



## *Cladophora*

### Overall Assessment

Status: Mixed

Trend: Undetermined

Rationale: *Cladophora* is widely distributed over hard surfaces (e.g. bedrock, boulders, piers, etc.) in the nearshore of all the Laurentian Great Lakes and reaches nuisance levels in Lakes Ontario, Erie Michigan, and isolated locations in Lake Huron. Fouling of shoreline by beached algae, composed mostly of *Cladophora*, is now an annual feature across many beaches and harbors in these lakes. Quantitative monitoring information is limited in geographic coverage and sporadic in duration. There is inadequate information to track temporal trends in the distribution or abundance of *Cladophora* at this time with the exception of Lake Michigan.

### Lake-by-Lake Assessment

#### Lake Superior

Status: Good

Trend: Unchanging

Rationale: Shore fouling by *Cladophora* has not historically been an issue in Lake Superior. There is no observational evidence that the occurrence of *Cladophora* has changed in recent years.

#### Lake Michigan

Status: Poor

Trend: Unchanging

Rationale: *Cladophora* is widely abundant in the nearshore over parts of the western shores of the lake covering a high proportion of the lakebed composed of hard surfaces. Reported biomass levels exceed the thresholds for shore fouling consistent with observations of shore fouling in multiple geographic areas. There have been surveys of the regional distribution of *Cladophora* and detailed area-specific studies of *Cladophora* productivity and ecology in recent years. Circumstantial evidence and simulation models suggest that growth rates and bloom formations increased following dreissenid mussel invasion. Monitoring of biomass levels annually since 2006 indicates that while peak biomass varies among years there is no trend.

#### Lake Huron

Status: Mixed

Trend: Undetermined

Rationale: *Cladophora* grows near suspected points of nutrient input over the Canadian and U.S. shorelines of the main basin where adjacent shoreline may also be fouled. In the absence of point sources of nutrients, *Cladophora* growth and biomass accrual is minimal in the main basin. Recently *Cladophora* has been detected at low densities at depths where wave scouring is reduced. However, there is insufficient monitoring information to determine if this represents a recent change. Shore fouling by algae thought to be composed partially of *Cladophora* has been reported in areas of Saginaw Bay (see below).

## Lake Erie

Status: Poor

Trend: Undetermined

Rationale: *Cladophora* is widely distributed in the shallow nearshore Lake Erie, notably the northern shoreline of the eastern basin where hard substrate is widely distributed. *Cladophora* biomass reached nuisance levels following dreissenid invasion, and shoreline fouling is widespread along the Canadian portion of the eastern basin. Circumstantial evidence and simulation models indicate that biomass and shoreline fouling increased following dreissenid invasion.

## Lake Ontario

Status: Poor

Trend: Undetermined

Rationale: *Cladophora* is widely distributed in the nearshore covering a high proportion of the lakebed composed of hard substrate. Reported biomass levels at multiple locations, particularly at sites influenced from point sources of nutrients, exceed threshold nuisance conditions. There have been surveys of the regional distribution of *Cladophora* and detailed area-specific studies of *Cladophora* ecology in recent years. There is insufficient information to determine if the distribution and abundance of *Cladophora* has changed in recent years.

## Other Spatial Scales

### Saginaw Bay

Status: Undetermined

Trend: Undetermined

Rationale: Periodic fouling of shoreline and beaches in Saginaw Bay by decaying plant material of mixed composition termed "muck" appears to be a long-standing feature of parts of Saginaw Bay which predates the arrival of dreissenid mussels (Craig Stow personal communications). *Cladophora* contributes to the varying mix of plants that includes macrophytes, *Chara*, other filamentous algae and diatoms (periphyton) that accumulates on the shoreline. The contribution of *Cladophora* to shore fouling is not well defined at this time.

## Purpose

- To evaluate temporal and spatial trends in biomass and areal coverage of *Cladophora* in the Great Lakes.
- Data can be used to infer the availability of *Cladophora* to be transported to the lake shore where it may foul beaches and clog water intakes.
- The *Cladophora* indicator is used in the Great Lakes indicators suite as an Impact indicator in the Human top level reporting category.

## Ecosystem Objective

*Cladophora* should not be found at nuisance levels. Waters and beaches should be safe for recreational use and be free from nuisance algae which may negatively impact water intake infrastructure and beach use. This indicator supports Annexes 3 and 11 of the GLWQA.

## Ecological Condition

### Background

Prior to the mid-1980s, fouling of shorelines by rotting mats of the filamentous green algae *Cladophora* was common place in parts of the lower Great Lakes. Excessive *Cladophora* growth and bloom formation during this period were associated with phosphorus pollution. An apparent hiatus of *Cladophora* blooms and shore fouling from the mid 1980s until the mid 1990s has been interpreted, based on limited field monitoring and hind casting

using field-calibrated growth models and historical water quality data, as a positive outcome of the reduction in phosphorus loading to the Great Lakes set in place by the Great Lakes Water Quality Agreement. Beginning in the mid-1990 there have been growing numbers of reports of shore fouling including areas that did not experience shore fouling in the past. Today *Cladophora* contributes to degradation of the aesthetic value of Great Lakes beaches and waterfronts and sporadically fouls water intakes of power plants. Researchers in Canada and the US have examined the present day occurrence of *Cladophora* in parts of Lakes Ontario, Erie, Michigan and Huron and confirm the overabundance of *Cladophora* and associated shore fouling dispersed over wide areas around the Great Lakes. Detailed accounts of *Cladophora* as a nuisance algae in the Great Lakes and the recent changes in environmental condition facilitating the proliferation of *Cladophora* today are given by Auer and Bootsma (2008), Auer et al. (2010), Bootsma et al. (2004) and Higgins et al. (2008).

The colonization of the Great Lakes by zebra and quagga mussels (dreissenid mussels) has had a strong effect on lake ecosystems including features which are influential to the growth of benthic algae such as increased bioavailability of nutrients, increased water clarity and increased distribution of hard surfaces (dreissenid shells) that *Cladophora* filaments can attach. Increased water clarity associated with particle-filtering activity of dreissenid mussels acts to reduce light limitation of algae growth with depth and increase the area of lakebed available to support growth of benthic algae. In short, the more light reaching the lakebed means more habitat available for growth. The positive effects of changed water clarity on *Cladophora* production have been documented for Lakes Ontario, Erie and Michigan (Higgins et al. 1995; Malkin et al. 2008; Tomlinson et al. 2010).

Recent surveys across Lake Erie, Ontario, Michigan, and Huron indicate that *Cladophora* growth in these lakes are limited by phosphorus availability. A challenging and still evolving question concerns the role that dreissenid mussels play in facilitating the supply of phosphorus to support the growth of algae on the lakebed including *Cladophora*. Dreissenid mussels scavenge nutrients in particulate form from the water column through active filtration and subsequently release phosphorus in dissolved form and in particulate form as feces, or pseudofeces. It remains to be determined whether increased quantity and bioavailability of phosphorus associated with dreissenid waste products are a significant part of the nutrient budget of *Cladophora*, and under what conditions. From a management perspective, understanding the role of dreissenid mussels in the nutrition of *Cladophora* is critical because this knowledge is needed to predict how growth rates and bloom formations will react to changes in phosphorus loading at various geographic scales (e.g. local point sources, basin scale, regional scale). The potential management of *Cladophora* (lakewide and at locally enriched sites) is dependent on an accurate understanding of the relationship between external inputs of phosphorus and *Cladophora* productivity. While it is currently possible to predict *Cladophora* growth rates (and the potential for blooms) based on ambient phosphorus concentrations, it remains difficult to make such predictions based on external loads due to the uncertain role of the dreissenids in modifying exposure to phosphorus. What is clear is that the proliferation of *Cladophora* in Lake Ontario and Lake Michigan is not attributable to increased basin-scale nutrient concentrations. Open lake concentrations of phosphorus have been trending downward in both lakes over the period of the apparent resurgence in *Cladophora*. Paradoxically, the wide dispersal of high *Cladophora* biomass over nearshore areas of Lakes Erie, Ontario and Michigan indicates that at some base level the overabundance is supported by basin-scale nutrient levels. Such changes suggest that the bioavailability of P has increased since dreissenid invasion. The absence of wide-spread *Cladophora* in the more phosphorus poor Lakes Huron and Superior is consistent with this hypothesis. Nutrient regimes in the nearshore can be highly variable with scope for local and/or regional nutrient inputs to affect productivity of *Cladophora* as has historically been the case in Lake Huron. Recent studies in Lake Ontario indicate that *Cladophora* biomass is higher in urbanized areas than over less developed shoreline (Higgins et al. pending).

### *Biomass and Areal Cover of Cladophora as Metrics of Occurrence*

Field based assessment of the distribution and abundance of *Cladophora* is challenging due to the high spatial and temporal variability that characterize *Cladophora* growth, biomass accrual, and sloughing (e.g. detachment from lake bottom and physical transport to beaches or depositional zones). *Cladophora* biomass can be highly variable across relatively short timeframes (days to weeks), complicating the comparison of biomass (e.g. evaluating trends) over space (e.g. between lakes) or over longer time frames (between years). The effects of variable growth rate on standing biomass is further complicated by the ongoing and erratic sloughing of the attached algae by water movement which periodically transports algae to the shoreline with increasing frequency as water temperature rise over the summer. Such complications are well documented features of the ecology of *Cladophora* in the Great Lakes (see Journal of Great Lakes Research 1982 *Cladophora* special issue; Higgins et al. 2008).

Nonetheless, given appropriate consideration for seasonality, biomass, areal coverage, and nutrient content of filaments can be useful indicators of the status of *Cladophora* and water quality. First, sub-optimal timing of sampling will tend to underestimate biomass and areal coverage. None-the-less, where field measurements of biomass or cover indicate that nuisance conditions exist they most likely do. Second, while estimates of biomass suffer from problems of accuracy and precision, it is generally possible to determine whether nuisance conditions are a lake-wide phenomenon or a response to localized conditions (e.g. point source nutrient loading). Such a distinction is critical for management, since the management response should occur at the appropriate spatial scale to effectively address the problem (i.e. lake wide or localized nutrient abatement strategies). The capacity of *Cladophora* to respond to localized areas of nutrient input at the shoreline, especially obvious in areas where *Cladophora* does not occur on a regional scale, complicates the reporting of occurrence data. Random placement of measurement sites over the nearshore can provide an area-wide appraisal of conditions; however, it may not detect problematic shoreline fouling that is focused at localized areas of *Cladophora* growth along the shoreline. Reliance on broader scale assessment of areal cover using remote or visual semi-qualitative methods may offer means to augment surveys. The depth distribution of *Cladophora* is variable among areas. Abundance with depth is influenced by onshore-offshore gradients in water clarity, nutrients, physical disturbance, substrate, temperature and possibly abundance of dreissenid mussels. Since the depth of maximal biomass is variable there is no one optimal depth of where sampling should occur. Typically, biomass is highest below the wave zone (> 0.5m depth) where scouring can reduce standing crop, and above the depth where light becomes growth limiting (variable among sites). In general it is optimal to survey several depths at each site. Available data for *Cladophora* biomass and coverage is reported in Figures 1 and 2. Where data was available for multiple depths, the finding for the depth of maximum development of *Cladophora* is reported.

Previous efforts have indicated that areal density (areal coverage x height of the *Cladophora* bed from the lake bottom) can be effectively used to provide reasonable estimates of biomass (Howell 1998, Higgins et al. 2005). Such an approach, combined with deployable camera systems, or hydroacoustics (Depew et al. 2009), may be a useful means to increase the spatial coverage of sampling activities. A three level status evaluation is suggested until a more robust approach is developed and tested: 1) Poor is the condition where there is high surface cover (>50%) of *Cladophora* over optimal habitat on a regional-scale and where multiple locations surveyed by random sampling designs reach biomass levels that exceed the nuisance threshold of 50 g/m<sup>2</sup> dry weight ( see Canale and Auer 1982), 2) Mixed is when neither of the criteria for poor are met but where there are multiple areas of localized growth of *Cladophora* on the lakebed which result in public complaints of fouling over limited portions of shoreline, and, 3) Good is when *Cladophora* is largely absent in quantities that result in shore fouling prompting public complaint. See figures 1 to 3 for a summary of *Cladophora* occurrence data.

The nutrient content of *Cladophora* filaments is a useful metric of the potential for nutrient abatement programs to be effective in controlling growth. While quantities of potentially limiting nutrients may be highly variable (spatially and temporally) in the overlying water column, or below analytical detection limits, values of these nutrients within *Cladophora* tissues represent their availability for growth. While concentrations of carbon, nitrogen and phosphorus in *Cladophora* biomass are sometimes measured, it is phosphorus that most often limits growth rates in the Great Lakes region and is the most informative (Higgins et al. 2008). Levels of phosphorus are typically expressed as a proportion of dry mass ( $Q_p$ ). There has been a significant amount of research devoted to linking tissue concentrations of phosphorus to potential growth rates (e.g. Auer and Canale 1982, Painter and Jackson 1989). Generally, values of  $Q_p$  exceeding 1.6 mg P/g are considered saturated in P, values between 0.16 and 0.06 mg P/g are considered P limited, and values below 0.06 mg P/g are insufficient to sustain growth rates and are thus critically limiting. As with biomass,  $Q_p$  exhibits intra-site variability and care is required to account for the effects of seasonality and of non-nutrient related factors affecting  $Q_p$  (e.g. light level) when comparing  $Q_p$  among areas or years.

#### *Availability of Cladophora Monitoring data*

The 2008 SOLEC report " *Cladophora* in the Great Lakes: Guidance for Water Quality Managers" critiques monitoring of *Cladophora* in the Great Lakes. Briefly, monitoring of the status of *Cladophora* in the Great Lakes after about 1985 was largely lacking until recently when the apparent resurgence was reported in Lake Ontario, Erie and Michigan. Monitoring is sporadic and proceeds largely independently in pockets often supported by area-specific research activities. The lack of any systematic, Great lakes-wide monitoring of *Cladophora* has been repeatedly cited as a shortcoming in understanding present day *Cladophora* shore fouling problems. Despite being a widespread problem in the lower Great Lakes, information on the occurrence of *Cladophora* is primarily

associated with the work of a small number of research groups examining the environmental basis for the apparent resurgence following dreissenid invasion, and is generally geographically-focused in areas where algae fouling problems occur. There have been agency based monitoring surveys of *Cladophora* distribution over parts of Lakes Ontario, Erie, Michigan and Huron. Surveys of the distribution of *Cladophora* in Lake Ontario were included in the study design for the bi-national cooperative monitoring of the coastal zone in 2008 (Higgins et al. pending).

At present there is little information with which to assess year to year variability in the occurrence of *Cladophora* in areas of high abundance. It is not known whether the abundance of *Cladophora* is changing in any consistent manner with the exception of Lake Michigan where biomass has been monitored on a regular basis since 2006 by researchers at the University of Wisconsin-Milwaukee (Figure 4). Notable in this work is the attention to through time data collection to identify peak seasonal abundance allowing robust comparisons of *Cladophora* biomass among years. The wide variability in biomass among years in the absence of a temporal trend (Figure 4) suggests that monitoring of *Cladophora* to detect change will be demanding.

#### *Development of a Great Lakes Cladophora Monitoring Strategy*

Recent publications have made recommendations on how monitoring of *Cladophora* in the Great Lakes might be improved. Auer et al. (2010) recommended that biomass and nutrient status of *Cladophora* tissues are the most practical choice of metrics for characterizing nuisance *Cladophora* conditions over space and time. The assessment of *Cladophora* biomass and nutrient status at a limited number of sentinel sites around the Great Lakes would be a useful means to determine temporal trends (within and between years) and provide data for calibrating/validating *Cladophora* growth models. Sites within each lake should be geographically dispersed, include areas where growth is driven primarily by lake-wide nutrient concentrations and also sites where growth is driven by point sources (i.e. tributaries, sewage or industrial discharges, etc.). Methodologies for such monitoring programs are relatively simple and low-cost, but are labor intensive and sensitive to the timing of surveys (Higgins et al. 2005, 2008; Auer et al. 2010). While useful as sentinels, the ability of a monitoring program focused on a limited number of sites to capture the status of *Cladophora* at larger spatial scales (i.e. basin, lake, region) is limited.

New and emerging tools are potentially available to augment, and increase the efficacy of, survey techniques to assess the distribution and abundance of *Cladophora*. Recently, hydro-acoustic technologies have been used to map *Cladophora* distribution patterns across larger spatial scales (kilometers) than could be accomplished with snorkeling or diver based (meters) surveys (Depew et al. 2009). The use of remote sensing to determine large-scale distribution patterns of *Cladophora* is being evaluated by researchers at Michigan Technological University (Sayers et al. 2011) and elsewhere. Images in the visible light range collected by satellite are evaluated using algorithms which interpret the presence of algae on the shallow lakebed in terms of surface coverage and biomass concentration. Examples of remotely estimated distributions of *Cladophora* on the shores of Lake Michigan and Ontario are presented in Figure 5. Such an approach holds promise to assess distribution of *Cladophora* in the Great Lakes at lake-wide and regional scales.

Originally developed during the late 1970's (Auer et al. 1982), *Cladophora* growth models have recently been revised to address conditions post-dreissenid invasion (Higgins et al. 2005, 2006; Tomlinson et al. 2010). Such models are useful to assess management options at local, and to some degree, lake-wide scales. However, such models require intensive sampling efforts to provide model inputs (e.g. solar insolation, water clarity, temperature, soluble phosphorus) at sufficient spatial and temporal resolution for model simulations to be meaningful. Efforts are currently underway to link *Cladophora* growth models with three-dimensional lake-wide hydrodynamic-biological models that provide the necessary environmental input data required to estimate *Cladophora* growth at moderate spatial scales (e.g. 50m x 50m). If successfully calibrated and validated, such models will be highly useful tools to advise potential management approaches to controlling *Cladophora* blooms at local, lake-wide and regional scales.

Ideally, opportunities for the testing and evaluation of candidate techniques can be integrated with ongoing monitoring and research studies with the aim of working towards more in depth monitoring of *Cladophora* distribution in the future.

#### **Comments from the author(s)**

The ability to fit *Cladophora* biomass or cover data to end points predicting adverse levels of shore fouling is a desirable attribute of an environmental indicator for *Cladophora*. The often cited value of 50 gDW m<sup>2</sup> as a threshold for transition to nuisance conditions was developed prior to colonization by dreissenid mussels and should

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be re-examined under present day conditions considering that the depth distribution of *Cladophora* is generally deeper today and that the shoreline may accumulate algae from deeper depths than in the past. A metric describing incidence of shoreline fouling based on field observation or public complaints to responsible authorities, or beach postings should be considered as a complimentary element of a *Cladophora* indicator. Notwithstanding the significance of the occurrence of *Cladophora* on the lakebed as an indicator of ecosystem condition, the overabundance of *Cladophora* is considered a water quality problem primarily due to the fouling of shoreline and beaches by detached algae.

While *Cladophora* represents the bulk of the shore fouling algae at many locations, there are additional species of benthic green algae which can occur in area affected by *Cladophora* shore fouling. Filamentous green algae of the family zgnemataceae (e.g. *Spirogyra*, *Zygnema* and *Mougeotia*) are often observed co-occurring with *Cladophora*. In parts of Lake Huron and Michigan the filamentous green algae *Chara* also contributes to fouling of shoreline. A further contributor to the organic material dominated by *Cladophora* which washes up on the shoreline is a diverse assemblage of micro algae which grow amongst and upon *Cladophora* and are more generally termed periphyton. In some cases there may be a "muck-like" appearance to beached material which is likely due to the contribution of periphyton.

### Assessing Data Quality

Insert "x" under the statement that best corresponds with each data characteristic

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X	X			
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X	X			
Clarifying Notes:						

### Acknowledgments

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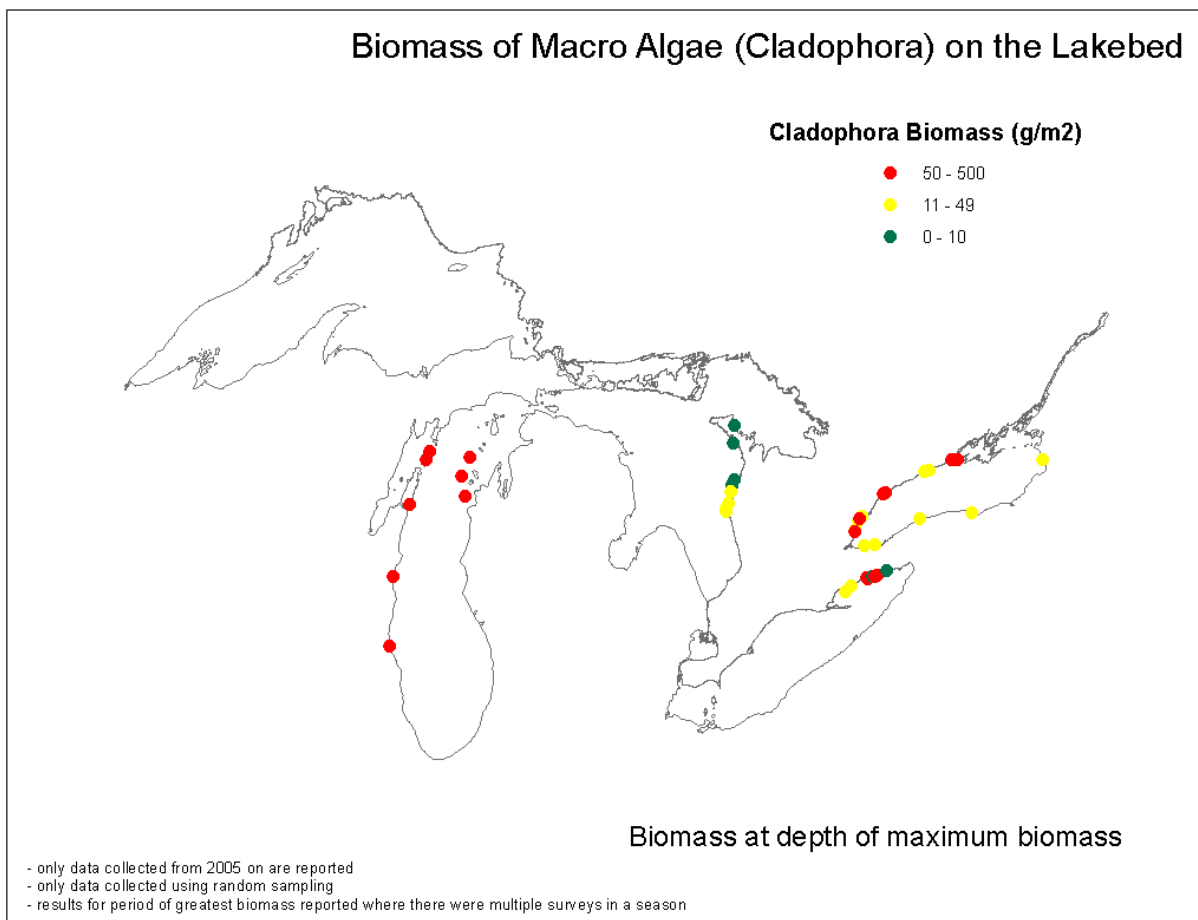
Figure 3. Locations where there have been reports of nuisance *Cladophora* since 1995. Nuisance defined broadly as including: causing fouling of shoreline and beaches, fouling of water intakes and areas reported with conspicuous presence of *Cladophora*.

Figure 4. Seasonal biomass of *Cladophora* from 2006 to 2011 in the nearshore of Lake Michigan at a site near Milwaukee. Figure provided courtesy of Harvey Bootsma, Great Lakes Water Institute, University of Wisconsin-Milwaukee.

Figure 5. Examples of Areal distribution of *Cladophora* determined by remote sensing.

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**Figure 1.** Maximum biomass levels of *Cladophora* reported for Great Lakes sites since 2005.

Source:

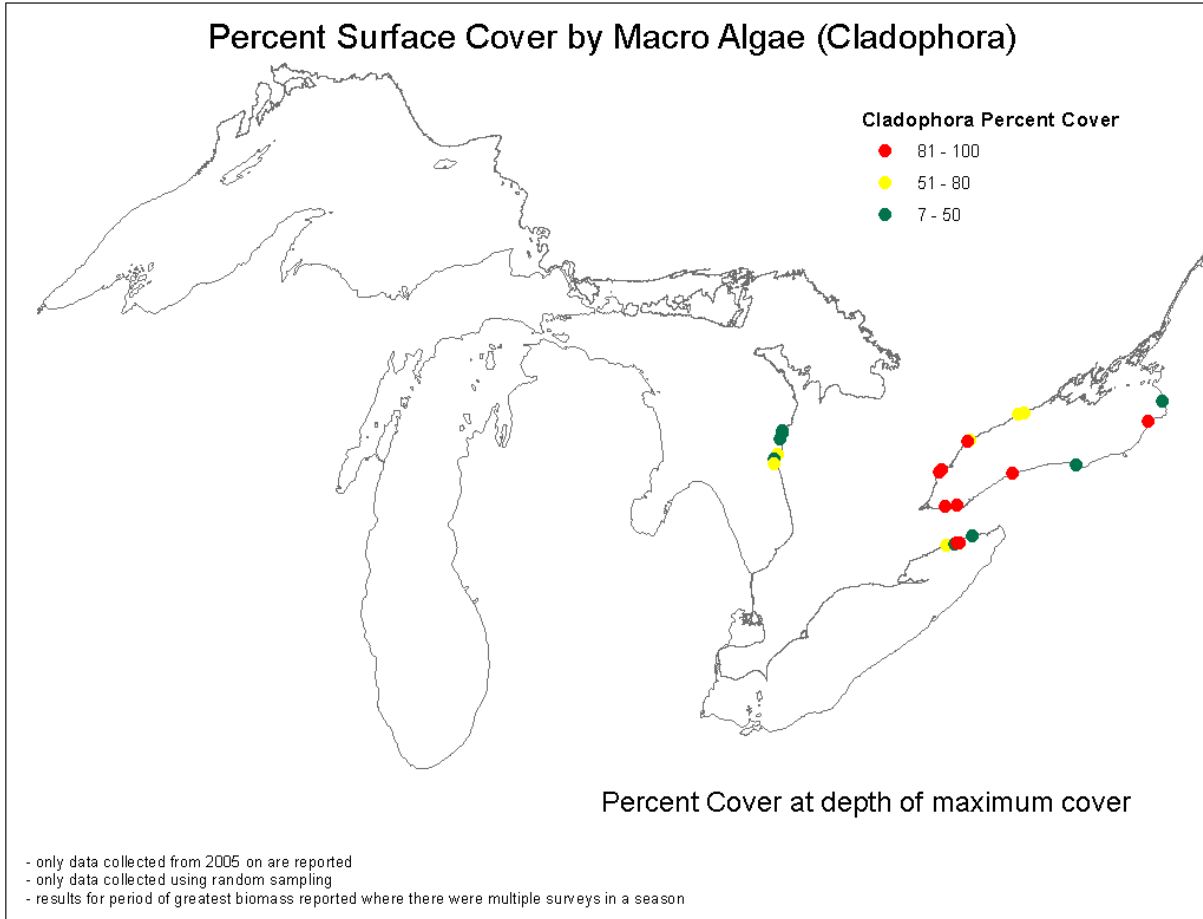
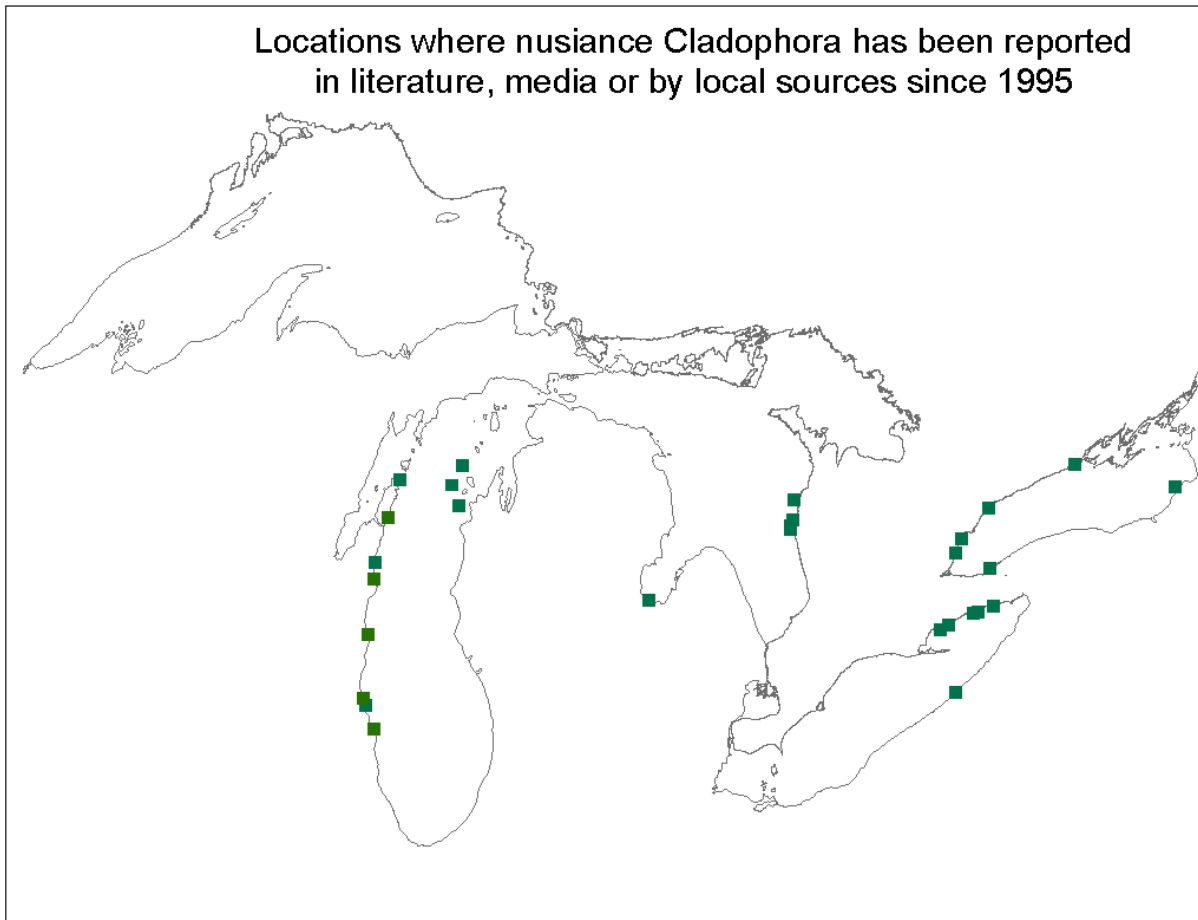


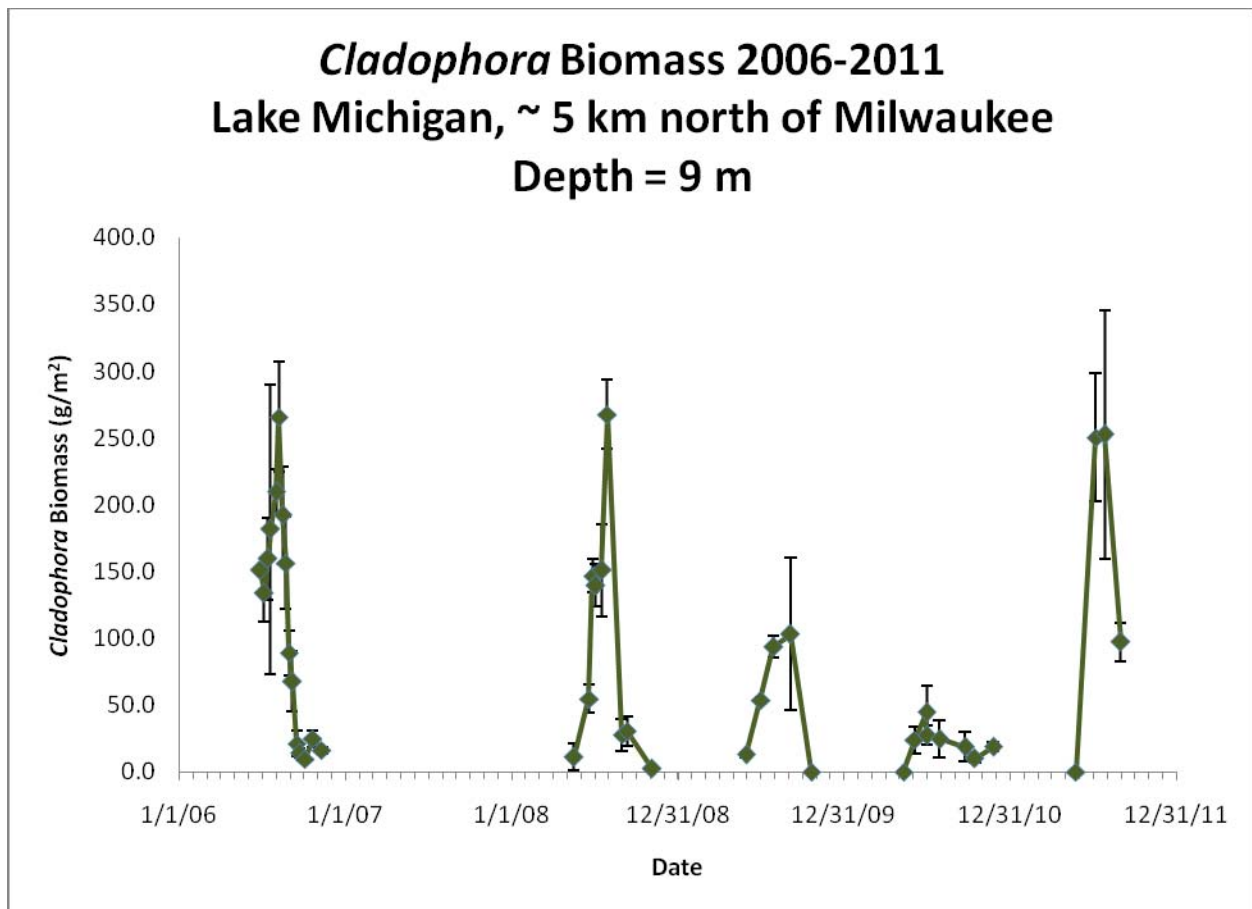
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Source:



**Figure 3.** Locations where there have been reports of nuisance *Cladophora* since 1995. Nuisance defined broadly as including: causing fouling of shoreline and beaches, fouling of water intakes and reported areas of conspicuous presence of *Cladophora*.

Source:



**Figure 4.** Seasonal biomass of *Cladophora* from 2006 to 2011 in the nearshore of Lake Michigan at a site near Milwaukee. Graph provided courtesy of Harvey Bootsma, Great Lakes Water Institute, University of Wisconsin-Milwaukee.

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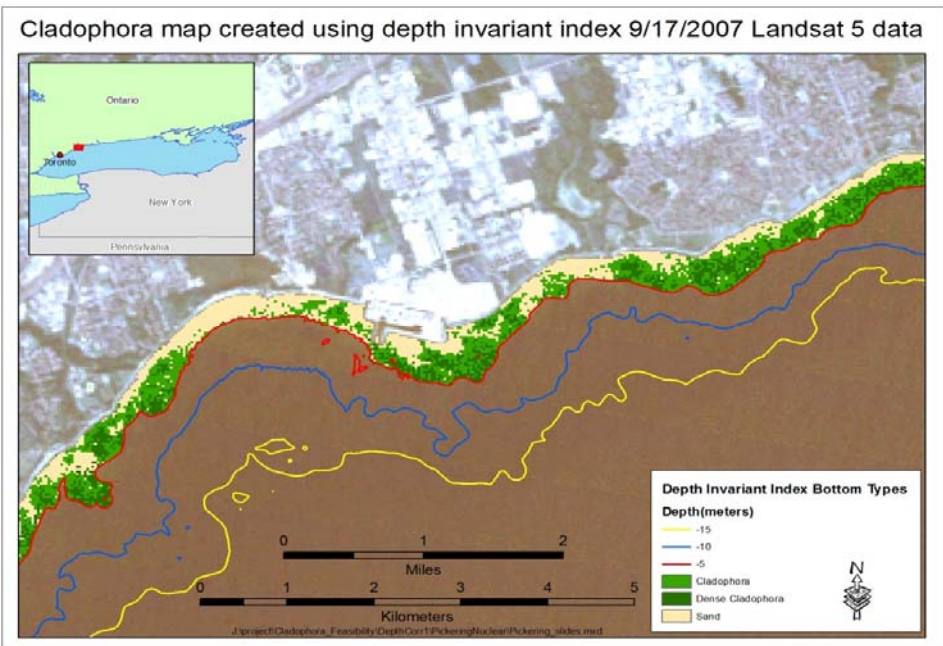
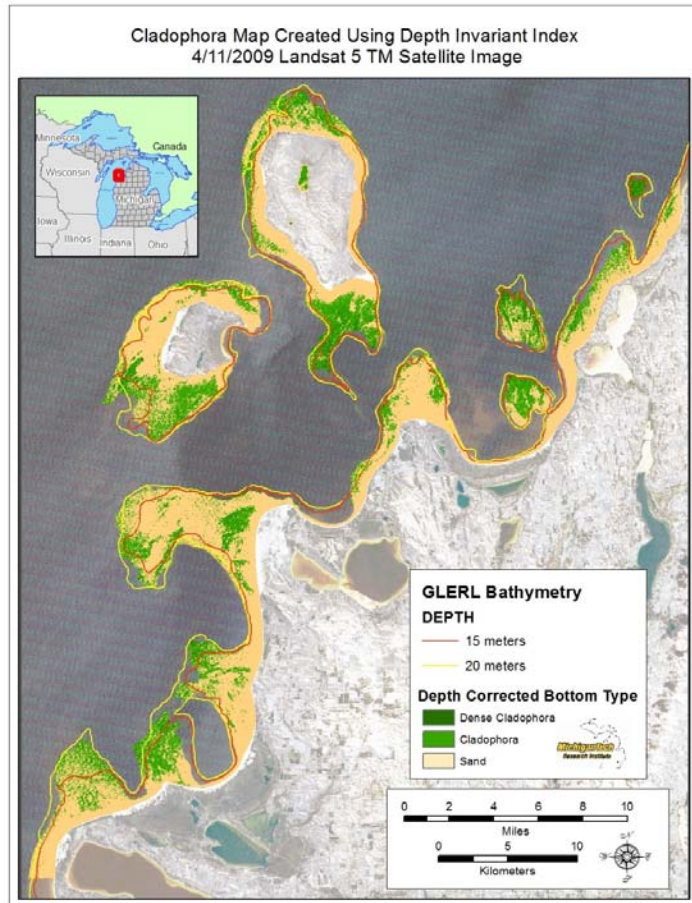


Figure 5: Distribution of *Cladophora* in NE Lake Michigan and NW Lake Ontario determined by remote sensing. Source: Images courtesy of by M. Sayers, Michigan Tech Research Institute.