

Causes, Consequences and Management of Nuisance *Cladophora*

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by

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Cover Photos: Top: *Cladophora* accumulation on Bradford Beach, Milwaukee; Center: *Cladophora* at a depth of 9 meters in Lake Michigan; Bottom: Quagga mussels in spring, with early *Cladophora* growth.

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Executive Summary

This report contains the results of a study to determine causes of, and potential management options for, excessive growth of the filamentous green algae, *Cladophora* sp., in Lake Michigan. The problem was approached through a combination of *in situ* measurements in the lake, laboratory experiments, and numerical models. *In situ* data were used to validate a *Cladophora* model for Lake Michigan, and a graphical user interface was developed which allows for simple data entry and manipulation of the model to test management scenarios. The model simulate *Cladophora* growth, tissue phosphorus content, and biomass on a daily basis using measurements of temperature, irradiance and soluble reactive phosphorus concentration as inputs. The validated model was used with historic (pre-mussel) and recent data to determine how changes in light, temperature and dissolved phosphorus may have influenced *Cladophora* growth and biomass in Lake Michigan. The model indicates that increased nearshore dissolved phosphorus concentration is partly responsible for increased algal abundance, but the most important factor has been the increase in water clarity resulting from filter feeding by zebra and quagga mussels. Increased clarity has resulted in increased light intensities on the lake bottom, allowing for more *Cladophora* growth at shallow depths and for a 2-fold increase in the depth range of *Cladophora*, from a maximum depth of about 5 m prior to the mussel invasion to a current maximum depth of 11 to 12 m. It is this depth extension that is primarily responsible for increased algal biomass per unit of shoreline.

In addition to assessing the factors that influence *Cladophora* growth and biomass, this study included the development of an empirical quagga mussel (*Dreissena bugensis*) model that simulates soluble reactive phosphorus (SRP) excretion by mussels as a function of water temperature, mussel size, and food concentration (the model focuses on the quagga mussel because this species has now largely replaced the zebra mussel, *Dreissena polymorpha*, in Lake Michigan). Laboratory and field studies indicate that soluble reactive phosphorus (SRP) excretion by quagga mussels depends both on food supply and water temperature, with excretion rates rapidly increasing when temperature exceeds 12°C (59°F). As a result, moderate increases in summer nearshore temperatures may result in large increases in P excretion by mussels. The mussel P excretion model was used, along with data on mussel size distribution, mussel densities, and nearshore distribution, to estimate the P loading to the Lake Michigan nearshore zone resulting from mussel metabolism. For the Wind Point to Fox Point stretch of shoreline, it is estimated that during the *Cladophora* growing season mussels excrete SRP at a rate more than 4 times greater than the loading rate from the mouth of the Milwaukee River. Therefore, efforts to control *Cladophora* growth through the reduction of nearshore P concentrations must consider reducing the availability of food for mussels. This food is provided both as particulate material that enters the lake directly from rivers, and as plankton which grows in offshore waters and is mixed into the nearshore zone. The relative importance of these two pathways is not yet known, but it will determine the rate at which phosphorus concentrations and *Cladophora* biomass in the nearshore zone respond to any decrease in phosphorus load.

Although increased water clarity is the primary cause of increased *Cladophora* abundance, the only practical management option is to reduce in-lake dissolved phosphorus concentrations. In moderate to high-nutrient areas (i.e. where SRP concentrations are frequently greater than $1.0 \mu\text{g L}^{-1}$), such as nearshore areas close to river mouths, a 50% decrease in soluble reactive phosphorus concentrations will likely result in modest *Cladophora* biomass reductions of 25% or less, because when temperature and light conditions are optimal, *Cladophora* can grow at relatively low dissolved phosphorus concentrations. In nearshore areas where soluble reactive phosphorus concentrations are already low (less than $1 \mu\text{g L}^{-1}$), a 50% decrease may result in *Cladophora* biomass reductions of as much as 74%, depending on depth, with greater proportional reductions occurring at deeper depths. However, when setting phosphorus management objectives, it must be remembered that *Cladophora* growth responds to dissolved phosphorus concentrations in a depth zone of 5 to 15 cm above the benthos, and concentrations within this bottom layer may not reflect those in the overlying water column. For the purpose of *Cladophora* management, *Cladophora* P content and near-bottom dissolved P concentration, rather than water column SRP concentration, may be more relevant variables to use for monitoring programs and for setting management targets.

Because many of the obvious steps to reduce phosphorus loads have already been taken over the past three decades, further reductions will be a challenge. Agricultural sources can best be managed by focusing on “hot spots” where phosphorus concentrations are high and/or runoff and erosion are excessive. For urban centers there may also be significant industrial point sources of phosphorus that can be considered. Much of the phosphorus uptake by *Cladophora* occurs between May and early July, and uptake during this period can support growth for several weeks into the summer. Therefore phosphorus reduction efforts will be most effective if they focus on the April – June period. While *Cladophora* in areas near river mouths may respond quickly to any changes in river nutrient loads, large, lake-wide reductions in *Cladophora* abundance will only occur when the rate of phosphorus flow through the mussel filter feeding – excretion pathway is attenuated. This pathway is controlled by offshore plankton production and physical nearshore – offshore exchange rates, which are currently not well quantified. Because plankton production is influenced by dissolved phosphorus concentrations in offshore waters, and because these concentrations respond slowly to changing river loads, a lag time of 5 to 10 years between decreased phosphorus loads and significant *Cladophora* response can be expected.