Role of hydrology and spring diatom bloom on *Dreissena polymorpha* (zebra mussel) recruitment

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Abstract

Diatoms are known to be an important food source for *Dreissena polymorpha*, an invasive zebra mussel species introduced into the Great Lakes region. An outbreak in diatom and *D. polymorpha* populations was noticed in the summer of 2004 in Ford Lake, after a season of reduced flushing rates. However, diatoms seemed to have little affect on zebra mussel recruitment after a whole-lake experiment was performed in the summer of 2008 to enhance the vertical mixing of water. Diatoms prospered, while there was little zebra mussel production. Hydrology seems to indirectly affect zebra mussel recruitment. In 2004, average flushing rates exceeded 20 days in the month of April and in the first-half of May. That summer, zebra mussel recruitment was large. In subsequent years from 2005-2008, flushing rates were faster and zebra mussel production was minimal. Hydrology seems to serve as a master-control on *D. polymorpha* recruitment by altering trophic level interactions.

Introduction

The Great Lakes system of North America is often a hotspot for the introduction of invasive species (Bryan et al., 2005; Stepien et al. 2005). The region is important for trade and commerce, and many international ships enter and leave the Great Lakes every day. Trade areas become susceptible to invasive species transported in the ballasts of ships. Although there have been some policies adopted to control the spread of invasive species by the treatment of ballast waters (Naylor et al., 2001) exotic, aquatic species still remain a threat to native waters.

The zebra mussel, *Dreissena polymorpha*, is a successful non-indigenous, invasive species to North America (Fig. 1). *D. polymorpha* was introduced to North America in 1986, initially into the Great Lakes system (Hebert et al., 1989). Since then, this species has extended its range to other freshwater ecosystems of North America including the St. Lawrence, Hudson and Mississippi Rivers (Ricciardi et al., 2007). *D. polymorpha* may out-compete other native mollusk species in these inland waters – drastically reducing population levels and altering trophic level interactions – which may ultimately reduce biodiversity in and around freshwater locales (Ricciardi et al., 1995).

Fig. 1 An image of the veliger larva of zebra mussel, *Dreissena polymorpha*, shown center, surrounded by diatoms, mainly *Aulacoseira*.

Unlike many native unionid bivalves that have epizoic and parasitic larval stages, *D. polymorpha* has free-living larval stages. Its first postembryonic larval stage is a trochophore, followed by metamorphosis into a veliger – its second larval stage. These larval stages of *D. polymorpha* may be important in its invasiveness. The larvae have the capacity to remain free-living in the water column for weeks before attaching themselves to a substrate. By contrast, local unionid species have a complex life history that includes a host organism. Unionid larvae parasitize the gills of particular fishes before colonizing a secure surface as adults. Therefore, unionids have the dual challenge of finding an adequate host fish and, consequently, a suitable environment in which to live. The ability to remain free-living for a few weeks allows *D. polymorpha* to disperse to suitable environments where they may attach to local unionid species that have already colonized a substrate, and then to out-compete unionids for resources. Unionids have not been able to adapt to the encroachment of *D. polymorpha* and subsequently have suffered decreased biodiversity within the Great Lakes (Ricciardi et al., 2007).

Dreissena have a diet consisting primarily of microalgae. They are often associated with nuisance algal blooms. The freshwater cyanobacterium *Microcystis* is toxic to many freshwater and terrestrial species (Reynolds & Walsby, 1975). Harmful blooms are understood to be the result of increased nutrient enrichments into altered lakes. In the presence of *Dreissena*, a larger portion of the algal community will be composed of these toxic cyanobacteria, producing adverse effects (Downing et al., 2001). *Dreissena* are shown to be positively correlated with increasing *Microcystis* levels in low-nutrient lake ecosystems; therefore, the invasion of this species into new lakes can trigger intense algal blooms, which may further affect the trophic structure of the lake, as well as human resources and activities (Sarnelle et al., 2008).

Zebra mussels have colonized the Huron River ecosystem in southeast Michigan. Lehman, Ferris & Platte (2007) reported a correlation between spring diatom abundance and *Dreissena* larval recruitment. These diatoms, a type of microalgae, may prove to be a substantial food source for adults. In April and May of 2004, a large diatom population developed in Ford Lake. The elevated diatom biomass was hypothesized to have provided plentiful food for the adults, contributing subsequently to extraordinary reproductive success. Neither the diatom success nor the subsequent production of veliger larvae were repeated in the years 2005 to 2007.

The relationship between *Dreissena* and diatom population levels appears to be an indirect effect of river hydrology. In 2004, flushing time for Ford Lake exceeded 20 days, allowing for the accumulation of diatoms in the lake (Ferris & Lehman 2007). In the following years, water residence times were lower than in 2004 (flushing times were less than 20 days), resulting in decreased populations of both veligers and diatoms (Lehman et al. 2007). Interannual variations in river hydrology were ascribed as a master variable in community dynamics.

In 2008, Ford Lake became the site of a whole-lake experiment that enhanced vertical mixing of water for most of the summer (Lehman et al., 2009). As expected, diatom populations prospered. We decided to use the altered algal community as an opportunity to test whether elevated diatom abundance alone was sufficient to trigger enhanced *D. polymorpha* recruitment.

Methods

Study Site

Ford Lake is an impoundment of the Huron River located in southeastern Michigan, U.S.A. (42.21° N, 83.56° W). The lake has a volume of 17,370,000 m^3 and a surface area of 4.039 km^2. The mean depth is 4.3 m and the maximum depth is 11 m (Lehman et al., 2007).

Hydrology

River discharge data are supplied from United States Geological Service (USGS) online archives for station 04174500. This data site, 04174500, is located in Ann Arbor, upstream from Ford Lake. According to Lehman & Ferris (2007) the influx of water flow to Ford Lake was estimated at 9.2% greater than that measured at the USGS site plus the discharge from the Ann Arbor Waste Water Treatment Facility. Consequently, daily discharge measured at the gage site was adjusted by a factor of 1.092 plus the daily discharge volume from WWTF, to estimate flow entering Ford Lake.

Zooplankton Sampling

Zooplankton, including veligers, were collected weekly from May to September of 2004-2008. The samples were collected by vertical net tows from 10 m to the surface while the boat was at anchor. The conical plankton net had a mouth diameter of 30-cm, a 1:5 aspect ratio and 64-µm mesh aperture (Lehman et al., 2007). Collections were preserved in sucrose-formalin and were transported to the laboratory for enumeration.

Laboratory Procedure

In lab, the plankton samples were diluted to either 100 or 200 mL depending on the abundance of algae. 5 mL of each sample were quantitatively removed for zebra mussel counts. These subsamples were placed into a 5-mL patent lip vial with neoprene stopper. Veliger counts were taken via Sedgewick-Rafter cells with 1-mL capacity. The counting cells were placed on a microscope stage, Olympus BHA compound microscope, at an actual magnification of 188X (10X objective, 15X eyepiece & 1.25X interference contrast prism). The entire cells (1 mL) were systematically searched and counted for zebra mussel veligers. Two replicate counts were conducted per sample.

After searching the entire cells for veligers, the total count recorded for the subsample was multiplied by 100 or 200, depending on the dilution amount. This is the number of veligers in the entire plankton sample. The total number of veligers was then divided by the area of the net mouth used to collect the plankton samples (30-cm mouth diameter). The area of the net mouth was calculated by the formula $\pi(0.15\ m)^2$. The resultant value is the number of veligers per square meter in the lake.

Results

In the summer of 2004 there was a large recruitment of zebra mussels in Ford Lake. During the preceding spring there had been a large abundance of diatoms and a relatively long flushing time, sometimes exceeding 30 days. We compared graphs depicting zebra mussel abundance and diatom biovolume for 2004 and for subsequent years up to 2008. We also compared the graph of zebra mussel abundance and flushing time of Ford Lake from 2004-2008.

Zebra mussel abundance and diatom biolvolume

Diatoms were extremely abundant in April of 2004, until thermal stratification decreased population numbers (Ferris & Lehman, 2007). The elevated population of diatoms in 2004 (Fig. 2) was followed by a substantial production of zebra mussel veligers and subsequent recruitment to benthic substrates. This positive correlation between zebra mussels and diatoms remained consistent into the years 2005, 2006 & 2007; population levels were low for both species. However, when the whole lake experiment was performed in 2008 to increase diatom biovolume throughout most of the summer, zebra mussel recruitment remained low.

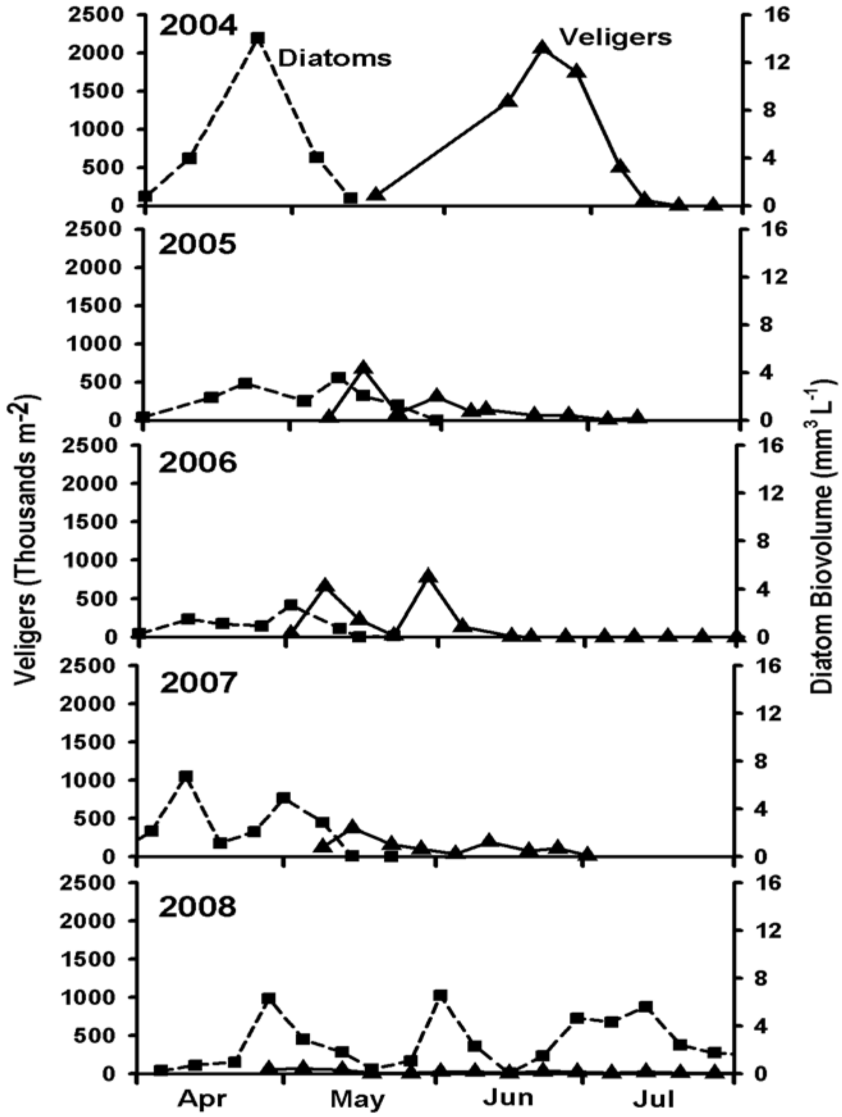

Fig. 2 Abundance of *Dreissena* veligers (triangles and solid lines) and diatom biovolume during 2004-2008.

Flushing time and Dreissena recruitment

There was a substantial increase in zebra mussels in 2004 following decreased flushing rates during April and the first part of May. The average flushing rates of Ford Lake, modified from USGS data, were 21.5 days for the month of April and 20.6 days from May 1st to May 10th. In April of 2005 flow rates exceeded 20 days for a brief period, but the average flushing rate was 12.6 days. Zebra mussel populations increased briefly in mid-May. In the years 2006-2008 zebra mussel abundance remained fairly low in the summer months after elevated flushing rates in the months of April and May. The average flushing rate for April of 2008 was calculated at 7.5 days.

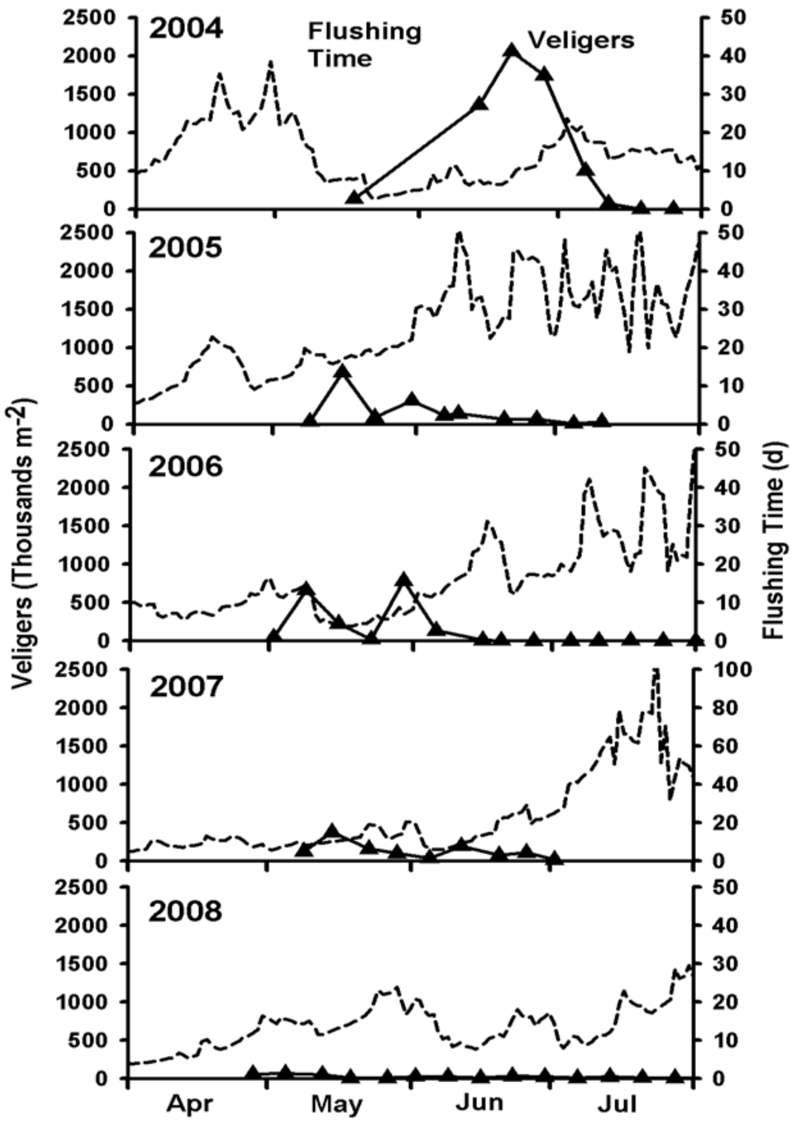

Figure 3: Flushing rates of Ford Lake (dotted line) and *Dreissena* abundance during 2004-2008. Note change of scale for flushing time in 2007.

Discussion

As diatoms provide a food source for *D. polymorpha*, it is likely that they have an effect on zebra mussel populations. Though, from the results of this study, diatom biovolume appeared to play a lesser role on zebra mussel recruitment in Ford Lake. In 2004, diatoms were prevalent in the lake and outwash rates were low. Zebra mussels prospered. However, when the whole lake experiment conducted in the spring and summer of 2008 generated spurts of diatom abundance, zebra mussel population levels remained minimal. Diatom biovolume during 2008 never reached the elevated peak encountered in 2004; however, zebra mussels did not show any population lag cycles around diatom recruitment. The diatom blooms induced in 2008 did not appear to correspond to veliger production.

As proposed by Lehman et al. (2007), the recruitment of zebra mussel populations in Ford Lake seems to be controlled primarily by hydrology. Flushing rates through the lake may serve as a master control, indirectly affecting *Dreissena* abundance and may play a role in stabilizing and altering trophic level interactions.

Regarding the lake outwash rates, zebra mussel recruitment in May and June of 2004 was considerably elevated with respect to succeeding years, after a decreased outwash rate in Ford Lake during April (average 21.5 days). In years 2005-2008, flushing rates experienced brief durations of decreased flows, but never as extensive and pronounced as in 2004. Increased flushing rates seem to directly affect zebra mussel veliger production – *D. polymorpha* recruitment was extremely small.

Another interesting deduction is the seasonal timing when zebra mussel populations seem to grow and reproduce. *Dreissena* populations appear to begin increasing during the summer months of May and June. Perhaps the outwash rate of Ford Lake specifically in April has a powerful control on the dynamics of the lake community structure. According to Lehman et al. (2007), a reduced flushing time allows lake systems such as Ford Lake to develop a clear water phase important for grazing species. Hydrology could work as a master variable, affecting the seasonal succession of *Dreissena*, as well as other phytoplankton and zooplankton, due to interannual variations in river flow. *D. polymorpha* may not be able to compete as well as other species for resources following seasons with elevated flushing rates. Furthermore, faster flushing rates may cycle plankton species rapidly through the lake before a community structure has the opportunity to stabilize.

In conclusion, hydrology seems to play an important role in Ford Lake and other lake systems by indirectly affecting trophic level interactions. Future seasonal abundances of organisms in a freshwater system can be deduced through the understanding of the effects of hydrology on planktonic communities.

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