US Army Corps of Engineers
Waterways Experiment Station

Zebra Mussel Research Technical Notes

Section 1 — Environmental Testing **Technical Note ZMR-1-34**

January 1998

Impacts of Zebra Mussel Infestations on Water Quality

Background Dense populations of zebra mussels (*Dreissena polymorpha*) have the potential to greatly impact water quality. By removing particulates and associated nutrients and contaminants from the water column and redistributing them to the sediments, zebra mussels affect water clarity, nutrient and contaminant cycling, and sediment quality.

Purpose This technical note describes potential changes in water quality as a result of zebra mussel infestations in aquatic systems, based on a review of the literature. The preliminary results of field studies to assess nutrient cycling are also presented. Important reference sources for more detailed information are listed at the conclusion of this technical note.

Results of laboratory investigations to describe impacts at the sediment-water interface are presented in Technical Note ZMR-1-33.

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Water quality impacts A number of processes that are associated with dense populations of zebra mussels have significant potential to impact water quality. These include the high filtration rates required for feeding, high excrement rates associated with nonselective filtration and selective retention, increased nutrient cycling, and respiration-based demand for dissolved oxygen.

Dense assemblages of bivalves are being considered as a major component in nutrient recycling in estuaries (Dame and others 1991), and zebra mussel infestations would be expected to have similar potential for impact in freshwater systems. These effects may impact distribution of macrophytes (Skubinna, Coon, and Batterson 1995), density and composition of planktonic and benthic

Prepared and published by the Zebra Mussel Research Program, U.S. Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

communities (Fahnenstiel and others 1995a), and possibly the entire food web.

Since the distribution of zebra mussels in surface waters is limited primarily by low calcium levels and low pH (Ramcharan, Padilla, and Dodson 1992), the potential to impact most of the water resources in North America is quite high based on projections of zebra mussel distribution. Dermott and Munawar (1993) reported that 80 percent of Lake Erie's bottom had zebra mussels, suggesting that even lack of substrate may not be a limiting factor. However, distribution and abundance are clearly related to substrate and other physicochemical factors. A number of studies have indicated that even turbid waters may be habitable with zebra mussels that respond with adaptations in filtration and an increase in pseudofeces production rather than a decrease in filtration.

Zebra mussels may impact the biota of aquatic systems via changes in water quality and impacts on native organisms such as unionid clams (Mackie 1991) and other benthic invertebrates (Griffiths 1993). Indirect alteration or control of processes that are rate- or concentration-limited by nutrient availability may occur in areas with dense populations of zebra mussels. Madenjian (1995) estimated a 26 ± 10 percent decrease of primary production for western Lake Erie by zebra mussels, while Fahnenstiel and others (1995a) demonstrated that decreases in phytoplankton productivity were accompanied by increases in benthic primary productivity. Lowe and Pillsbury (1995) documented a shift from diatom domination of the benthic algal community to a flora dominated by filamentous green algae. These impacts on species diversity, nutrient cycling, and energy production could have profound impacts on an aquatic system.

Zebra mussel impacts on water quality may have beneficial applications such as biomanipulation for algal removal (Reeders and de Vaate 1990). Changes in the aquatic ecosystem (for example, a shift from algal to macrophyte dominance or a change in the fishery) may provide additional opportunity for water quality management. Applications for water quality management also include removal of nutrients and metals from wastewater and concentration to the bottom sediments. However, de Kock and Bowmer (1993) demonstrated bioaccumulation transfer of cadmium and organochlorine contaminants from zebra mussels (serving as a food source) to the tufted duck and its eggs, suggesting a need for further investigation of contaminant transport.

Potential beneficial uses of zebra mussels include biomonitoring of heavy metals and polychlorinated biphenyls, and ecotoxicological studies for water quality assessments.

Effects of filtration/excretion

Zebra mussels filter suspended particles between 10 and 450 microns in size and redeposit rejected particles in mucus-encapsulated pellets of pseudofeces, while selectively retaining suitable food in the 10- to 40-micron size range (Ten Winkel and Davids 1982). As much as 90 percent of the filtered particles is deposited to the sediments. This removal of suspended matter (seston) may impact water clarity and bottom substrate composition (Leach 1993). Of interest is recent information that zebra mussels also expel particles unsuitable for food (specifically *Microcystis*) via the inhalant siphon in addition to passage as pseudofeces and exclusion of large colonies with tentacles guarding the entrance to the siphon (Vanderploeg, Liebig, and Nalepa 1997).

Filtration rates ranging from 2 to 180 cm^3 $mussel^{-1}$ hr^{-1} have been reported for zebra mussels (Bunt, MacIsaac, and Sprules 1993), and clearance rates are equal to other freshwater bivalves (Lei, Payne, and Wang 1996). Recent model studies of other bivalves suggest that complete filtration of large volumes can occur within days, depending upon the organism and its population density. For example, a zebra mussel infestation of 40,000 organisms per square meter would filter 9,600 m^3 in 1 day at a filtration rate of 100 cm^3 $mussel^{-1}$ hr^{-1}. A lake with a bottom area of 809,400 m^2 (200 acres) and a volume of 4×10^6 m^3 (for example, a small flood control project) with 10 percent infestation (approximately 40,000 organisms per square meter) would be completely filtered in 0.5 day, or 1.9 times per day. Even at a density of 10,000 organisms per square meter, complete filtration would occur in 2.1 days, or 0.5 time per day. These values compare well with estimates of 11 to 18 days for large Dutch lakes (Reeders, de Vaate, and Slim 1989), 0.02 and 1.3 times per day for Saginaw Bay, Lake Huron (Fanslow, Nalepa, and Lang 1995), and between 0.5 time per day for western Lake Erie and 4 times per day for Sunken Chicken Reef (Bunt, MacIsaac, and Sprules 1993).

The estimates stated above are for continuous filtration by adult mussels and hydrodynamic conditions that make the whole lake subject to filtration; actual complete filtration of the whole lake is unlikely. Such estimates do not account for avoidance by plankton, variability in organism size, and variations in filtration rates. Additionally, filtration capacity is also influenced by environmental factors such as temperature and seston concentration (Sprung 1995), which vary seasonally in lakes. The effects of temperature have been demonstrated by Aldridge, Payne, and Miller (1995) in studies which showed that oxygen consumption and ammonium excretion rates increase and filtration rates decrease with increased temperatures. This suggests that impacts of the zebra mussel will vary between regions and seasonally within a region.

Effects on water quality

The effects of dense zebra mussel infestations on water quality include changes in nutrient cycling and water clarity, depletion of dissolved oxygen, and trophic classification. For example, efficient filter-feeding in an infested lake may shift its trophic classification toward oligotrophy using indices such as chlorophyll *a* concentrations, Secchi disk depths, and nutrient concentrations.

Leach (1993) has reported chlorophyll *a* concentration decreases of 27 to 43 percent related to dense infestations. Johengen and others (1995) determined that zebra mussels were a significant sink for phosphorus in Saginaw Bay, Lake Huron. However, Mellina, Rasmussen, and Mills (1995) suggest that impacts on phosphorus cycling are important only when annual phosphorus accumulated into mussel biomass represents more than 20 percent of the annual load to the lake. These researchers suggested a decoupling of the nutrient-chlorophyll relationship, described by Dillon and Rigler (1974) for phosphorus.

While increased concentrations of soluble reactive phosphorus, ammonium- and nitrate-nitrogen, silica, and chloride have been reported in association with zebra mussel infestations, total phosphorus concentrations were nearly identical to pre-infestation concentrations in studies conducted by Holland, Johenegen, and Beeton (1995). Decreased phytoplankton and increased water clarity, attributed to increased filtration, indicated a change from eutrophic to oligotrophic conditions if total phosphorus concentrations are not used as an indicator. However, Fahnenstiel and others (1995b) reported similar results (decreased chlorophyll and increased water clarity) but also a decrease in total phosphorus; they suggested alteration of spatial partitioning of resources rather than a change in trophic state.

Evaluation of changes in nitrogen species concentrations and the ratio to phosphorus concentrations provides insight to potential changes as well. Studies of trends in nutrient concentrations associated with infestation suggest that zebra mussel populations accelerate the conversion of nitrogen to consumable nutrients for benthos and phytoplankton. Gardner and others (1995) demonstrated that community ammonium regeneration rates were enhanced in the presence of zebra mussels, although community uptake rates of ammonium appeared to decrease. Additional studies examining ammonium to nitrate ratios suggest that shifts from phytoplankton species to non-nitrogen fixing, blue-green algae may occur. For example, blooms of *Microcystis* have recently been documented in Saginaw Bay (Vanderploeg, Liebig, and Nalepa 1997).

Impacts of zebra mussel infestations on oxygen resources include a potential for significant oxygen depletion (approximately 44 g m^{-2} day^{-1}, which is an order of magnitude greater than typical sediment oxygen demand values) and a considerable decrease in waste assimilative capacity. Coupled with efficient removal of phytoplankton, impacts on dissolved oxygen resources in areas with little reaeration may be quite severe. For example, in an infested reach of the Seneca River, an average depletion of 1.7 mg L^{-1} in dissolved oxygen concentrations was observed, and minimum concentrations fell from 5 to 3 mg L^{-1}, pre- and post-infestation, respectively.

Field studies — Seneca River, New York

Impacts of zebra mussels on nutrient cycling in the Seneca River, New York, have been investigated as part of the Zebra Mussel Research Program. The Seneca River drains about 9,000 km^2 of the Finger Lakes region of New York to Lake Ontario. The study was conducted in a channel cut, downstream from Cross Lake (Figure 1). The site provides an opportunity for a quantitative study in a riverine environment, since discharge is continuously measured at a downstream U.S. Geological Survey gauge.

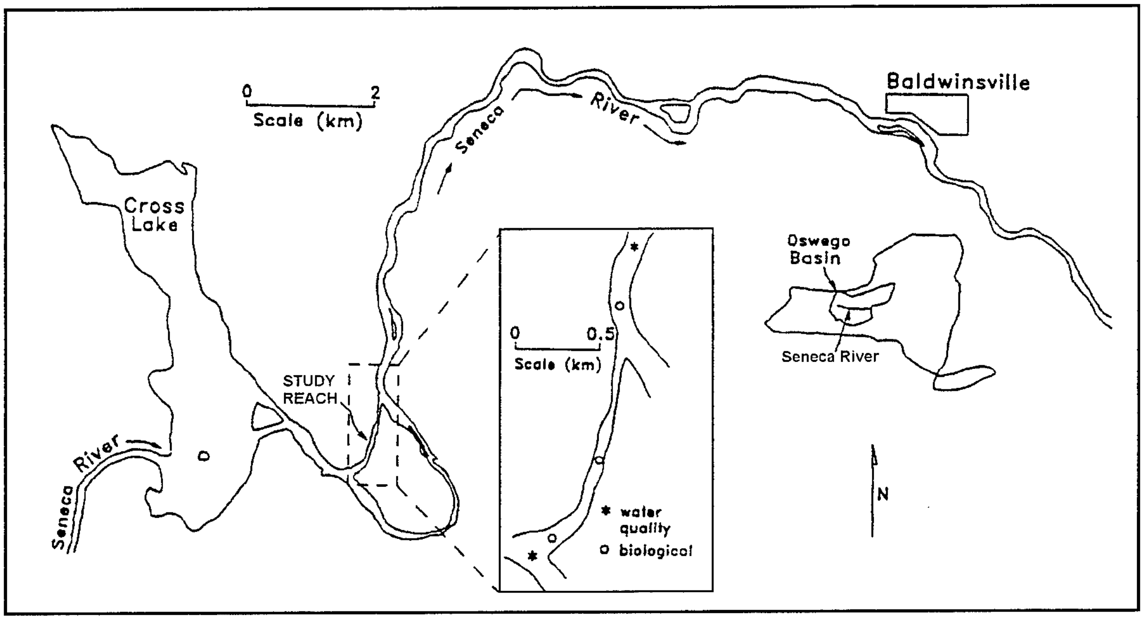

Figure 1. Seneca River study reach. (Insets show the locations of monitoring sites within the study reach and the Seneca River within the Osego River basin in New York.)

Zebra mussel biomass at this site is monitored by scuba surveys that are conducted by the New York State Museum. Water quality monitoring, conducted upstream and downstream of the channel cut by the Upstate Freshwater Institute, forms the basis for quantifying selected water quality impacts, normalized by the resident biomass of the mussels in the channel. Detailed study results are presented in (Effler and others 1997).

Water quality changes that were observed after zebra mussel infestation included decreased dissolved oxygen and increased ammonia and soluble reactive phosphorus (Figure 2). Prior to infestation (1990/1991), the dissolved oxygen concentrations ranged from 5 to 9 mg L^{-1}, with measurements of 7 to 8 mg L^{-1} occurring for 40 percent of the observations. In contrast, in 1993, the dissolved oxygen concentrations ranged from 3 to 9 mg L^{-1}, with measurements of 4 to 5 mg L^{-1} occurring for 40 percent of the observations after infestation. Total ammonia values increased from less than 0.08 mg L^{-1} occurring for 75 percent of the observations prior to infestation to 2.24 mg L^{-1} with 70 percent of the observations greater than 0.12 mg L^{-1} after infestation. A similar trend for soluble reactive phosphorus was observed, with pre-infestation concentrations less than 10 μg L^{-1} for greater than 90 percent of the observations and post-infestation concentrations ranging from 10 to 70 μg L^{-1} with an occurrence of 35 percent for concentrations between 40 to 50 μg L^{-1}.

The estimated average summertime release/recycle rates of ammonia and soluble reactive phosphorus for the channel cut, represented as "areal fluxes," were 1.6 ($\pm$1.2) g N m^{-2} day^{-1} and 190 ($\pm$155) mg P m^{-2} day^{-1} for ammonia and soluble reactive phosphorus, respectively. These fluxes are quite high, that is, about an order of magnitude

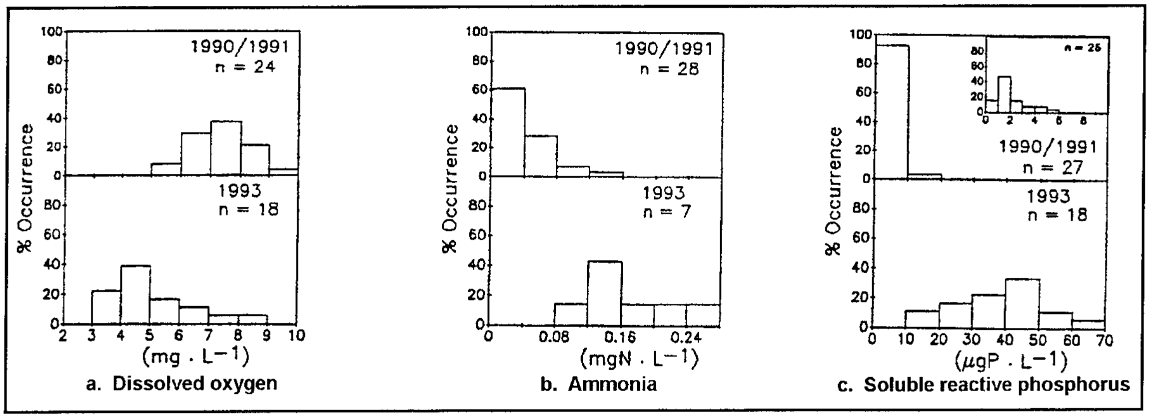

Figure 2. Comparison of summertime distributions of water quality parameter concentrations for the Seneca River for 1990/1991 (pre-infestation) and 1993 (post-infestation)

greater than sediment release rates observed for enriched sediments within the anoxic hypolimnion of eutrophic lakes.

Nutrient fluxes were normalized for biomass estimates, and preliminary relationships were developed as a function of zebra mussel density (Figure 3). These relationships represent a basis to estimate nutrient recycle rates, given quantitative survey results of the biomass of zebra mussels present. Additional studies are necessary to refine these preliminary relationships to account for seasonal variability, effects of stress, age structure of the population, and other factors that would affect zebra mussel biological processes.

Summary

The potential for considerable impacts on water quality in North America is quite high for areas susceptible to invasion and establishment of dense infestations. Impacts in these areas may include degradation of dissolved oxygen resources, increased nutrient cycling (which may impact community structure), increased water clarity, increases in macrophyte communities, changes in benthic communities, and reductions and changes in phytoplankton communities. The extent of these potential changes will be a function of distribution and population dynamics and densities of the zebra mussel.

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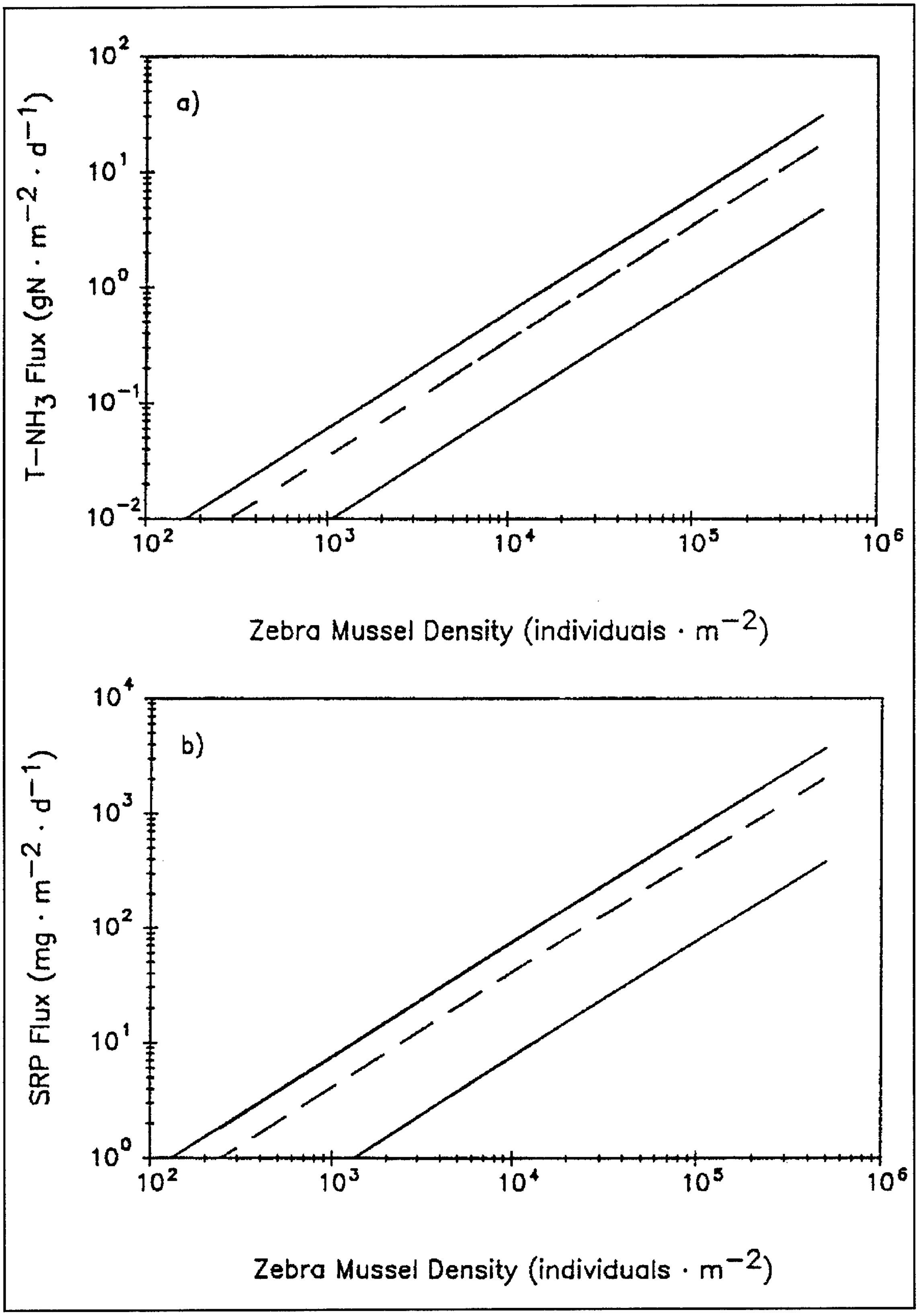

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