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ABSTRACT
Zebra mussels established populations in Croton Pond, an impoundment on the Muskegon River in Michigan, between 1999 and 2000. Subsequently, declines in the filter feeding invertebrate communities downstream of the impoundment have occurred. Because of these changes, I investigated the impacts of zebra mussels on the production and downstream transport of phytoplankton in Croton Pond and the Muskegon River. Chlorophyll a concentrations were determined at multiple sites upstream, in the pond, and downstream. In addition, simulations were set up to predict algal biomass had zebra mussels not been introduced into the reservoir. Chlorophyll data indicates that the algal biomass in this portion of the river continually decreased with downstream flow. Clearance rates of zebra mussels were found to be 108 mLind.$^{-1}$hr^{-1}, immediately below Croton Dam while the incubations showed phytoplankton daily production rates to be 1.92 μgL^{-1} in the absence of zebra mussels. These data combined are a strong indication that the changes in chlorophyll a throughout the stream were a result of zebra mussel filtration. Decreased downstream transport of algal biomass may account for declines in other filter feeding invertebrate populations. In addition, zebra mussel filtering rates may directly limit the expansion of zebra mussel populations downstream due to food limitation.

Key words
zebra mussels, chlorophyll *a*, phytoplankton, Hydrolab$_{tm}$, incubations, Croton, Muskegon River

Introduction

The introduction of exotic species to the Great Lakes has caused major changes in these waters over the past twenty years. Researchers have observed changes in both vertebrate and invertebrate populations alike as a result of changes caused by these new species. Among these foreign species, zebra mussels (*Dreissena polymorpha*) have been of particular concern. Filtering rates often lead to an increase in water clarity, which is an indication that phytoplankton are being consumed at a rapid pace.

Zebra mussels are an extremely prolific nuisance species that was first discovered in the Great Lakes in June of 1988 at Lake St. Clair. Researchers believe that the species may have been introduced as early as 1986 (Griffiths et al. 1989). Since then, zebra mussels have spread throughout the entire Great Lakes region and to many waterways in the eastern United States (http://www.anr.state.vt.us 2001). The successful infiltration of zebra mussels results largely from their life and reproductive cycles. A single female can produce over a million eggs during one summer season. This rapid cycle results in millions of tiny veligers that are easily transported by the currents throughout connected bodies of water. Once connected to a substrate, these veligers grow into adult zebra mussels, which are approximately 1 inch in length. Colonies of zebra mussels can reach densities of thousands of individuals per square meter. The average lifespan of zebra mussels in North America is two to three years. Other factors, such as lack of competition, also contribute to the success of zebra mussels. Because zebra mussels are benthic filter feeders, they occupy an ecological niche previously unoccupied by any other species in the Great Lakes; therefore, there is no competition from native species and there are few natural

predators in North American freshwaters. The few that do exist pose no significant threat to the mollusk. These factors combined explain the widespread abundance of zebra mussels in the Great Lakes. Zebra mussels have great impact on phytoplankton and nutrient concentrations of the waters they occupy. Filtering rates often lead to an increase in water clarity, which is an indication that phytoplankton are being consumed at a rapid pace. Studies have shown that clearance rates of zebra mussels in North America to be as high as 516 mLind.$^{-1}$hr^{-1} (Leach 1993).

More recently, zebra mussels have begun to spread inland. Croton Pond, an impoundment on the Muskegon River in Michigan, was probably invaded in the late 1990s. By the year 2000, zebra mussel densities below Croton Dam reached 8,000 m^{-2} and an astonishing 25,000 m^{-2} by 2001. Studies have shown that since their arrival there have been dramatic changes in the invertebrate composition of the Muskegon River below Croton (Luttenton, *per.com.*). There is reason to believe that these changes are a result of lower phytoplankton biomass, a major food source for invertebrates, that is due to filtration by zebra mussels which pulls primary production into the benthos and limits the growth rate of other filter feeders through resource competition (Jack and Thorp 2003). The purpose of this study was to determine how zebra mussels are affecting the transport of phytoplankton from Croton Pond to the Muskegon River downstream from the impoundment.

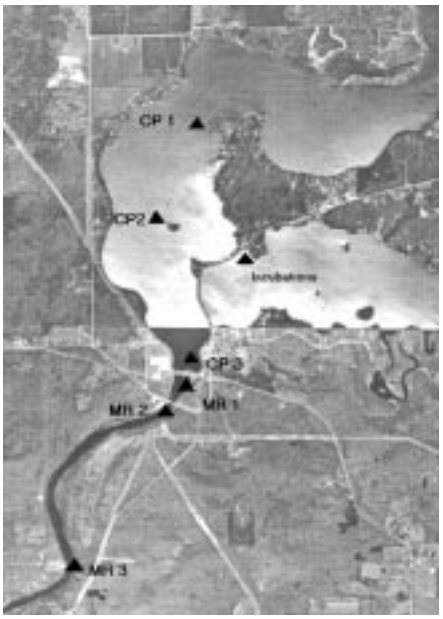

Figure 1. *Aerial map of Croton Pond, Croton, Michigan, May 1, 1993. Courtesy of the United States Geological Survey (http://terraserver-usa.com accessed: July 12, 2003). Shows six of eight sample sites as well as the incubation site.*

Methods

Sample Sites

Eight sample sites, three in the pond and five sites downstream from Croton Dam, were established for this study (Figure 1). The impoundment sites were located in the upper (CP1), middle (CP2), and lower (CP3) sections of Croton Pond (Figure 1). Riverine sites were located immediately below the dam (MR1), approximately 300 m downstream (MR2), at the Pine Street access (MR3), Thornapple access (MR4), and Newaygo access (MR5). These sites were located approximately 1.75 km, 8.75 km, and 18.0 km downstream from Croton Dam respectively (Figure 2).

Incubations were conducted in an isolated area near the middle of Croton Pond (see Figure 1). This site was chosen because it was a protected area of the pond that exhibited conditions similar to sample sites within Croton Pond.

Data Collection

A Hydrolab® was used to measure temperature, percent oxygen saturation, dissolved oxygen concentration, conductivity, total dissolved solids, pH, oxidation-reduction potential, and chlorophyll *a*. Chlorophyll *a* concentrations were used to determine the algal biomass at different points along the river. Samples were taken on four different dates from June 16, 2003 to July 14, 2003, and on each date sampling techniques were the same. Measurements were made at the surface

Figure 2. *Aerial map southwest of Croton, Michigan, May 1, 2003. Courtesy of the United States Geological Survey (http://terraserver-usa.com accessed: July 12, 2003). Shows three of eight sample sites.*

of Croton Pond because this is the water that will pass over the dam and contains all the phytoplankton that will potentially make its way downstream.

Incubations were set up to estimate the productivity of phytoplankton without filtration from zebra mussels. Two incubations were set up in the month of July 2003. For each period, four 10 L-optically-corrected bottles were filled with lake water and sealed 72.5 hours for the first incubation and 44 hours for the second incubation. After the incubation time elapsed, conditions within each of the bottles were determined using the Hydrolab®. Ambient water conditions were also determined before and after the incubations.

Figure 3. *Temperature in °C on June 16, 2003; July 9, 2003; July 12, 2003; and July 14, 2003 in the Muskegon River and Croton Pond, Michigan.*

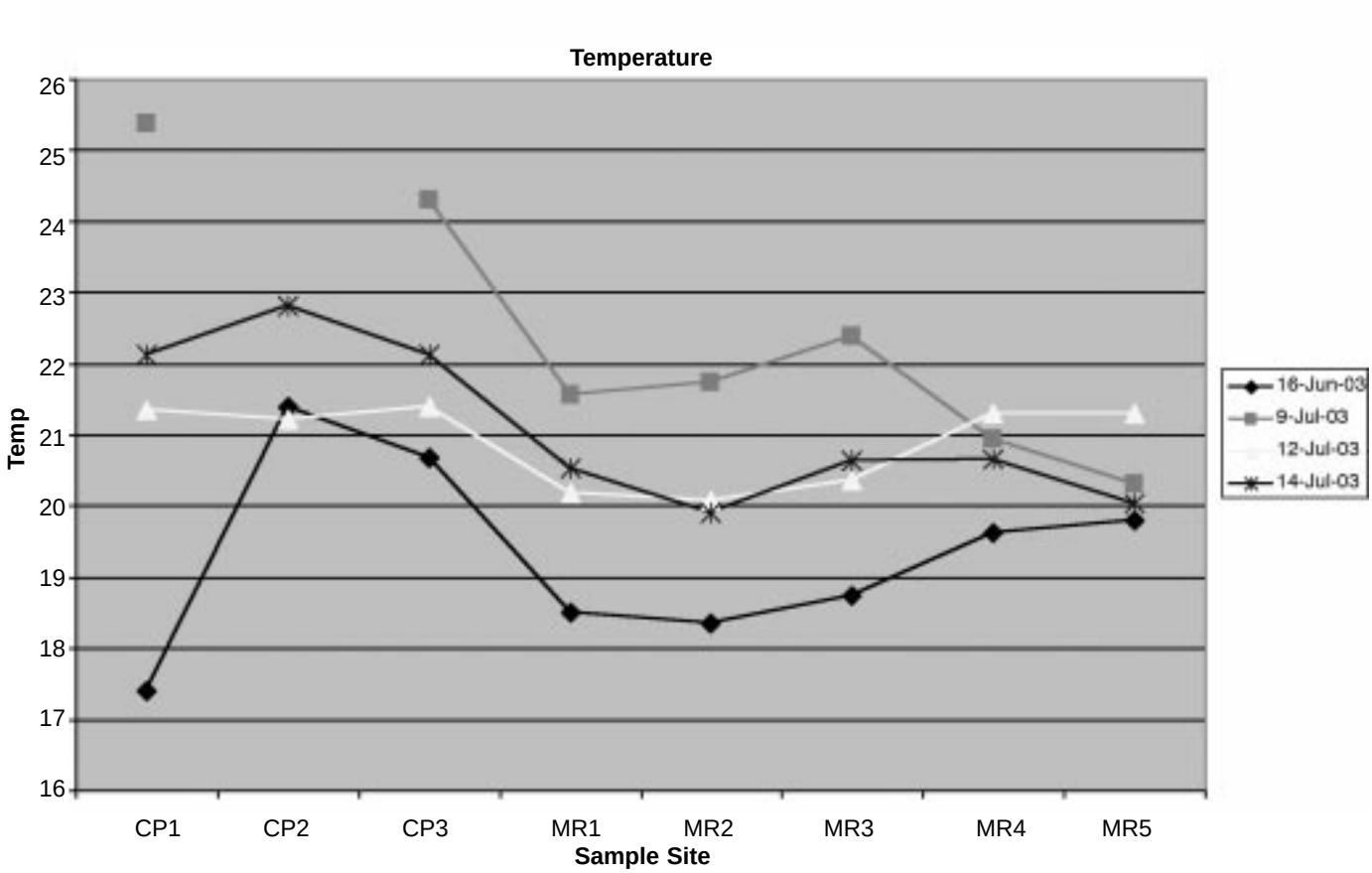

Figure 4. *Dissolved oxygen on June 16, 2003; July 9, 2003; July 12, 2003; and July 14, 2003 in the Muskegon River and Croton Pond, Michigan.*

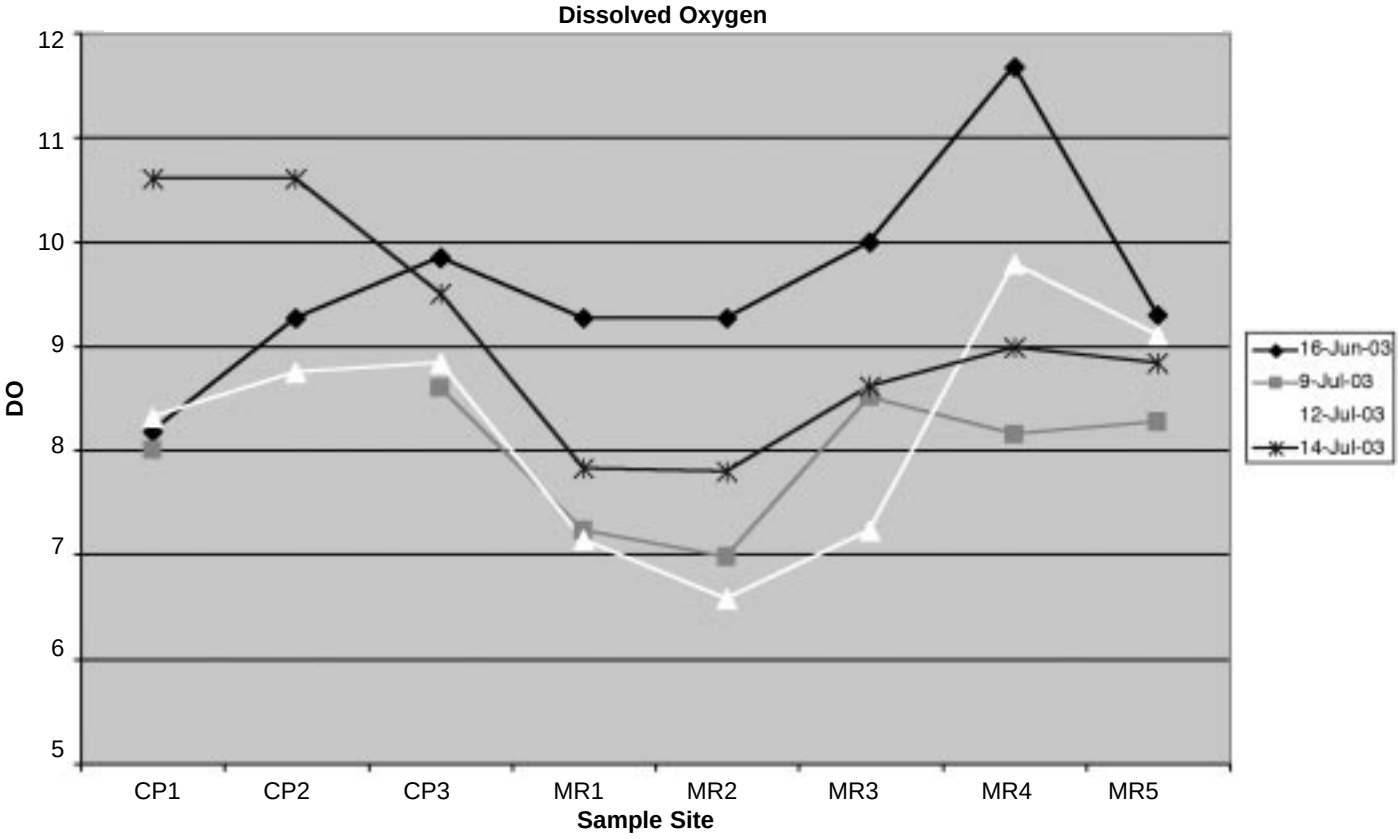

Figure 5. *Chlorophyll a on June 16, 2003; July 9, 2003; July 12, 2003; and July 14, 2003 in the Muskegon River and Croton Pond, Michigan.*

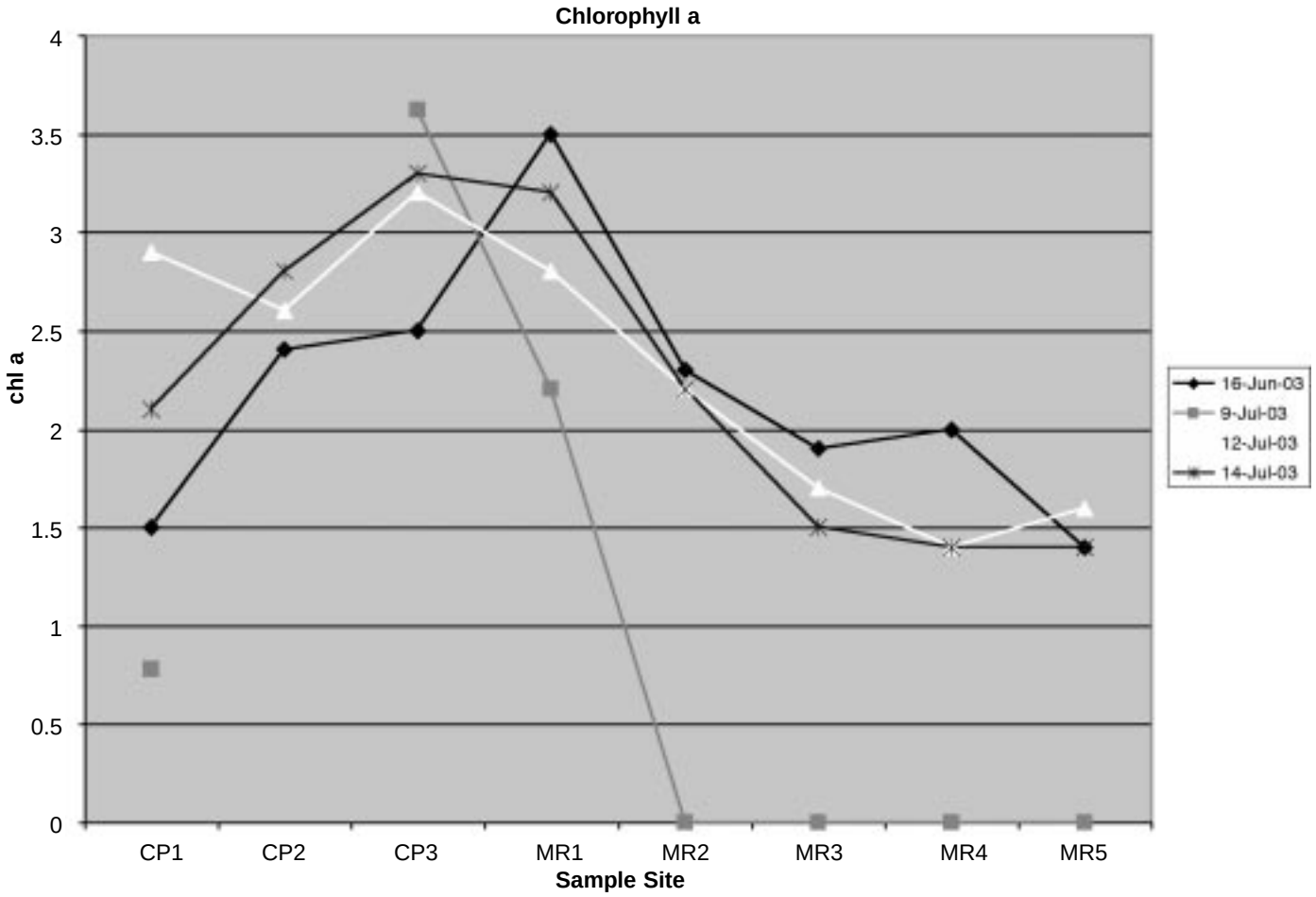

Table 1. *Hydrolab® raw data for the first incubation period from 5:00 p.m. on July 9, 2003 to 5:30 p.m. on July 12, 2003, Croton Pond, Croton, Michigan.*

Incubations Wed. 7-9-03 5:00pm thru Sat. 7-12-03 5:30pm								
	Temp	DO%	DO	SpC	TDS	pH	ORP	Chl *a*
Ambient before	21.21	98.1	8.74	355.7	0.2279	8.65	276	2.6
Ambient after	22.01	101.3	8.90	469.5	0.2229	8.67	272	3.1
Bottle 1	22.82	112.1	9.70	465.8	0.2981	9.07	235	9.8
Bottle 2	22.99	109.8	9.44	462.8	0.2964	9.10	229	6.6
Bottle 3	22.90	117.5	10.10	467.2	0.2990	9.06	221	8.5
Bottle 4	22.58	119.5	10.42	465.1	0.2978	9.12	215	10.4
Average	22.82	114.2	9.92	465.2	0.2978	9.09	225	8.8

Table 2. *Hydrolab® raw data for the second incubation period from 5:30 p.m. on July 12, 2003 to 1:30 p.m. on July 14, 2003, Croton Pond, Croton, Michigan.*

Incubations Sat. 7-12-03 5:30pm thru Mon. 7-14-03 1:30 pm								
	Temp	DO%	DO	SpC	TDS	pH	ORP	Chl a
Ambient before	22.01	101.3	8.90	469.5	0.2229	8.67	272	3.1
Ambient after	24.51	114.1	9.54	468.1	0.3002	8.87	241	3.2
Bottle 1	24.51	121.3	10.11	462.7	0.2961	8.98	242	5.5
Bottle 2	24.56	116.8	9.75	461.2	0.2952	9.03	238	7.3
Bottle 3	24.51	114.8	9.59	461.3	0.2954	9.04	238	7.5
Bottle 4	24.51	112.8	9.42	461.6	0.2956	9.02	238	6.8
Average	24.52	116.4	9.72	461.7	0.2956	9.02	239	6.8

Results

Measurements of chemical and physical variables indicated only slight variation along the river. The data of particular interest were temperature, dissolved oxygen, and chlorophyll *a*. Note that on July 9 there were no readings for middle Croton Pond due to equipment failure.

Temperature remained relatively constant throughout the river. Temperatures on June 16, ranging from 17.4°C to 21.39°C, and July 9, ranging from 20.3° to 25.38°C, had more variance from one sample site to the next than on July 12, ranging from 20.08°C to 21.38°C, and July 14, ranging from 19.97°C to 22.81°C (Figure 3). Within Croton Pond, the temperature increases from upstream Croton to middle Croton and slightly decreases at the downstream sample site. There is a larger drop in temperature as the water passes over the dam. This is probably because the surface water mixes with colder water as it passes over the dam. After that point, the temperatures tend to level off between 20°C and 21°C.

Dissolved oxygen readings varied among sample dates. June 16, the coldest sample date, had dissolved oxygen readings from 8.18 to 11.67 (Figure 4). Concentrations were lowest on July 12 ranging from 6.58 to 9.79. The data for July 9 and July 14 were intermediate between these dates. The lowest dissolved oxygen reading was 6.58.

Chlorophyll *a* had consistent trends among the sample dates. Chlorophyll *a* tended to increase within the impoundment and decrease after Croton Dam. Highest chlorophyll concentrations were at CP3 and MR1, while lowest concentrations were at MR5 (Figure 5). On July 9 chlorophyll *a* readings were 0.78 μgL^{-1} at upstream Croton, 3.62 μgL^{-1} at downstream Croton, and 2.20 μgL^{-1} just below the dam. At the next site, below Croton Street, chlorophyll *a* dropped to 0 μgL^{-1} and never picked up for the remaining sites.

The incubations showed an increase in algal biomass when the water was isolated from zebra mussel filtration. The first incubation period lasted 72.5 hours (Table 1). The ambient chlorophyll *a* reading after the incubation period was 3.1 μgL^{-1} for that period whereas the chlorophyll for the four bottles averaged 8.8 μgL^{-1}. The second incubation period lasted 44 hours (Table 2). The ambient chlorophyll after the incubation period was 3.2 μgL^{-1} and the four bottles averaged 6.8 μgL^{-1}. Ambient data for the incubation periods can be found in Tables 1 and 2.

Discussion

Changes in temperature among sample dates may explain some of the variation in dissolved oxygen data. As temperatures increase, dissolved oxygen decreases; as temperatures decrease, dissolved oxygen increases. This is because colder waters can hold more oxygen in solution. For example, on June 16, 2003, the dissolved oxygen readings were higher when the temperature readings were the lowest. The opposite is true for July 12. The temperatures were higher on this date and corresponded to the lower dissolved oxygen readings. However, the data for July 9, 2003 and July 14, 2003 do not hold true to this trend. Dissolved oxygen concentrations on these dates are higher than the readings for July 12 in spite of the fact that the temperatures were warmer. These data suggest that other factors may influence dissolved oxygen. For example, dissolved oxygen concentrations for July 9 and 14 may have resulted from the intense sunlight on those two dates. There was far more sunlight on July 9 and July 14 than on June 16 and July 12, which would increase the rate of photosynthesis. This would result in increased levels of oxygen for those days. The more constant temperatures during the later dates are possibly a result of the prolonged exposure to the summer season.

In Croton Pond, flow has been greatly reduced and this portion of the river has become more lake-like as a result. With the reduced flow, phytoplankton has the opportunity to incubate within the impoundment before it passes over the dam. Therefore, it was expected that there would be an increase in chlorophyll *a* in the pond from upstream to downstream. This was indeed the case for June 16 and July 14. Because data are missing on July 9, it is uncertain if the same trend would have been observed. However, I believe that there is a strong possibility that the trend continued because the increase was so great from the upstream Croton site to the downstream Croton site. The one exception was on July 12 when chlorophyll *a* decreased slightly from upstream Croton to the middle of Croton and then increased at the downstream Croton site. This slight decrease may have been a result of the numerous jet skis that were being used in this portion of the pond and which may have caused mortality among the phytoplankton or mixing of the water column.

The algal biomass was highest within the pond at the downstream portion for each date. Because the surface water from the downstream portion of the pond passed over the dam, it was expected that these readings would be similar to the site immediately below the dam. Although there was some variance, the chlorophyll *a* concentrations below Croton Dam were similar to the concentrations directly upstream from the dam.

From MR1 to MR5 the data suggests that zebra mussel filtration affects the transport of phytoplankton downstream.

The general trend shows that algal biomass decreases downstream from the dam. The greatest decrease for each sample date is from below Croton Dam to below Croton Street, a distance of approximately 300 m. On July 9, the chlorophyll *a* concentration fell from 2.20 μgL^{-1} to 0 μgL^{-1}, which indicates that the phytoplankton was completely filtered out of the water within this stretch. This was not very surprising for two reasons. First, July 9 was the only date that temperatures at those sites fell between 20° and 24°C, which is the optimal temperature range for zebra mussel filtration (Descy et.al. 2003). Second, this stretch supports the highest densities of zebra mussels. Based on unpublished data (Luttenton, *unpublished data*), there are 25,000 zebra mussels per m^2 in this portion of the river. Assuming this area is approximately 300 m long and the average width is 133.3 m, I estimate the total area to be 39,990m^2. Further, assuming a uniform distribution of zebra mussels, I estimate the total population to be roughly 999,750,000 individual zebra mussels in this small area of the river. Finally, assuming the water was completely filtered, it was possible to calculate the clearance rate of the zebra mussels in this area. Discharge on July 9, 2003 was found to be 1,060 ft^3s^{-1} (USGS data, http://waterdata.usgs.gov/mi/nwis). Converting the discharge to 108,057,086.59 Lhr^{-1} the filtration rate was found to be 108 $mLind.^{-1}hr^{-1}$. This value falls within clearance rates published by Reeders, et.al. (1989) who reported zebra mussel filtration to range from 78-170 $mLind.^{-1}hr^{-1}$.

Below site MR2, zebra mussel populations are very limited, yet chlorophyll *a* concentrations remain low. Furthermore, the concentrations at MR5 were lower than at sample sites upstream. Though time limited the opportunity to rule out other factors, it seems safe to say that zebra mussels are a great factor limiting the transport of phytoplankton down the river and affecting it to such an extent that it does not recover downstream of zebra mussel colonies. Turbulent mixing and physical damage to phytoplankton cells may also partially account for low chlorophyll *a* concentrations at downstream sites.

There are no data prior to zebra mussel colonization in the pond; therefore, the incubation experiment served as a tool to estimate the algal biomass in the pond if there were no zebra mussels. Because the presence of zebra mussels may have changed the composition of phytoplankton substantially, the incubation data may be a very rough estimate of what the actual chlorophyll *a* concentrations would have been. Because the two incubation periods differed in duration, I calculated production rates as $\mu L^{-1}hr^{-1}$, then converted that to an average daily production rate. The average for the first incubation period was 1.89 $\mu gL^{-1}day^{-1}$ and 1.96 $\mu gL^{-1}day^{-1}$ for the second incubation period. This indicates that without zebra mussels the phytoplankton levels could possibly increase on average an additional 1.92 $\mu gL^{-1}day^{-1}$ every day during its transport through the pond. Filtration by the zebra mussels is limiting the amount of phytoplankton produced in Croton Pond, thus greatly reducing the amount available for export downstream.

Conclusions

This study indicates that the introduction of zebra mussels into Croton Pond has influenced phytoplankton, and therefore, affected food resources for filter feeding invertebrates. First, the incubation experiments suggest that zebra mussels are filtering phytoplankton at a high rate, limiting the amount of phytoplankton that is exported over the dam. Second, the high densities of zebra mussels immediately below the dam are clearing the already low concentrations of chlorophyll *a* immediately below the dam. The continuing decrease of chlorophyll *a* as the water flows downstream is an indication that the zebra mussels are altering the phytoplankton composition to a point where it is not able to recover.

Historically, *hydropschid caddisflies* were abundant in the Muskegon River. The low algal biomass downstream may explain why there has been a loss of these filter feeding invertebrates. Without enough food, these organisms are unable to survive in these portions of the river. In addition, zebra mussels may be limiting their own spread downstream. It appears that the mollusk has reached carrying capacity within the Muskegon River. It filters out all of its own food supply, making it virtually impossible for individual mollusks to survive downstream.

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Literature Cited

Descy, J. P., E. Everbecq, V. Gosselain, L. Viroux, and S. Smitz. 2003. Modelling the impact of benthic filter-feeders on the composition and biomass of river plankton. Freshwater Biology 48:404-417

Griffiths, R. W., W. P. Kovalak, and D. W. Schloesser. 1989. The Zebra Mussel, *Dreissena polymorpha*, (Pallas 1771), in North America: Impacts on raw water users, in Symposium: Service water system problems affecting safety-related equipment. Palo Alto, California.

Jack J. D., and J. H. Thorp. 2000. Effects of the benthic suspension feeder Dreissena polymorpha on zooplankton in a large river. Freshwater Biology 44:569-579.

Leach, J. H. 1993. Impacts of the zebra mussels (*Dreissena polymorpha*) on water quality and fish spawning reefs in western Lake Erie. Pages 381-397 in T.F. Nalepa and D.W. Schloesser (editors). Zebra Mussels: Biology, impacts and controls. Lewis Publishers/CRC Press, Boca Raton, Florida.

Reeders, H. H., A. B. Van de Vaate, and F. J. Slim. 1989. The filtration rate of Dreissena polymorpha in three Dutch lakes with reference to biological water quality management. Freshwater Biology 22:133-141.