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Research Article

Comparing a microbial biocide and chlorine as zebra mussel control strategies in an Irish drinking water treatment plant

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Abstract

A need exists for an environmentally friendly mussel control method to replace chlorine and other traditional control methods currently utilised in drinking water plants and other infested facilities. Zequanox® is a newly commercialised microbial biocide for zebra and quagga mussels comprised of killed *Pseudomonas fluorescens* CL145A cells. The objective of this study was to compare the efficacy of a developmental formulation of Zequanox (referred to as MBI 401 FDP) and chlorine treatments on adult and juvenile zebra mussels by running a biobox trial in conjunction with chlorine treatments at an infested Irish drinking water treatment plant. Since 2009, the plant management has used a residual chlorine concentration of 2 mg/L in autumn to control both adult zebra mussels and juvenile settlement in their three concrete raw water chambers. Juvenile mussel settlement was monitored in three bioboxes as well as in three treatment chambers in the plant for three months prior to treatment. Adult mussels were seeded into the chambers and bioboxes four days before treatment. In October 2011, the bioboxes were treated with MBI 401 FDP at 200 mg active substance/L, while chlorine treatment took place in the water chambers. The MBI 401 FDP treatment lasted only 8 hours while chlorine treatment lasted seven days. Juvenile numbers were reduced to zero in both the bioboxes and treated chambers within seven days. Adult mussel mortality reached 80% for both the chlorine and MBI 401 FDP treatment; however, mortality was achieved faster in the chlorine treatment. These results provided important insights into zebra mussel control alternatives to chlorine and supported further development of the now commercial product, Zequanox.

Key words: invasive mussel control; juveniles; adults; water quality

Introduction

The zebra mussel *Dreissena polymorpha* (Pallas, 1771), is an invasive, exotic aquatic bivalve, which has greatly affected lakes, canals and other aquatic ecosystems in Ireland (Minchin et al. 2002; Lucy 2010; Lucy et al. in press) since first invading in the early 1990's (Minchin and Moriarty 1998). The control methods currently used in Ireland, Europe and North America are necessary in industries requiring water abstraction, for example in drinking water treatment plants and land-based fish hatcheries where juvenile zebra mussels settle in water pipe networks and ancillary plants, developing into fully grown zebra mussels (Mackie and Claudi 2010). In such cases, either physical removal and/or chlorine dosed at approximately 2 mg/L is frequently used to control the mussels (Mackie and Claudi 2010) as is the case in the drinking water treatment plant in Sligo, used in this study. At 2 mg/L chlorine treatments can take up to 21 days to be effective (Mackie and Claudi 2010). At the Sligo drinking water treatment plant, flow through raw water chambers receiving chlorine treatment are bypassed for the chlorination period and the treated water is released back to the discharged water body. Trihalomethanes can be formed in drinking water as a result of the chlorination of organic matter in the raw water supplies (Coffin et al. 2000) and according to Wright et al (2007) THM formation is enhanced when dead mussels are present. The use of chlorine also presents

more risks to the user; oversaturation of the air can cause the mucous membrane to become irritated and severe coughing can occur (West Virginia Department of Health and Human Resources 2010). With drinking water plants in particular, high chlorine concentrations in the water may impact the taste and odour (Roche and Benanou 2007) . In the USA, chlorine discharge limits permissible in receiving water should not exceed 19 µg/L more than once every three years on average under the acute toxicity criterion. Under the chronic toxicity criterion, the 4 day average concentration should not exceed 11 µg/L more than once every three years on average (Tikkanen et al 2001).

Marrone Bio Innovations (MBI), a company specialising in the development and commercealisation of natural biocides in Davis, CA, USA, is the commercial license holder of *Pseudomonas fluorescens* strain CL145A; a microbe used to control invasive zebra and quagga (dreissenid) mussels. In 2012, MBI registered and commercialised Zequanox, a spray dried powder comprised of killed *Pseudomonas fluorescens* CL145A cells, in the United States and Canada. *Pseudomonas fluorescens* CL145A cells have been shown to be lethal to dreissenid mussels (Molloy et al 2013a), but pose minimal to no risk to other aquatic organisms (Molloy et al 2013b). This bacterial species is present worldwide and commonly found in food. In nature, it is a harmless bacterial species that is known to protect the roots of plants from disease (Marrone Bio Innovations 2012). It has been shown that killed *Pseudomonas fluorescens* CL145A cells have no negative impacts to aquatic organisms in Irish waters at treatment concentrations required to achieve >80% zebra mussel mortality (ecotoxicology trials Sara Meehan unpublished).

The main objective of this study was to demonstrate the efficacy of MBI 401 FDP (a developmental formulation of Zequanox) at controlling zebra mussels in Ireland. This was done in a biobox trial at a drinking water treatment plant by comparing juvenile settlement pre and post treatment with MBI 401 FDP as well as adult mussel survival after treatment. In addition, these results were compared to juvenile settlement and adult mussel survival after chlorine treatment in the plant's raw water chambers. Water quality, before, during and after treatment with MBI 401 FDP, was also monitored to determine the impact from treatment to source water quality and to the environment.

Sligo drinking water treatment plant, Ireland

This research study was carried out at a drinking water treatment plant, located on the perimeter of Sligo city in the north-west of Ireland (54°25'07"N, 08°45'22"W). This plant extracts between 6000 to 7500 m^3 of raw water per day for treatment from a nearby lake, Lough Gill (14.3 km^2). The raw water chambers in the plant house are infested with zebra mussels (Figure 1). During summer reproduction, the free floating zebra mussel larvae (veligers) are able to pass through the first stage of mesh filtration at the lake abstraction point. The veligers are then pumped 1 km with the influent water, via the intake pipe, and then enter the water chambers in the treatment plant where they settle on the walls and begin to grow. Lough Gill has been infested with zebra mussels since approximately 2004 and high densities were present in the raw water chambers by 2009.

Sligo drinking water treatment plant began using chlorine to treat the zebra mussel infestation in the raw water chambers in 2009 and have been treating once a year, in autumn following the reproductive season. During treatment, the plant is forced to shut down the chambers being treated; this process delays operations for the duration of the treatment (typically seven days) as well as the additional time for the set up and break down of the treatment.

Materials and methods

Biobox and chamber set up

Bioboxes are used to monitor mussel settlement in power plants or other similar facilities by mimicking the flow in industrial piping and demonstrating the resulting zebra mussel settlement in piping and water chambers (Mackie and Claudi 2010). The biobox is connected to the main inflow of raw water to the plant.

Three 200 L bioboxes were placed on a flow through system in the Sligo drinking water treatment plant on the 13th of July 2011 (Figure 2). These tanks received water from the water treatment plant's main chambers via gravity flow, with a total flow of 287,000 L over 13 weeks until the 11th of October 2011. Of these three tanks, one was established to serve as the experimental control (tank 1) and the other two (tanks 2 and 3) were to receive MBI 401 FDP treatments. The tanks were covered with heavy plastic with weights on each side to protect from any harsh weather exposure or interference.

Figure 1. Zebra mussel infestation in raw water chambers at Sligo drinking water plant (photograph by Eamon Fox).

Figure 2. Bioboxes outside of Sligo drinking water treatment plant (photograph by Sara Meehan).

Three PVC plates (15 cm × 15 cm) were placed in each of the three tanks to allow for natural zebra mussel settlement (Marsden 1992; Lucy 2006). These plates were suspended in the tanks from a metal rod inserted lengthways across the top of the tank. Every week, either the middle or bottom plate was removed (in rotation) and replaced by a new plate so biweekly juvenile settlement rates could be estimated (Marsden 1992; Lucy 2006). The top plate was maintained throughout in order to monitor seasonal settlement. Water temperature, dissolved oxygen, and pH were recorded every week in each tank using a handheld Orion 5-star meter.

Three PVC plates (15 cm × 15 cm) were also placed in each of the plant's three raw water chambers on the 13th of July 2011. These plates were suspended lengthways from the top of each chamber and were held in place by a rope hung from a ladder (Figure 3). Of these three chambers, one was established to serve as the experimental

Figure 3. Bags with adult mussels and PVC juvenile settlement plates attached to the suspension rope, deployed in the drinking water treatment plant chambers (photograph by Sara Meehan).

control (chamber B) and the other two (chambers A and C) were to receive chlorine treatment. Weekly removal of plates and recording of water quality parameters was the same as for the bioboxes.

Preparation of bioboxes and chambers for MBI 401 FDP and chlorine treatment

In addition to measuring and treating juvenile settlement, adult zebra mussels from a wild population in Lough Conn, Co. Mayo were seeded into each of the bioboxes to test whether treatment is effective on all life stages (Mackie and Claudi 2010). Three mesh bags containing 50 mussels each were suspended in each biobox on the 7th of October 2011; this was 3 days in advance of treatment to allow the mussels to acclimatise (Figure 4).

Prior to treatment on the 10th of October 2011, the bioboxes were moved from the water treatment plant to the research facility at IT Sligo (Figure 5). The bioboxes were then no longer on a flow-through system. Twenty-four hours prior to MBI 401 FDP treatment, the seeded mussels were checked for mortality and any dead mussels were replaced with healthy, live mussels.

Pre-treatment juvenile settlement on the PVC plates was assessed. The middle and bottom plates in the treated tanks (tanks 2 and 3) were removed prior to treatment due to the low numbers of established mussels. The top plate (which was the plate that accumulated settlement over the duration of the settlement season) was left in the bioboxes for treatment. Treatment was carried out after the Irish seasonal reproductive period (Lucy 2006).

One week after treatment of the bioboxes with MBI 401 FDP, the treatment of the raw water chambers at the drinking water treatment plant took place on the 17th of October 2011. The same methods for assessing adult mortality and juvenile settlement were applied here as with the bioboxes - adult mussels were seeded into the chambers and the top plate was assessed for settlement before repositioning in the chambers.

Application in bioboxes

MBI 401 FDP (a dry powder) was a 100% active substance (or active ingredient). The powder was mixed on-site with Lough Gill water to create the following stock solution concentration:

$C_1V_1 = C_2V_2$ where

C_1 = target treatment concentration (mg active substance (a.s.)/L)

Figure 4. Bags with adult mussels used to assess mortality were suspended in the bioboxes and chambers (photograph by Sara Meehan).

Figure 5. Bioboxes set up outside of IT Sligo (photograph by Sara Meehan).

V_1 = volume of bioboxes (200 L)

C_2 = stock concentration (g a.s./L)

V_2 = volume of stock concentration to be injected (ml).

The target concentration was 200 mg active substance (a.s.)/L. These preliminary tests were carried out with the maximum allowable concentration in the U.S. in order to show efficacy and potential impact to water quality.

For each tank treated, 42 g (a.s.) of product was mixed with 0.93 L of water on a stir plate to achieve a stock concentration of 45 g (a.s.)/L. This stock concentration was injected into each

tank at a rate of 50 mL/min for 19 minutes to achieve the target concentration of 200 mg a.s./L. The product was fed to the tanks using a peristaltic pump. A mixer was placed in the chambers to keep the product in suspension for the duration of the treatment.

As MBI 401 FDP is comprised of organic material, it is known that turbidity and MBI 401 FDP concentrations are strongly correlated. To confirm that the target concentration of MBI 401 FDP in each treatment tank was reached and maintained, a site specific linear regression was developed to determine the linear relationship between product concentration and turbidity (Figure 6). This was done according to MBI standard operating procedure, Turbidity and MOI-401 Active Ingredient Correlation and Application Monitoring (MBI personal communication). Turbidity was monitored throughout the application and post-treatment period with a Hach 2100N turbidimeter.

Once the target concentration was reached, the treated water was held for 8 hours. The application time was based on previous trials carried out by MBI at Davis Dam, Lower Colorado River, and Bullhead City, Arizona, USA. After the 8 hour treatment time, the tanks were rinsed three times and replaced with fresh Lough Gill water that was transported to IT Sligo in 1000 L containers. All MBI 401 FDP treated water was discharged to the sewer.

After all rinses were completed, bioboxes were transported back to the drinking water plant and hooked back up to the flow through system. Adult and juvenile mussels were then checked for mortality, initially daily and eventually once a week until juvenile survival reached zero and adult mussel mortality reached a plateau.

Water quality in bioboxes treated with MBI 401 FDP

Water quality samples were taken before treatment, during treatment at 4 and 8 hours, and for each of the three rinses in treated tank 3 and the control tank. Water quality measurements included: temperature, dissolved oxygen (DO), pH, turbidity, biological oxygen demand (BOD), and total organic carbon (TOC). DO, pH and temperature were measured with an Orion 5 star meter. The analysis of BOD and TOC were subcontracted out to Alcontrol Laboratories. BOD was analysed following MEWAM BOD5 2nd Ed.HMSO 1988/ Method 5210B, AWWA/ APHA, 20th Ed., 1999; SCA Blue Book 130 and TOC was determined using US EPA Method 415.1 & 9060.

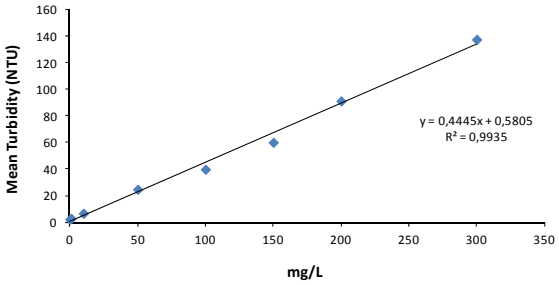

Figure 6. Site specific linear regression of MBI 401 FDP concentration and turbidity.

Application in chambers

On the 17th of October 2011, the raw water chambers were treated with chlorine. The chambers receiving treatment were bypassed meaning that the raw water goes directly to the pre ozone chamber bypassing micro straining. The treatment was carried out by the plant manager where drums of chlorine were slowly poured into the receiving chambers. The chlorine concentration was monitored via a hand held meter to ensure that the concentration of 2 mg/L residual chlorine was maintained in the treated chambers; when the concentration dropped below 2 mg/L more chlorine was added. This treatment was carried out over a total of seven days; adult and juvenile mussels were then checked for mortality, initially daily and eventually once a week until juvenile survival reached zero and adult mussel mortality reached a plateau.

Results and discussion

Several long-standing and accepted chemical treatment methods exist for controlling zebra mussels, including chlorination. Chorine however, carries potential impacts for the surrounding environment and potential hazards to the user during its application, all previously stated. A need exists for a control method that has a quick application time and does not pose risks to the receiving water and the user. The results presented below demonstrate the efficacy of MBI 401 FDP in controlling zebra mussels and compares MBI 401 FDP treatment to chlorine treatment.

MBI 401 FDP treatment - juvenile mussels

Juvenile settlement counted biweekly prior to treatment was relatively low reaching a peak of 5,000 juveniles/m^2 in the control biobox on the 10th of August 2011. As the number of settled juveniles is determined by the number of planktonic larva in the water, which in turn is determined by the water temperature (Lucy 2006; Garton and Haag 1993), relatively low summer water temperatures in 2011 (reaching < 10°C in August in the bioboxes) may have contributed to low settlement rates. In another Irish study, settlement reached a peak of 170,000 juveniles/m^2 where temperatures where higher and the same methodologies for gathering settlement was used (Lucy et al. 2005). Seasonal plates are also known to underestimate total natural settlement but are considered a good proxy (Lucy et al. 2005).

For the seasonal settlement plates, the control tank had the highest settlement with 4,670 juveniles/m^2, treated tank 2 had 3,670 juveniles/m^2, and treated tank 3 had 2,000 juveniles/m^2 (Figure 7). Treated juvenile survival declined rapidly between treatment and day 3; treated tank 2 reached 18% survival by day three and 0% survival seven days after treatment and treated tank 3 reached 16% survival by day three and 0% survival 6 days after treatment. The juvenile survival in the control began to decline between day 3 and 6. It is hypothesised that this decline in the control tank occurred from natural causes, as by day three, juvenile settlement was nearly depleted in treated tanks 2 and 3, whereas in the control tank, juvenile numbers did not begin to decline until after day three. The decline in the control and treated plates after day 3 could be attributed to the regular removal of the plates from the biobox for monitoring settlement and other natural causes. Additionally, according to Nichols (1996), 20% up to 100% natural mortality can occur pre and post settlement. It is hypothesised that the decline in juvenile survival prior to day 3 in treated tanks 2 and 3 was due to MBI 401 FDP treatment.

Chlorine treatment – juvenile mussels

Juvenile settlement measured biweekly in the chambers, prior to treatment, was relatively high in comparison to the biweekly biobox settlement reaching a peak of 14,670 juveniles/m^2 in chamber A on the 4th of August. Although this count is higher than that of the bioboxes it is still relatively low in comparison to the juvenile settlement measured in the study by Lucy et al (2005) for the 1st week of August between 2001 to 2003.

Treated chamber C had the highest seasonal settlement with 31,000 juveniles/m^2, treated chamber B had 18,330 juveniles/m^2, and control chamber A had 10,670 juveniles/m^2. Figure 8 displays mean juvenile counts in the water chambers before and after treatment with chlorine. Treated juvenile survival declined rapidly between treatment and day 2; treated chamber A reached 12% survival by day two and 0% survival six days after treatment and treated chamber C reached 35% survival by day two and 0% survival 6 days after treatment. The juvenile survival in the control began to decline between treatment and day 2. Although control survival initially declined more rapidly than treated chamber C, overall survival reached 0% more rapidly in the treated chambers, therefore we can attribute this decline in survival to treatment with chlorine, with decline in juvenile survival on the control plate resulting from its removal from the chambers during examination.

MBI 401 FDP treatment - adult mussels

After treatment, adult mussel mortality was monitored every 2–3 days for 16 days and then weekly for four weeks. At the end of the monitoring period on day 48 the control tank had 1.3% mortality, treated tank 2 had 80% mortality, and treated tank 3 had 81% mortality (Figure 9). Most of the adult mortality in the bioboxes occurred within the first 16 days after treatment; in treated tank 2 mortality was at 71% and in treated tank 3 mortality was at 76% by day 16. In similar biobox studies conducted in North America and Canada, >90% adult mussel mortality was observed (Figure 10). The water temperature during the Irish treatment was 13.8°C and for the post treatment monitoring period the min and max temperature was 13–15°C, in trials conducted in the USA the average water temperature was > 16°C.

Chlorine treatment - adult mussels

Adult zebra mussel mortality after treatment with chlorine was monitored every 2–3 days for ten days and then weekly for five weeks until 80% mortality was reached (the plant's treatment goal). In treated chamber A, by day 16, the adult mortality was at 76.5% reaching 87% by day 49, and in treated chamber C, at day 16, mortality was 79% reaching 83% by day 49 (Figure 11).

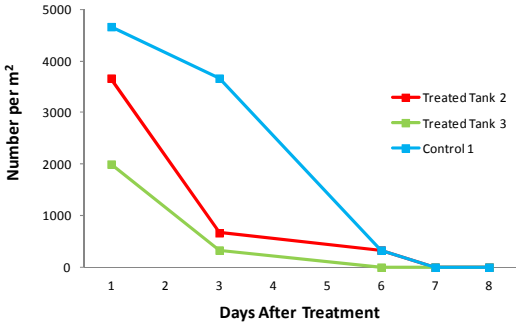

Figure 7. Mean number of juvenile mussels in the bioboxes after treatment with MBI 401 FDP.

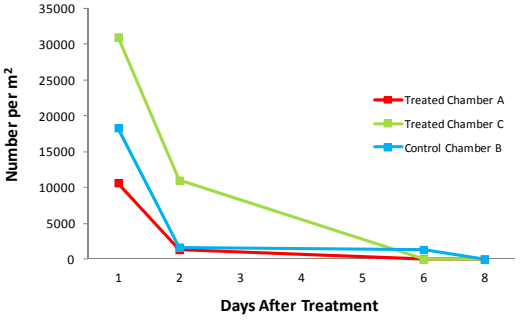

Figure 8. Mean number of juveniles in the water chambers after treatment with chlorine.

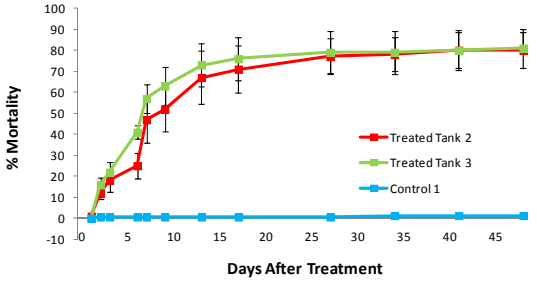

Figure 9. Mean mortality (± SD) of adult mussels in bioboxes after treatment with MBI 401 FDP.

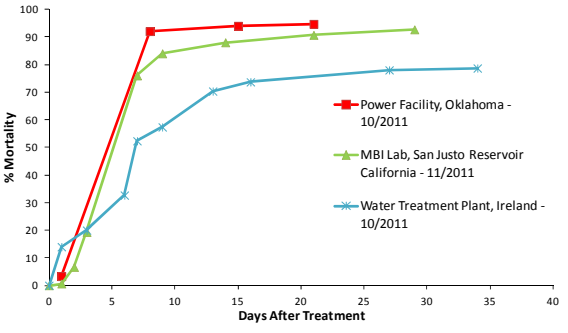

Figure 10. 2011 biobox trials with MBI 401 FDP in North America and Ireland.

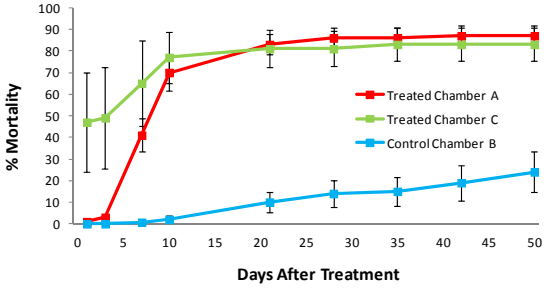

Figure 11. Mean mortality (± SD) of adult mussels in chambers after treatment with chlorine.

The low water temperature during chlorination (< 10°C) directly affects the length of time chlorination is required (Rajagopal et al. 2002) and the length of time it takes for mortality to reach > 70%. At the end of the monitoring period mortality in control chamber B was 24%. It is unknown why control mortality reached 24%; nevertheless, the high mortality attained in both the treated chambers indicates the treatment was effective. The rate of adult mussel mortality after chlorine treatment is on par with the mortality after MBI 401 FDP treatment.

Table 1. Water quality results before, during (4 and 8 hours) and after (3 rinses) biobox treatment with MBI 401 FDP. R1 = rinse 1, R2 = rinse 2, R3 = rinse 3.

Sample Date	Location	Turbidity (NTU)	Temp (°C)	BOD	TOC	pH	DO
Before Treatment							
	Control Tank 1	3.27	14.6	1.21	15	7.84	9.08
11-Oct	Treated Tank 3	3.18	14.5	2.94	10.6	7.82	9.23
4hr							
	Control Tank 1	2.79	14.5	1.48	15.2	7.76	8.93
11-Oct	Treated Tank 3	80.1	14.5	9	56.2	7.59	9.07
8hr							
	Control Tank 1	2.34	14.7	1.58	10	7.71	8.7
11-Oct	Treated Tank 3	79.3	14.9	8.81	54.6	7.59	8.81
R1							
	Control Tank 1	5.81	15	1.04	9.73	8.04	9.63
11-Oct	Treated Tank 3	7.36	15	2.14	10.3	7.83	9.68
R2							
	Control Tank 1	4.99	16	3.59	9.9	7.86	10.7
12-Oct	Treated Tank 3	4.48	15.9	3.22	9.91	7.89	10.6
R3							
	Control Tank 1	3.99	14.8	2.61	9.59	7.86	9.4
13-Oct	Treated Tank 3	4.35	14.6	1.17	9.41	7.96	9.22

MBI 401 FDP treatment - water quality

Results of water quality parameters taken before, during and after MBI 401 FDP treatment are presented in Table 1. These results, though gathered from samples in the static bioboxes, give an indication of the effects MBI 401 FDP would have on water quality if used in a similar static treatment in the raw water chambers of the Sligo drinking water treatment plant. However, if used in the plant the treated water would be discharged gradually back to the receiving lake, Lough Gill and would eventually be heavily diluted upon discharge. In treated tank 3, the temperature ranged from 14.5–15.9°C, and pH varied between 7.59 and 7.96. The turbidity ranged between 3.18 and 80.1 NTU. Dissolved oxygen varied between 8.81 and 10.61 mg/L. Biological oxygen demand (BOD) ranged between 1.17 and 9 mg/L and the TOC ranged between 9.42 and 56.2 mg/L.

Measurements of temperature, DO and pH did not differ by more than ± 1 unit before during and after treatment in the bioboxes; therefore, the treatment had little effect on these parameters. Turbidity did increase substantially; however, since turbidity and MBI 401 FDP concentration are strongly correlated, this increase was expected. After the three rinses, turbidity returned to background levels. An increase in turbidity is due to the nature of the product which is primarily composed of particulate organic matter.

A similar trend occurred with the BOD, which also increased to a peak of 9.00 mg/L during treatment at 4 hours and went down to 8.81 mg/L at 8 hours. Over time, it is expected that the BOD measurements would have continued to decrease as the dissolved organic matter degraded (Graham and Gilbert 2012). TOC followed the same pattern as BOD; at 4 hours it increased to 56.2 mg/L and then decreased to 54.6 mg/L at 8 hours. The TOC increased over the 8 hour treatment duration but decreased to background levels after the first rinse. This increase in TOC was expected as the product is primarily particulate organic matter.

Conclusions

Adult mortality reached 80% after treatment with both chlorine and MBI 401 FDP. The mortality of adults after chlorine treatment reached 80% by day 20. After MBI 401 FDP treatment, mortality was at 76% by day 20 and reached 80% by day 27. Mayer (2011) demonstrated that at lower water temperatures following treatment with *Pseudomonas fluorescens* mortality is slower. This was apparent in this trial when compared to

those carried out in the USA (Figure 10) mortality at Cairns Hill was slower to occur as the water temperature was lower.

It must be remembered that MBI 401 FDP treatment duration was 8 hours and chlorine treatment duration was 7 days. MBI 401 FDP treatment can begin and end within the working day whereas chlorine treatment is a continuous 24 hours a day treatment, and in this instance, 7 days long. This does not include the set up and breakdown. Chlorine treatments require this longer application time because the zebra mussels recognise chlorine as a harmful substance and shut their valves and cease feeding (Rajagopal et al 2003). Formulated *Pseudomonas fluorescens* CL145A cells (like those in MBI 401 FDP), however, are not recognised as harmful and the zebra mussels feed readily on them (Marrone Bio Innovations 2012).

Studies indicate *Pseudomonas fluorescens* CL145A cells specifically target zebra and quagga mussels (Molloy et al 2013b). In addition to many non-target studies carried out in the USA, (Molloy et al 2013b) Canada, and Europe, non-target trials carried out at IT Sligo in accordance with OECD and ASTM guidelines on 12 Irish aquatic organisms (some of which were collected from Lough Gill) show that calculated median effective concentration or median lethal concentration values were noted to be in excess of the treatment rates.

Chlorine is a general biocide; with its original purpose being a bleaching agent, chlorine gas was also used as a chemical warfare agent (Winder 2001). Airborne chlorine gas at a concentration of 3 mg/L causes mild irritation of the mucous membrane (the concentration used in this study fits within this category), above 5 mg/L causes eye irritation, 15–30 mg/L causes a cough, choking and burning, and finally 430 mg/L causes death after just 30 seconds exposure (Winder 2001). *Pseudomonas fluorescens* CL145A cells are designated as "Biosafety Level 1" by the American Type Culture Collection, and are defined as "having no known potential to cause disease in humans or animals" by American Biological Safety Association.

This study shows that MBI 401 FDP was an effective alternative zebra mussel control method and could be used in place of chlorine treatments, or, in conjunction with chlorine treatments in an Integrated Pest Management program (IPM). As an example, for this Sligo water treatment plant, a final chlorine treatment or an MBI 401 FDP treatment at 100–150 mg a.s./L at the end of the season could be performed to control zebra mussels in the system.

Moving forward, this trial has offered a suitable alternative to chlorine and has shown MBI 401 FDP's effectiveness as a zebra mussel control option.

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