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Do zebra mussels (*Dreissena polymorpha*) alter lake water chemistry in a way that favours *Microcystis* growth?

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Abstract

This study examined possible relationships between the presence of zebra mussels (*Dreissena polymorpha)* and *Microcystis* spp. abundance. Experiments were conducted in 12 microcosms designed to mimic shallow lake ecosystems. Fresh, aerated water with phytoplankton (*pseudokirchneriella* spp. and *Microcystis* spp.) was pumped into each microcosm daily to ensure zebra mussels were exposed to oxygen and food. Microcosms containing zebra mussels experienced significantly higher fluxes of nitrate ($p=0.019$) and lower fluxes of ortho-phosphate ($p=0.047$) into sediments. In a second experiment, water column nutrient concentrations were compared in microcosms with and without live zebra mussels. Consistent with results of the previous experiment, microcosms with zebra mussels had significantly less nitrate ($p=0.023$) and organic nitrogen ($p=0.003$) in the water column, while ammonium ($p=0.074$), phosphate ($p=0.491$), and dissolved organic carbon ($p=0.820$) in the water column were not different between microcosms with or without zebra mussels. Microcosms with zebra mussels also experienced a reduction in green algae (*pseudokirchneriella*) ($p<0.001$) and an increase in abundance of *Microcystis* ($p<0.001$) relative to microcosms without zebra mussels. In an experiment without zebra mussels, nutrient ratios (N/P) were manipulated to determine potential links between N/P and relative abundance of each phytoplankton. Manipulation of N/P was intended to mimic differences observed in microcosms with and without zebra mussels in the previous experiment. Low N/P (mimicking microcosms with zebra mussels) was related to an increase in *Microcystis* ($p<0.001$) and *Microcystis*/*Pseudokirchneriella* biovolume ($p<0.001$). It is this shift in N/P, and possibly some level of selective feeding, that is believed to have driven changes in the relative abundance of *Microcystis*. In lakes invaded by zebra mussels, alterations in the processing of nitrogen and phosphorus could contribute to the re-emergence of *Microcystis* blooms.

Keywords: Zebra mussels; Cyanobacterial bloom; N/P; Nitrate flux; Nutrient ratios; Nutrient flux; *Selenastrum*

1. Introduction

Nuisance blooms of freshwater cyanobacteria can cause taste and odour problems in drinking water and can lower the aesthetic value of lakes and ponds with surface scums. More seriously, many different cyanobacteria can produce potent toxins dangerous to humans

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and other animals (Rinehart et al., 1994; Negri et al., 1995; Sivonen and Jones, 1999; Hamill, 2001). Understanding the ecological drivers that trigger bloom formation is important in developing strategies to protect against future formation of blooms of potentially toxic cyanobacteria.

Favourable elemental ratios (low N/P and N/Si), are understood to increase the likelihood of cyanobacterial blooms in lakes (e.g., Pearsall, 1932; Rhee, 1978; Tilman et al., 1982; Smith, 1983; Stockner and Shortreed, 1988; Bulgakov and Levich, 1999), and high nutrient loading, generally, can trigger blooms (Klemer, 1976; Watson et al., 1997). The introduction of phosphorus loading reductions in the early 1970s led to declines in phytoplankton blooms (including cyanobacterial blooms) in the late 1970s and 1980s. However, cyanobacterial blooms are apparently becoming more common again in the lower Laurentian Great Lakes watershed despite continued restriction of P-loading. Recently, microcystin toxins have been measured at various locations in Lake Ontario and Lake Erie at concentrations exceeding the World Health Organization's advisory limit of 1 $\mu g\ L^{-1}$, while blooms producing other cyanobacterial toxins have been increasingly reported in the lower Great Lakes watershed (Boyer, 2006).

Some of the recent cyanobacterial blooms are believed related to the presence of zebra mussels (*Dreissena polymorpha*). Blooms of *Microcystis* were observed in Saginaw Bay in 1991–1995, following invasion by zebra mussels (Bierman et al., 2005). In the Bay of Quinte (Lake Ontario) *Microcystis* abundance increased (13-fold) after zebra mussel invasions in the 1990s while abundances of other taxa declined (Nicholls et al., 2002). In 1995, following the colonization of the western basin of Lake Erie by zebra mussels, *Microcystis aeruginosa* formed a large bloom creating a surface scum that covered much of the western end of the lake (Budd et al., 2002). Such blooms had not been observed in Lake Erie since the early 1970s (Makarewicz, 1993; Nicholls and Hopkins, 1993). During investigations of 39 inland lakes in southern Michigan during 2002–2003, Sarnelle et al. (2005) concluded that *M. aeruginosa* abundance was 3.6 times higher in the invaded lakes than in lakes without zebra mussels. Additional anecdotal evidence of *Microcystis* blooms in Michigan lakes following zebra mussel invasions are cited as personal communications in Vanderploeg et al. (2001).

One hypothesis that has been advanced to explain shifts to cyanobacterial dominance in bodies of water populated by zebra mussels has been selective feeding or particle sorting by zebra mussels (Heath et al., 1995). Vanderploeg et al. (2001) suggested that changes in phytoplankton composition of Saginaw Bay, specifically shifts toward greater abundance of *Microcystis* and other cyanobacteria, mainly were due to the selective rejection of cyanobacteria (*M. aeruginosa*) in pseudofeces when mussels were given *Microcystis* in combination with a preferred food source (*Cryptomonas*). However, while zebra mussels appear to be highly capable of sorting particles (Baker et al., 2000), *M. aeruginosa* appears to be preferred to a variety of green algae (*Micractinum* sp., *Curcigenia tetrapedia*, and *Scenedesmus quadricauda*) and the diatom *Cyclotella meneghiniana* (Baker et al., 1998). Therefore, while selective feeding by zebra mussels may play a role in phytoplankton community shifts toward cyanobacterial dominance in some systems, it seems that a shift toward less cyanobacterial biomass could also occur due to selective feeding.

Another possible explanation for increased cyanobacterial dominance in lakes with zebra mussels is that zebra mussels may alter nutrient availability in a manner that favours cyanobacteria (i.e., decreasing N/P) (Kaur et al., 2005). Zebra mussels are major recyclers of nutrients in invaded lakes (e.g., James et al., 2001; Karatayev et al., 2003). In the recycling process, elemental ratios of bioavailable nutrients may be altered. Arnott and Vanni (1996) found that zebra mussels excreted nutrients at $N/P<20$ with smaller mussels excreting even more P relative to N, and suggested nutrient excretion ratios might promote cyanobacterial blooms. Water column filtration by zebra mussels can remove nutrients associated with particles and plankton (Johengen et al., 1995). This could preferentially remove nitrogen (as ammonium adsorbed to particles) relative to phosphorus. Howell et al. (1996) found that fine particulate matter deposition and total organic carbon content of sediment increased in an eastern Lake Erie site following colonization by zebra mussels. Presumably, deposition of organically bound nitrogen to sediments would also increase, intensifying remineralization and N-cycling processes in sediments. Recently, enhancement of denitrification in zebra mussel beds has been demonstrated (Bruesewitz et al., 2004). As denitrification represents the only permanent sink in the nitrogen cycle for aquatic systems, enhanced denitrification could alter N/P availability in a way that favours growth of cyanobacteria over other phytoplankton.

The present study considers the ability of zebra mussels to change water chemistry in a way that would favour cyanobacterial growth. Two specific hypotheses were tested: (1) zebra mussels would enhance the removal of nitrate from the water column due to increased flux into sediments. The removal of nitrate would result in a