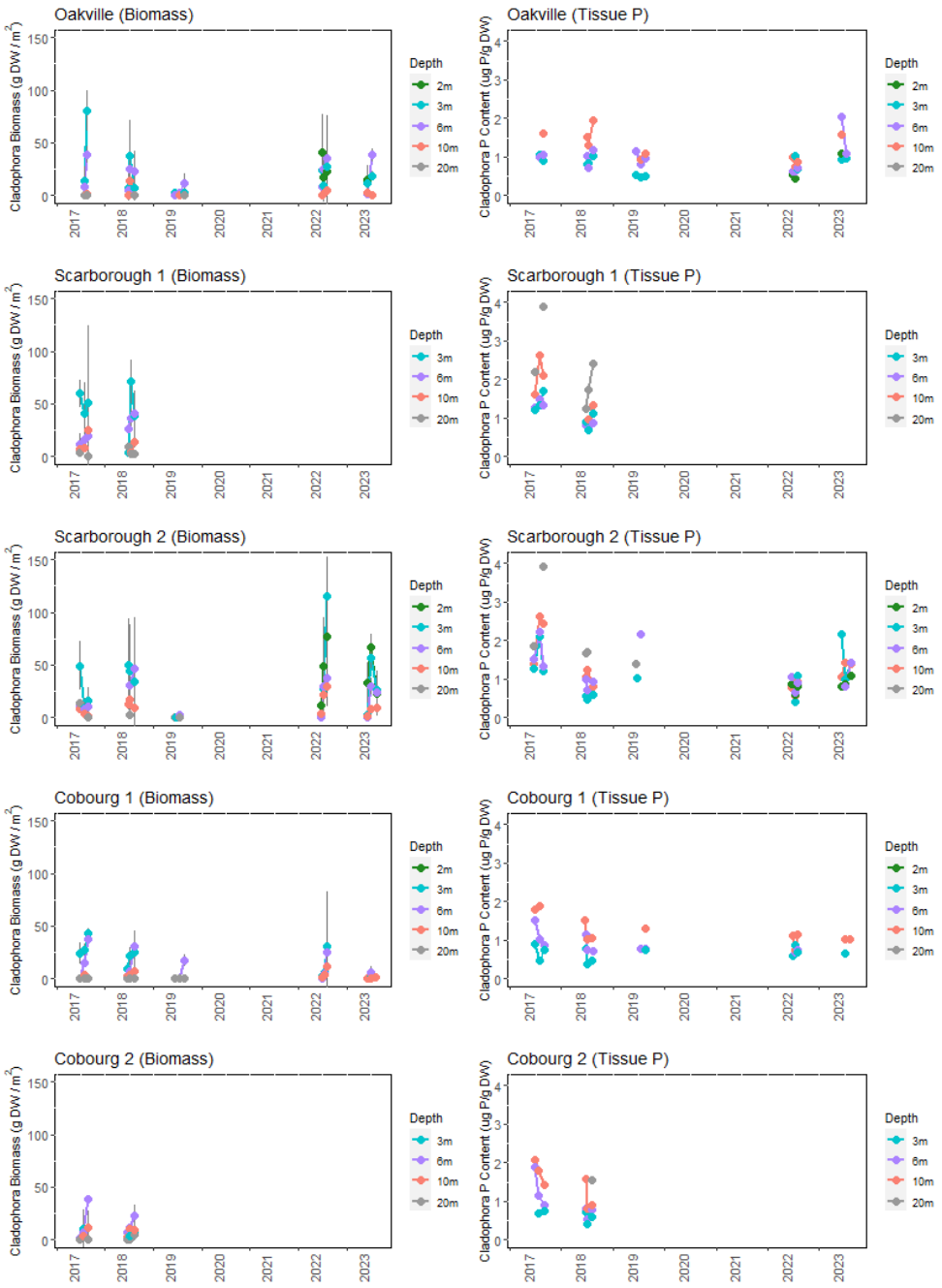


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