WATER RESEARCH 42 (2008) 1664–1674

Available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/watres

Zebra mussel filtration and its potential uses in industrial water treatment

Paul Elliott[a,*], *David C. Aldridge*[a], *Geoff D. Moggridge*[b]

[a]*Department of Zoology, University of Cambridge, Downing Street, Cambridge CB2 3EJ, UK*
[b]*Department of Chemical Engineering, University of Cambridge, Pembroke Street, Cambridge CB2 3RA, UK*

ARTICLE INFO

Article history:
Received 22 July 2007
Received in revised form
15 October 2007
Accepted 16 October 2007
Available online 18 October 2007

Keywords:
Dreissena polymorpha
Zebra mussel
Water treatment works
Biofilter
Water filtration
Flow-through system

ABSTRACT

The zebra mussel (*Dreissena polymorpha*) is a notorious freshwater biofouling pest, and populations of the species can alter aquatic environments through their substantial filtration capabilities. Despite the ecological importance of zebra mussel filtration, many predictions of their large-scale effects on ecosystems rely on extrapolations from filtration rates obtained in static laboratory experiments, not accounting for natural mussel densities, boundary layer effects, flow rates or elevated algal concentrations. This study used large-scale industrial flume trials to investigate the influence of these factors on zebra mussel filtration and proposes some novel industrial applications of these findings. The flume trials revealed some of the highest zebra mussel clearance rates found to date, up to $574 \pm 20\,\mathrm{ml\,h^{-1}\,g^{-1}}$ of wet tissue mass. Under low algal concentrations, chlorophyll *a* removal by zebra mussels was not proportional to mussel density, indicating that field rates of zebra mussel grazing may be much lower than previous studies have predicted. Increasing ambient velocities up to $100\,\mathrm{ml\,s^{-1}}$ ($\sim 4\,\mathrm{cm\,s^{-1}}$) led to increased clearance rates by zebra mussels, possibly due to the replenishment of locally depleted resources, but higher velocities of $300\,\mathrm{ml\,s^{-1}}$ ($12\,\mathrm{cm\,s^{-1}}$) did not lead to further significant increases in clearance rate. When additional algal cultures were dosed into the flumes, chlorophyll *a* removal increased approximately logarithmically with zebra mussel density and there were no differences in the clearance of three different species of alga: *Ankyra judayi*, *Pandorina morum* and *Cyclotella meneghinia*. Some novel industrial uses of these zebra mussel filtration studies are proposed, such as: (1) helping to inform models that predict the large-scale grazing effects of the mussels, (2) allowing estimates of zebra mussel densities in industrial pipelines, and (3) constructing large-scale biofilters for use in water clarification.

1. Introduction

Much attention has been drawn to the industrial biofouling effects of zebra mussels around the world (Claudi and Mackie, 1994), but zebra mussels also have profound ecological effects on aquatic environments. Filter feeders, such as the zebra mussel, can be major consumers of phytoplankton, exerting significant top-down control on phytoplankton levels (Caraco et al., 1997). Because zebra mussels can reach densities of over $700{,}000\,\mathrm{m^{-2}}$ (Pathy, 1994), filter large volumes of water and retain a wide size range of particles (Sprung and Rose, 1988; Silverman et al., 1996), zebra mussel populations are capable of removing over 90% of organic matter from the water (MacIsaac, 1996). Since the zebra mussel invasion of North America, chlorophyll *a* concentration (an indicator of algal population density) has dropped by over 90%

*Corresponding author. Tel.: +44 1223336617; fax: +44 1223336676.
E-mail address: pe206@cam.ac.uk (P. Elliott).
0043-1354/$ - see front matter
doi:10.1016/j.watres.2007.10.020

on the north shore of Lake Erie (Nicholls and Hopkins, 1993).

In addition to decreasing phytoplankton biomass, zebra mussels can cause shifts in phytoplankton community composition (Caraco et al., 1997; Smith et al., 1998). Laboratory studies and modelling have shown that zebra mussel filtration may differentially affect phytoplankton taxa (Vanderploeg et al., 1996; Bastviken et al., 1998). Most worryingly, cyanobacterial blooms have often occurred soon after zebra mussel establishment, despite large declines in overall chlorophyll *a* concentration (MacIsaac, 1996; Vanderploeg et al., 1996). This can cause concern for water treatment companies, as some species of cyanobacteria can produce hepatotoxins, which may pose a serious health risk for human populations (Jochimsen et al., 1998).

Given the potentially massive effects of zebra mussel filtration, a number of studies from both Europe and America have attempted to quantify the filtration and clearance rates of zebra mussels. The filtration rate (or pumping rate) of a mussel is defined as the volume of water that passes through the mussel's gills per unit time. In contrast, the clearance rate of a mussel is the volume of water that is completely cleared of suspended particles per unit time. For zebra mussels, there is enormous variability in recorded filtration and clearance rates, which range from 5 to 400 ml $mussel^{-1} h^{-1}$ (Ackerman, 1999; Baldwin et al., 2002). This variability may reflect true differences in filtration rate due to factors such as temperature (Vanderploeg et al., 1995; Lei et al., 1996), water velocity (Ackerman, 1999), particle size (Sprung and Rose, 1988) or resting periods (Morton, 1971).

Differences in clearance rates may also reflect differences in the experimental techniques used. The majority of studies on zebra mussel filtration to date have used the *clearance method* in which the decrease in particle concentration in an enclosed chamber containing zebra mussels is measured (e.g. Silverman et al., 1995; Lei et al., 1996; Horgan and Mills, 1997). Using this method, studies have found per capita clearance rates ranging from approximately 20 ml $mussel^{-1} h^{-1}$ (Baldwin et al., 2002) to approximately 287 ml $mussel^{-1} h^{-1}$. There have also been a small number of studies on zebra mussels using the *flow-through chamber method* (e.g. Ackerman, 1999; Baldwin et al., 2002), where the decrease in particle concentration in a water current flowing past the mussels is measured. These have found some of the highest clearance rates for zebra mussels to date, up 420 ml mussel h^{-1} (Baldwin et al., 2002). An advantage of this method is that algal concentration can be maintained during the experiment.

Riisgard (2001) questions the reliability of many of the techniques used to measure mussel filtration, asserting that the clearance method is one of the most likely techniques to provide reliable estimates of filtration rates when used under optimal laboratory conditions. Although this may be true, zebra mussels do not live under optimal laboratory conditions and there is still a great need to characterise the filtration abilities of zebra mussels at natural population densities, flow rates and algal concentrations. This study attempts to measure mussel filtration using a large, flow-through rig constructed on a water treatment facility in North London, England. This enabled the filtration of raw, untreated reservoir water to be measured under conditions of high zebra mussel density and with variable flow rates.

Such studies of zebra mussel filtration may also be of substantial applied use. Firstly, investigations of the relationship between zebra mussel density and clearance rates may help inform predictions of the large-scale grazing impacts of zebra mussels. Previously, population filtration rates have been estimated by combining laboratory measurements of the filtration rates of individual zebra mussels, with their density in the field (MacIsaac et al., 1992; Bunt et al., 1993; Fanslow et al., 1995). However, there have been no comprehensive investigations to validate the assumption that algal removal from a waterbody scales linearly with zebra mussel density. Secondly, studies of zebra mussel filtration may be of use to industries experiencing zebra mussel biofouling of their intake pipelines: if a relationship between algal clearance and mussel density does exist, algal concentrations at the end of a pipeline could be used to predict the level of infestation. Finally, there is the possibility that zebra mussels could actually be used as industrial biofilters. In Holland, zebra mussels have been considered a useful tool in the restoration of eutrophic lakes by biomanipulation (Reeders and Bij de Zaate, 1990; Reeders et al., 1993). Many water companies have problems with algal blooms in their raw water sources, and this investigation considers whether zebra mussels could be used to help alleviate this problem.

The goals of the work described in this paper are (1) to measure the clearance rates of zebra mussels in the semi-natural, flow-through conditions of a large industrial rig; (2) to explore the effects of zebra mussel density and water flow rate on zebra mussel clearance under conditions of normal and elevated algal concentration; and (3) to examine the potential of three applied uses of these zebra mussel filtration studies: for predicting large scale grazing effects of zebra mussels, for estimating densities of zebra mussel infestation in a pipeline and for developing an industrial biofilter based on zebra mussel filtration.

2. Methods

2.1. *Experimental apparatus*

Experiments were conducted in late September 2004 using a large flow-through rig at water treatment works in North London (a schematic of the rig is shown in Fig. 1). Raw, untreated reservoir water from a supplying reservoir was pumped at a rate of 12.6 $m^3 h^{-1}$ into a 4 m^3 steel header tank. The water then flowed by gravity out of 30 large taps in the sides of the tank and down 30 horizontal, independent, 4 m long flumes. Each flume consisted of square household guttering, of base width 68 mm, which was sealed at both ends by stop-end guttering units. A weir in the stop-end unit ensured a unidirectional flow of water in each flume and maintained a water depth of approximately 7 cm. Water drained into capture tanks at the ends of the flume, from which water was pumped into the wastewater system of the facility.

The flow in each flume was regulated by taps. Water was pumped into the header tank at a rate faster than it could flow from the taps by gravity, the remainder being taken away by an overflow pipe. Consequently, the head of water in the tank remained constant, as did flow rates in the flumes.