State of Knowledge of *Cladophora* in the Great Lakes Workshop

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EXECUTIVE SUMMARY

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Cladophora is a large, globally-distributed genus with a broad range of ecological characteristics. The species that dominates in the Great Lakes. *Cladophora glomerata*, has a unique ecology and behaves differently than do other members of the genus in other parts of the world, and indeed even in Canadian inland lakes. It was a nuisance alga during the 'eutrophication era' that led to implementation of the previous Great Lakes Water Quality Agreement (GLWQA), and nutrient control largely resulted in its minimization as a concern. However, *Cladophora*'s prevalence and biomass have increased steadily through the last decade in concert with the reappearance of other signs of eutrophication in Lake Erie and in correlation with the establishment and spread of dreissenids through Great Lakes.

The Annex 4 of the 2012 GLWQA is charged with developing guidelines for limiting nutrient releases in the Great Lakes (initially to Lake Erie) to an extent that will prevent the development of Harmful Algal Blooms, reduce the extent of central basin hypoxia, and control the development of nuisance algae (*Cladophora*). An implementation plan for reducing phosphorus inputs to Lake Erie is due by 2018. Although phosphorus load reduction targets have been developed and approved for Lake Erie, which are expected to control algal blooms and hypoxia, no recommendations have yet been made with regard to *Cladophora* because important research and modeling is in progress. Although *Cladophora* assessment is of concern, there is no coordinated or standard strategy for determining its distribution or extent. There is also a difference between determining areas of *Cladophora* growth and predicting where it will become a problem from stakeholders' perspectives. *Cladophora* assessment will be an important aspect of the Nearshore Framework (Annex 2) and the Baseline Assessment (Annex 7; Habitat and Species) initiatives under the GLWQA. *Cladophora* as a cause of beach fouling is a concern to the Lake-wide Management Plan (LAMP) partnerships of lakes Ontario, Erie, Huron and Michigan. Further, the Nearshore Assessment of Annex 2 of the GLWQA has been charged with assessing the condition of nearshore habitat, which is expected to include an assessment of *Cladophora*.

The GLWQA (Annex 10) has a responsibility to undertake a review of scientific information for management actions and policy development. Therefore, a workshop was convened by the Annex 10 (Science) and facilitated by the Lake Erie Millennium Network to determine the state of knowledge of *Cladophora* from the perspectives of the entire Great Lakes basin, from that of individual lakes, and with respect to areas within each lake where *Cladophora* is perceived to be a significant local problem. It was hoped that findings of the workshop would help guide a strategy for proposing nutrient reduction targets that will control *Cladophora*.

The workshop was organized into 4 modules relating to policy needs (discussed above), current monitoring efforts and needs, the state of modeling to predict the distribution and abundance of *Cladophora*, and the understanding of *Cladophora*'s biology.

<u>Monitoring Efforts and Needs</u>

Representatives from Environment Canada, US EPA GLNPO and the Ontario Ministry of Environment and Climate Change summarized the historical and current distribution of *Cladophora* and other Nuisance Benthic Algae (NBA) in the Great Lakes, the status of monitoring for *Cladophora*, and their perception of monitoring needs. In open discussion, other monitoring needs and possible approaches were identified.

The key manifestation of *Cladophora* and NBA is beach fouling (seen and reported by the public as 'beach muck'). The decomposing material is unsightly, creates odour problems, provides breeding sites for biting flies, and incubates microbes such as *E. coli* and the bacterium responsible for botulism in wildlife.

Cladophora production is greatest where water is shallow, clear, nutrient-enriched and has hard substrate, to which the algae attaches. Dreissenid mussels are believed to stimulate *Cladophora* production by capturing particles and releasing the particles' nutrients in soluble form, providing substrate for attachment, and increasing water clarity and the amount of sunlight reaching the lake bottom.

*Cladophor*a is a nuisance in much of Lake Ontario, on the north shore of Lake Erie's eastern basin, locally in portions of Lake Huron, and more extensively in Lake Michigan. It does not appear to be a nuisance in Lake Superior.

The Biodiversity Conservation Strategies of lakes Erie, Michigan and Ontario all identify *Cladophora* standing crop measures as indicators of ecosystem condition. Generally, mid-summer *Cladophora* maximum dry mass prior to seasonal senescence of less than 30-50 g/m^2 are thought to be indicative of 'good' conditions.

Current Monitoring Efforts: Collaborative Great Lakes monitoring is undertaken at the basin-wide level through a partnership between the US EPA and Environment Canada under the Great Lakes Water Quality Agreement as amended in 2012 (GLWQA), and is largely coordinated through the Cooperative Science and Monitoring Initiative (CSMI). In addition, the LAMPs identify monitoring needs in accordance with their management plans. Provincial and state monitoring programs also address coastal conditions. Both Canada and the US have nationally-funded agencies and programs that undertake program-directed monitoring.

The US EPA's National Coastal Condition Assessment has collected data from the US side of the Great Lakes in 2010 and 2015, which may be informative in this regard.

The LAMPs do not have dedicated monitoring programs for assessing *Cladophora* or Nuisance Benthic Algae (NBA – a generic term designed to refer to pertain to all forms of filamentous or macrophytic benthic vegetation). In lakes where it is considered to be a local problem, several individual monitoring efforts have been undertaken. Although they have varied in terms of methods, temporal frequency, period of record and security of funding, they have assessed distribution and biomass in nearshore waters to depths of up to 20 m.

Neither Environment Canada nor US EPA GLNPO currently have dedicated monitoring programs to assess *Cladophora*. Environment Canada has been researching *Cladophora* and its association with nutrient concentrations though its Great Lakes Nutrients Initiative and as part of its routine surveillance program, and in partnership with provincial initiatives. Similarly, EPA GLNPO is collaborating with other national agencies (USGS, NOAA) to better understand the problem.

Lake Ontario: The Lake Ontario LAMP is interested in *Cladophora* dynamics and will soon be asked to establish nutrient targets that will control *Cladophora* in the nearshore under Annex 4 of the GLWQA. *Cladophora* was first reported as a nuisance in 1914, but became a significant and widespread problem in the 1930s-1950s as phosphorus was introduced into detergents. Legislation introduced in the 1970s to reduce to Great Lakes phosphorus loadings resulted in improved conditions by the 1980s. However, the extent of reports of nuisance *Cladophora* has been increasing since the 1990s. Currently, 40% of the Lake Ontario shoreline is affected by nuisance levels, reflecting increasing water clarity and possibly an influence of altered nutrient concentrations. Although there is no dedicated monitoring program to assess *Cladophora* in Lake Ontario, the New York State Department of Environmental Conservation in partnership with US EPA began a program to monitor nutrients and *Cladophora* biomass at multiple US locations in 2015. Monitoring is expected to continue in future years.

In Ontario, *Cladophora* and nutrients are monitored by the MOEE as well as by various Conservation Authorities. However, there is no dedicated monitoring program. Water quality and Nuisance Benthic Algae (NBA) are monitored as needed and as possible. Although Lake Ontario's ambient water is classified as oligotrophic, phosphorus concentrations are elevated near many Canadian wastewater treatment plant outfalls. Extensive cover of NBA occurs in shallow water wherever there is sufficient light and suitable substrate. Biomass is maximum at depths of 3-6 m (80-140 g/m^2), but growth can occur as deep as 20 m.

Lake Erie: Lake Erie has considerable suitable substrate that is suitable for *Cladophora* growth and sufficient nutrients to promote high biomass. Existing research indicates that *Cladophora* blooms in eastern Lake Erie are not a result of point sources, but of basinwide SRP concentrations (especially in spring (Higgins et al.). However, waters from Canadian eastern basin tributaries are enriched to the extent that there is also moderate potential for a direct human influence on *Cladophora* growth at shorelines in the eastern basin.

Thick, dense growths of *Cladophora* develop at the shoreline in depths of 0.5-2 m at high density/biomass (up to 700 g DW/m^2). There are no benthic algae surveys for the central and western basins, but there is little evidence of *Cladophora* or NBA fouling along shorelines in these parts of Lake Erie. *Cladophora* is not much of a benthic algal problem in central basin shoreline areas, or much of one in the western basin. Nevertheless, a remote sensing survey of Submerged Aquatic Vegetation (SAV) estimated that 30% of Lake Erie's shoreline was affected by SAV. Additionally, *Lyngbya wollei* can become locally abundant at times.

Lake Huron: Three forms of Nuisance Benthic Algae contribute to fouling in Canadian waters of Lake Huron. *Cladophora* occurs at some locations shorelines, associated with areas of local nutrient inputs; *Chara* fouling occurs at depths of 2-3 m, but the causes are unknown. Deepwater periphyton (up to 8 g DW/m^2 of turf algae, containing small quantities of *Cladophora*) has been observed by divers and with video reconnaissance at depths of up to 20 m. Very little *Cladophora* is evident on the rocky substrate in most of Georgian Bay. *Cladophora* grows extensively in shallow areas of Saginaw Bay as do other nuisance algae including *Spirogyra* and *Chara*. All of these algae, their associated periphyton, and macrophytes have been documented to contribute to the beach muck problem in some areas along Saginaw Bay.

Extensive studies of the Lake Huron food web undertaken by the Lake Huron Binational Partnership in 2012 observed significant, strong benthification of the lower portion of the food web. Nutrient loadings were reported as being low or declining, but shoreline fouling on US coasts of Lake Huron is being reported in places with little urban development or agricultural load. Approximately 15% of Lake Huron's shoreline was estimated by remote sensing to be affected by nuisance levels of submerged aquatic vegetation. Offshore waters are becoming ultra-oligotrophic. Although no specific lakewide monitoring is being undertaken, it is thought that *Cladophora* is growing in the nearshore and sloughing. However, the fate of that biomass is largely unknown.

Lake Michigan: No coordinated monitoring has been directly undertaken for the entirety of Lake Michigan. However, extensive monitoring has been carried out since 2006 in selected locations for areas near Milwaukee, Green Bay and near Manitou Islands/Sleeping Bear Dunes areas. A remote sensing survey (Brooks et al. 2015) estimated that 28% of Lake Michigan's shoreline was affected by SAV.

Monitoring needs: Information on factors regulating *Cladophora* as a nuisance alga is needed to allow nutrient loading targets to be recommended and implemented under Annex 4 of the Great Lakes Water Quality Agreement. Insufficient research has been conducted to date to allow targets to be set.

The Lake Erie, Lake Michigan and Lake Ontario LAMPS all identify a need to monitor and research *Cladophora* to determine the extent to which nuisance blooms are linked to agricultural activity and runoff from urban watersheds.

The Biodiversity Conservation Strategies of lakes Erie, Michigan and Ontario all identify *Cladophora* standing crop measures as indicators of ecosystem condition. Generally, latesummer dry mass of *Cladophora* <30 g dry mass/m^2 are thought to be indicative of 'good' conditions. However, meeting participants did not specifically discuss or endorse this criterion. The complexity of interactions among the factors influencing *Cladophora* growth, biomass, and extent is so great that several researchers called for identification of a number of 'sentinel' sites at which intensive monitoring would take place to measure all of the variables needed to calibrate hydrodynamic, nutrient dynamic and *Cladophora* growth models. The program could be designed at a technical planning workshop to ensure that all key parameters and standardized methods and analyses are identified. Extensive data sets already exist for a number of Great Lakes sites (e.g., Green Bay, Milwaukee, northeastern Lake Erie, northwestern Lake Ontario).

Research and Monitoring Needs Identified During Open Discussion

Monitoring is needed both to delineate the spatial extent of concerns and to help researchers and modelers better understand the changes that are occurring. All presenters agreed on the need for developing shared protocols, common goals, and common metrics so the data can be used together. There was also recognition that "*Cladophora*" is sometimes used as a catch-all term for benthic vegetation. In fact, other forms of filamentous algae and aquatic plants (turf algae, *Chara*, *Lyngbya*, *Spirogyra*, etc.) are often locally present or dominant. A more appropriate generic term is **Nuisance Benthic Algae** (NBA). While models are available to describe *Cladophora* growth dynamics, no comparable models are currently available for these other NBA.

There is a need to better understand the interaction between *Cladophora* and dreissenid mussels. The patterns in Saginaw Bay pose some challenging questions, where *Cladophora* is becoming more prevalent despite dreissenid densities being low. This pattern is seen elsewhere in Lake Huron, too. Because of the very large size range of dreissenids, density *per se* is a poor predictor. Biomass or filtration capacity are more informative drivers of water clarity. Furthermore, the role of dreissenids in SRP enrichment of the near-bed boundary layer and its effect on *Cladophora* growth needs clarification. Investigations of internal recycling through microbial activity should also be conducted.

Our ability to predict summer *Cladophora* blooms from spring nutrient conditions is limited, but spring pulses of nutrients, either from tributaries or from the open water may stimulate rapid spring development of the thallus, leading to luxuriant summer growth under suitable summer conditions (warm, clear water, and adequate nutrients). One of the predictors of short term growth in an area is to estimate *Cladophora* tissue phosphorus content collected from a depth of 2-5 m. However, the federal vessels responsible for lakewide routine monitoring and surveillance cannot sail in water this shallow. Shoreline surveys of conditions at depths of 2-10 m require availability of smaller vessels that can easily be towed and launched from local boat ramps. Some combination of rapid-travel synoptic sampling (providing ground-truthing) and remote sensing may be one approach to assess growth potential. However, a trade-off must be made between areal coverage and intensity of sampling at specific locations.

Additionally, it is not clear if *Cladophora* growth and biomass estimates are effective predictors of beach fouling on nearby shorelines. There is only a limited correlation between the development of *Cladophora* in the nearshore zone and its presence on beaches and other coastlines as 'muck'. Even in the water, biomass *per se* is probably not the best indicator of the potential for sloughing. Instead, some measure of production is thought to have more potential. The total phosphorus content of a sample of material collected at depth of 2-5 m provides an estimate of growth potential integrated over the past 1-2 weeks. *Cladophora* with a low content (<0.07 µg /mg dry mass) is unproductive, whereas material with high content (>0.2 µg/mg dry mass) will likely be highly productive and will generate significant biomass that can slough and wash up on shore. There is also a need for better understanding of how maximum seasonal biomass links to hydrodynamics, including long-shore transport.

A better definition is needed of what constitutes 'beach muck' as well as how to quantify it. Beach muck can be ephemeral and highly dependent on changing currents and weather conditions. *Cladophora* surveys are needed to comply with the Beach Act. However, assessment methods are currently semi-quantitative. Furthermore, *Cladophora* abundance is an optional variable in the US national database of beach condition. It is reported as 'algae'. It would be very helpful if a *Cladophora* monitoring handbook could be developed for use by local watershed groups, Tribes and agencies, as well as guidelines for Best Management Practices. It could include descriptions of *Cladophora* and other potentially dominant species. *Cladophora* researchers and modeling experts who can speak in simple terminology can effectively explain the relationships and help managers understand the relationships and uncertainties.

There is an expectation that a monitoring program for *Cladophora* must fulfil two different roles, each of which requires different emphasis. One approach is to estimate biomass across broad spatial areas with a suitable spatially-delimited design, supplement this information with remote sensing data to document distribution, and interpolate the basin-wide distribution and abundance. A second approach is to focus intense monitoring at a number of key 'sentinel sites' that can both provide trend estimates of biomass and allow measurements of the key parameters and dynamic processes needed to model *Cladophora* growth. The refined growth model and estimated parameters can then be used to predict the basin-wide distribution and abundance. The challenge will be to find a combined program that adequately addresses the needs of parameterizing models and providing the distributional data necessary to both validate the predictions and report on the status of *Cladophora* in order to assess the effectiveness of adaptive management actions.

Modeling: Five modeling presentations were given to summarize the on-going work and recent findings derived from several models as applied to lakes Ontario, Erie, Huron and Michigan. Predictions and the spatial resolution of the existing *Cladophora* models have benefitted greatly from the availability of simulated data provided by new physical models that can estimate how nutrients are delivered by currents and how temperature varies within the Great Lakes. This generated optimism that we can start to make some meaningful predictions about *Cladophora* growth for local, regional, and lake-wide areas and to assess how key parameters can be expected to modify growth.

The best measure of *Cladophora* health is thought to be phosphorus concentration within the plant tissues rather than biomass. The key parameters recognized to control *Cladophora* distribution and growth are phosphorus (soluble reactive phosphorus), light reaching the substrate (a combination of light at the water surface and the attenuation rate, which is variously influenced by phytoplankton primary production, dreissenid filtering, turbulence-induced resuspension, and delivery of sediments from tributaries), characteristics of the lake bottom (hard substrate is required), temperature (which regulates both the growth rate of *Cladophora* and the filtering activity of dreissenid mussels), and water depth. Dreissenids and hydrodynamics are modulators, in that they control the clarity of water and the transport or availability of phosphorus. There was consensus among the modelers that increased model resolution and intensive, detailed monitoring is needed to understand the complete picture at dedicated monitoring sites. This would complement the collection of key data across the lakes.

Biology: Presentations related to understanding the growth, distribution and senescence of *Cladophora* summarized new information but reinforced the complexity of the interactions. Senescence is perhaps the most poorly understood aspect of the *Cladophora* life cycle. Although temperature is a factor, growth experiments have demonstrated optimal growth at temperatures well above what is found *in situ* when the filaments begin to senesce. Senescence may relate to net respiration of cells at the base of the *Cladophora* mats (under low light, high temperature) scenarios, programmed cell death, or some combination of factors yet to be explained.

Dreissenids seem to play an important role in facilitating *Cladophora* development, perhaps especially early in the growing season. They package the nutrients that are delivered by the currents (either as SRP or perhaps packaged within offshore-derived phytoplankton). Warm spring temperatures can significantly influence the rate of growth and result in high summer biomass. But other features, such as turbidity and storm actions can all make prediction more challenging. Dreissenid densities have been declining in lakes Erie and Huron despite a perception that they are an important regulator of *Cladophora* growth and distribution. Dreissenid densities and biomass continue to increase in the deepest waters of northern Lake Michigan. Nevertheless, new remote sensing technology offers promise for developing better maps of distribution. Still, multiple approaches are needed, including shoreline cruises to assess biomass and direct samples to assess nutrient concentration of the tissues.

Synthesis and Recommendations

Group discussions on the final day of the workshop have provided important direction for the next steps to be taken. There was optimism that our use of new modeling tools, improved monitoring and new information on factors regulating growth will allow us to make predictions on how nutrient management may influence *Cladophora* growth and distribution in some nearshore habitats.

Modeling Recommendations: Based upon the modeling presentations, general discussions, and breakout sessions, the following summary statements and provisional recommendations were made for advancing and enhancing models to reduce uncertainties:

- Continue water quality model framework coupling and linking efforts, to the Great Lakes *Cladophora* Model and *Cladophora* Growth Model
- Continue to develop both lake-wide and high-resolution nearshore models
- Increase lake-wide, regional, and local model resolution by moving to unstructured or nested grid models increased resolution in the nearshore zones where Cladophora is known to be an issue.
- Develop an explicit benthic boundary layer in models that can characterize and quantify microscale nutrient gradients, biodeposits, and nutrient cycling and exchange by dreissenid mussels, related to *Cladophora.*
- Develop approaches to reliably estimate nearshore water clarity based on sediment type, shoreline orientation, wind direction and speed, and tributary discharges.
- Enhance model sloughing algorithms for timing and temperature and integrate predictions with transport and fate modules to forecast the deposition of *Cladophora* on beaches.
- Using enhanced models, forecast the phosphorus load and concentration required to reduce *Cladophora* biomass to acceptable levels.
- Develop approaches (including field validation) to estimate the accuracy and predictive uncertainty associated with these models.

Monitoring Recommendations: In addition to specific advancements, the presentations and discussions yielded several summary statements for enhancing research and monitoring in support of model development and calibration, including:

- Establish sentinel time-series concurrent sampling of multiple constituents over a growing season preferably at bi-weekly intervals at least one reference site and one impacted site per lake for each of the Great Lakes except Lake Superior. Measurement of routine and customary parameters in addition to enhanced-information parameters are suggested.
- Develop a binational, coordinated *Cladophora* surveillance program that includes *in situ* monitoring and remote sensing validated by ground-truthing.

Priority Parameters needed to improve modeling precision and capacity: The highest-priority parameters that must be measured to enhance the models' effectiveness are

- stored phosphorus (tissue concentrations)
- *Cladophora* biomass
- Light extinction coefficients and surrogate variables (e.g., turbidity, total suspended solids)
- Concentrations of bioavailable phosphorus and
- Water temperature

Other important variables are

- Dreissenid biomass
- Temperature structure (Seasonal, diel and vertical profiles)
- Hydrodynamics, primary production,
- Area of suitable substrate
- Biomass of other associated NBA

Other needs: Critical ancillary activities that should be undertaken to support the development of *Cladophora* assessment, reporting and tracking programs include (but are not limited to):

- Support the development and calculation of nutrient loads from tributaries
- Research to better define microscale nutrient layering and nutrient recycling in the benthic boundary layer related to dreissenids.
- Develop a standard measurement of in-lake *Cladophora* (or NBA) biomass.
- Develop a standard measurement of *Cladophora* (or 'beach muck) biomass on the shoreline.
- Develop a standard measurement and timing for estimating phosphorus storage (tissue concentration) in *Cladophora* (or NBA)

Candidate Options for Annex 4 Regarding Nutrient Loading Targets to Control Cladophora *in eastern Lake Erie:* In general discussion, individuals identified a full range of potential options that could be adopted by the Annex 4 (Nutrients) subcommittee for *Cladophora* in the eastern basin of Lake Erie Eastern Basin, ranging from 'take no action because insufficient information presently exists' to 'base recommendations on strict precautionary principles'. The following suggestions were made. Further discussion and review by a panel of experts is necessary to evaluate and prioritize the options.

- Current empirical data and modeling predictions lack sufficient precision to generate consensus among modelers; defer making recommendations until more information becomes available
- Until recommended targets are in place apply the adaptive management process and adjust nutrient loads in relation to observed status and trends
- Conclude that the only available management control option is phosphorus reduction; one cannot alter light, temperature, substrate, and/or dreissenid biomass
- Reconcile different modeling results upon which to set loading and concentration targets (adjust target expectations to achieve a specific range that is deemed to be acceptable (presently 30-50 g dry mass/m^2 ; ** to ** g dry mass/m^2); convene a small, expert panel to review existing data and recommend appropriate, theoretically achievable values;
- Set water concentration targets based on modeled and empirical data: 1 µg/L SRP and 6 µg/L Total P for nearshore areas
- Convene a small expert panel to consider the value of recommending a 40% reduction in Total Phosphorus load for all tributaries on the northern shore of Lake Erie
- Convene a small expert panel to consider the value of recommending a 40% reduction in Total Phosphorus load for all wastewater treatment plants discharging to the northern shore of Lake Erie