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COMPARISON OF THREE SODIUM CHLORIDE CHEMICAL TREATMENTS FOR ADULT ZEBRA MUSSEL DECONTAMINATION

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ABSTRACT Chemical treatment for the control of the spread of zebra mussels in watercraft is typically focused on the early life stages of the mussel. Adult mussels may be spread via attachment or entangling to gear that is brought on board. Sodium chloride is a chemical that has been recommended for use during some aquacultural practices as a mussel disinfectant. The effectiveness of three sodium chloride–based salts (high-grade sodium chloride, iodized table salt, and water softener salt) was examined for their use as an adult zebra mussel decontamination solution. High-grade sodium chloride and iodized table salt both caused complete mortality at 30,000 mg/l in 24 h. Water softener salt caused complete mortality at the same concentration at 48 h. Iodized table salt caused complete mortality at a lower concentration faster than the laboratory-grade sodium chloride. On the basis of the results of this study, iodized table salt may be an acceptable alternative to high-grade sodium chloride for decontamination of zebra mussels, costing much less and leading to an increase in spread-prevention effectiveness.

KEY WORDS: sodium chloride, zebra mussel, *Dreissena*, decontamination, iodized table salt, water softener salt

INTRODUCTION

The zebra mussel *Dreissena polymorpha* (Pallas, 1776) is a bivalve native to the Black, Caspian, and Azov Seas in eastern Europe (Benson et al. 2014), which was discovered in North America in the 1980s. It spread rapidly throughout the northeast and upper mid-western United States, mostly through overland transport by trailered watercraft (Padilla et al. 1996, Johnson et al. 2001). The continued spread of the zebra mussel and a second dreissenid, the quagga mussel *Dreissena rostriformis bungensis* (Andrusov, 1897), into the western United States has led some government agencies to create inspection (Zook Phillips 2015) and disinfection programs (DiVittorio 2015) to prevent their further spread. Chemical treatments are one of the several methods recommended for the decontamination for watercraft and equipment by the U.S. Bureau of Reclamation (DiVittorio et al. 2012). Chemical treatments are recommended for the treatment of larval stage mussels, not adults (DiVittorio et al. 2012). This is because adult mussels can detect chemicals, such as chlorine, in the water and close their valves to avoid additional exposure (Rajagopal et al. 2002). Recommended chemicals for zebra mussel decontamination are diluted household chlorine bleach, undiluted white vinegar, potassium permanganate solution, and quaternary ammonium solution (DiVittorio et al. 2012). The use of sodium chloride as a treatment for decontamination has been recommended for aquaculture practices where water-containing fish can be treated without causing mortality to the fish (Waller et al. 1996, Pucherelli et al. 2014). Both studies investigated the use of sodium chloride as a treatment for veligers, not adults. This was because the water being used for aquaculture purposes can be filtered to keep adult mussels from entering haul trucks or other tanks (Waller et al. 1996). There are other situations where adult mussels could be transported overland, such as attachment to equipment or gear used during recreational boating or the collection of scientific data. This study looked to investigate the potential use of sodium chloride as a disinfectant for adult zebra mussels for recreational watercraft users. Our first hypothesis was that sodium chloride would cause 100% mortality of adult mussels within 96 h of exposure. The sodium chloride used in most laboratory testing is of high grade and is not the same as sodium chloride–based salts available to the average watercraft user. Therefore, the effectiveness of two sodium chloride–based salts (iodized table salt and water softener salt) was tested to compare their results to the high-grade sodium chloride results. Our second hypothesis was that the sodium chloride–based chemicals would work equally as well as the high-grade sodium chloride at causing mortality to adults.

MATERIALS AND METHODS

Adult Collection and Preparation

Rocks colonized by adult mussels were collected in the fall of 2014 at the State University of New York College at Oneonta Biological Field Station Thayer Boathouse on Otsego Lake, NY, in water around 1 m depth using a variety of clam rakes. The rocks were brought back to the laboratory in trays and coolers. Mussels were removed from the rocks using a paint scraper (similar to Costa et al. 2008) and were placed into a small tray with a constant flow of fresh Otsego Lake water. Mussels bunched together via byssal threads were pulled apart and placed into the tray. Once all the mussels were in the tray, 11 mussels were selected at random and placed into a 800-μm-mesh bag. Those with any physical damage were discarded. A total of 150 bags were filled with mussels. All extra individuals were placed into a separate bag. The bags were placed into a large aquarium (~150 l) with a slow constant flow of lake water for at least 72 h for the mussels acclimate to the bags and to determine any mortality due to handling and/or stress (similar to Comeau et al. 2011). The aquarium was lightly aerated with compressed air. After the 72-h holding period, the mesh bags were removed one at

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TABLE 1.

Collection date, experiment start date, and average water quality parameters measured from the holding tank and experimental tanks ($n = 3$ tanks per concentration level) at 24-h intervals during each experiment in the fall of 2014.

Treatment	Collection date	Experiment start date	Tank/concentration	Time (h)	Temperature (°C)	Specific conductivity (mS/cm)	pH	Dissolved oxygen (mg/l)
High-grade sodium chloride	October 16	October 19	Holding tank	0	16.40	0.312	8.39	9.10
				24	16.30	0.368	8.59	9.99
				48	17.05	0.288	9.11	8.92
				72	16.86	0.299	9.15	8.95
				96	16.67	0.309	9.18	8.97
			0 mg/l	0	15.05	0.298	8.40	9.63
				24	18.27	0.315	8.14	10.19
				48	18.75	0.291	8.43	9.09
				72	18.81	0.291	8.51	9.06
				96	18.88	0.292	8.60	9.03
			500 mg/l	0	15.19	1.253	8.09	9.52
				24	18.16	1.303	8.14	10.22
				48	18.55	1.210	8.22	9.06
				72	18.67	1.214	8.27	9.04
				96	18.79	1.219	8.33	9.02
			3,000 mg/l	0	15.18	5.628	8.08	9.46
				24	18.20	5.850	8.18	10.04
				48	18.70	5.419	8.16	8.90
				72	18.79	5.427	8.19	8.88
				96	18.89	5.435	8.22	8.86
			10,000 mg/l	0	15.18	16.813	7.91	9.20
				24	18.26	17.477	8.07	9.63
				48	18.81	16.197	8.08	8.51
				72	18.89	16.230	8.09	8.45
				96	18.98	16.263	8.11	8.38
			30,000 mg/l	0	14.88	45.257	7.70	8.47
				24	18.41	47.263	7.97	8.53
				48	18.91	43.723	7.99	7.60
				72	18.97	43.815	7.98	7.57
				96	19.02	43.907	7.97	7.54
Iodized table salt	October 24	October 28	Holding tank	0	15.85	0.339	8.37	9.55
				24	18.30	0.336	9.01	8.99
				48	17.14	0.323	8.96	9.00
				72	16.55	0.316	8.93	9.00
				96	15.97	0.309	8.90	9.00
			0 mg/l	0	17.16	0.307	8.22	9.30
				24	19.09	0.293	8.19	8.95
				48	18.76	0.295	8.30	9.07
				72	18.60	0.295	8.35	9.13
				96	18.43	0.296	8.41	9.18
			500 mg/l	0	16.91	1.271	8.01	9.36
				24	18.95	1.223	8.01	8.94
				48	18.64	1.226	8.07	9.03
				72	18.48	1.227	8.10	9.08
				96	18.33	1.229	8.14	9.12
			3,000 mg/l	0	16.84	5.453	7.92	9.32
				24	18.89	5.556	8.01	8.78
				48	18.53	5.581	8.06	8.90
				72	18.34	5.593	8.08	8.96
				96	18.16	5.606	8.11	9.01
			10,000 mg/l	0	16.74	16.317	7.86	9.27
				24	18.91	16.497	8.00	8.48
				48	18.53	16.588	8.03	8.57
				72	18.33	16.634	8.04	8.61
				96	18.14	16.680	8.06	8.65
			30,000 mg/l	0	16.59	44.497	7.67	8.62

continued on next page

TABLE 1.

Continued.

Treatment	Collection date	Experiment start date	Tank/concentration	Time (h)	Temperature (°C)	Specific conductivity (mS/cm)	pH	Dissolved oxygen (mg/l)
				24	19.00	45.007	7.94	7.52
				48	18.69	45.140	7.92	7.59
				72	18.53	45.207	7.91	7.62
				96	18.38	45.273	7.90	7.65
Water softener salt	November 13	November 18	Holding tank	0	14.24	0.324	8.68	10.55
				24	14.47	0.321	8.51	10.18
				48	14.58	0.323	8.53	10.14
				72	15.38	0.322	8.45	10.24
				96	15.14	0.317	8.32	10.05
			0 mg/l	0	10.79	0.314	8.26	10.39
				24	17.75	0.313	8.18	9.88
				48	17.81	0.312	8.16	9.68
				72	17.97	0.313	8.15	9.82
				96	18.05	0.310	8.13	9.14
			500 mg/l	0	10.65	2.130	8.14	10.56
				24	17.76	2.130	8.12	9.73
				48	17.83	2.120	8.14	9.82
				72	17.87	2.140	8.13	9.86
				96	17.90	2.133	8.08	9.14
			3,000 mg/l	0	10.70	5.466	8.04	10.50
				24	17.72	5.580	8.08	10.10
				48	17.84	5.520	8.10	9.76
				72	17.88	5.530	8.08	9.43
				96	17.89	5.576	8.10	9.00
			10,000 mg/l	0	10.69	15.773	7.92	10.24
				24	17.70	15.920	7.98	9.93
				48	17.81	16.260	8.00	10.00
				72	17.92	16.310	8.04	9.99
				96	18.04	16.847	8.07	8.47
			30,000 mg/l	0	10.76	36.267	7.69	9.54
				24	17.63	38.270	7.74	8.52
				48	17.80	37.840	7.77	8.75
				72	18.02	38.860	7.79	8.30
				96	18.23	41.793	7.89	7.53

a time and the mussels inside were examined for mortality. If there was a dead individual, it was removed from the bag. If no mortality occurred, one mussel was selected at random and removed from the bag. If multiple mortalities occurred, the dead mussels were removed and live specimens from the extra bag of mussels were used to bring the total to 10 individuals per bag. The number of mortalities during the acclimation period was less than 10.

Chemical Treatment

A total of 15 glass tanks were rinsed with lake water and scrubbed with a sponge soaked in lake water. The tanks were then emptied, rinsed, and emptied again. To each tank, 20 l of Otsego lake water was added. The needed amount of each chemical was measured on an electronic scale and then added to a tank. The four chemical concentrations used for the treatments were 500, 3,000, 10,000, and 30,000 mg/l; the highest concentration being the equivalent of seawater. Also, 10,000 mg/l was the concentration found to be effective on zebra mussel veligers and settlers by Waller et al. (1996). There were three replicates of each concentration as well as three control tanks with no chemicals. Once the salt was added to the water in a tank, the water was mixed with a wooden dowel until the chemical was completely dissolved. The tanks were prepared from weakest to strongest concentration (all 500 mg/l tanks were prepared, then the 3,000 mg/l tanks were prepared, etc.) and the dowel was rinsed with lake water between tanks. The chemicals that were tested were sodium chloride ($NaCl$; Amresco, Solon, OH), iodized table salt (Morton Salt, Inc., Chicago, IL), and sodium chloride–based water softener salt (Solar Extra Coarse Crystals; Culligan International Company, Rosemont, IL). Airstones were added to each tank and they were lightly aerated with compressed air to ensure continued mixing of the treatment water. Once all tanks had been mixed and all chemicals were dissolved, 10 bags of mussels were placed into each aquarium and hung from a wooden dowel. Each bag represented an exposure period (0, 1, 2, 4, 6, 12, 24, 48, 72, and 96 h). After all tanks had their bags immersed, the time 0 h bags were then removed from each tank. Once bags were removed from the treatment tanks, they were labeled with their exposure time and hung from wooden dowels in the large holding tank

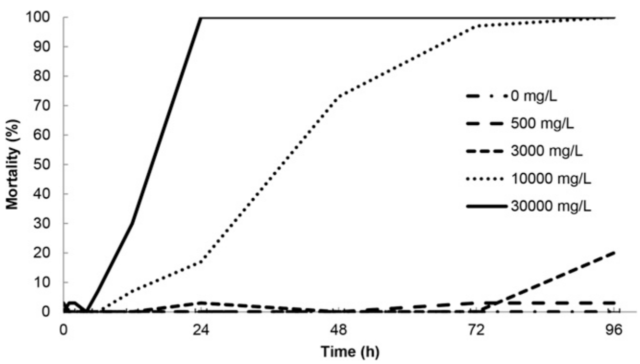

Figure 1. Average mortality (%) of adult zebra mussels (N = 3 groups with 10 mussels in each group) from Otsego Lake after exposure to sodium chloride (NaCl) of varying concentrations in Fall 2014.

originally used for mussel acclimation to the bags. One dowel would hold all the bags from an individual tank. Mussels were left in this tank for at least 48 h for recovery. Mussels were examined for mortality between 48 and 72 h after being removed from their chemical treatments. This was done because it has been shown that mussels that appear dead at the end of a chemical treatment can recover after being placed in clean water free of chemicals (Pucherelli et al. 2014). Mortality was determined by the mussel having gaping valves when removed from the mesh bag and placed on a paper towel. Mussels with a slight gap had a blunt probe placed into the valve gap and if the mussel closed it was considered alive. A mussel with no movement of the valve after probing was considered dead. Only mussels with a slight valve gap were probed, or when more than half of a sample group was fully gaping showing mortality. After mortality assessment, the shell length of each mussel was measured using a Mitutoyo Absolute digital caliper (model number: CD-6″CX; Mitutoyo Corporation, Kawasaki, Japan) and recorded along with the mortality status. Between tests, tanks were emptied, scrubbed with an abrasive pad, rinsed with lake water at least two times, and then air-dried before the next round of testing was performed.

Water Quality

An YSI (model number: 6820V2-M; YSI Incorporated, Yellow Springs, OH) multiparameter water quality sonde was used in each chemical treatment tank at times 0, 24, 48, 72, and 96 h. Before each measurement, the YSI was calibrated following standard operating protocols to ensure probe accuracy. All tanks of the same concentration were measured starting from the control tanks and increasing in concentration. The probe was rinsed with lake water between concentration levels. The water in the recovery/holding tank was measured at 0, 24, 48, 72, and 96 h. The parameters measured were temperature, specific conductivity, pH, and dissolved oxygen as percentage and as mg/l. Measurements were taken from the chemical treatment tanks after mussels had been removed for the same exposure time. Measurements in the recovery tank were also taken after mussels of the same exposure time were added to the tank. This was to measure the maximum amount of chemicals being added at a time in the holding tank, as the constant flow of fresh lake water would replace the water in the tank over time diluting the chemical.

Statistical Analysis

Descriptive statistics were run on the shell length of all mussels. They were also used to determine the average mortality for each concentration at each time interval and to create a graph showing mortality at each interval. Mortality data were used to create the LD_{50} and LD_{99} with 95% confidence intervals (CI) for 4, 6, 12, and 24 h with SAS (version 9.3; SAS Institute Inc., Cary, NC). The LD_{50} and LD_{99} were the concentrations of chemical that would result in 50% and 99% mortality of mussels for the selected exposure time. It was determined that 24 h would be the longest time that would be considered a reasonable amount of time for a watercraft to be decontaminated with chemical treatments. An analysis of variance was used to compare the shell length of mussels that were killed and those that survived, as well as by concentration. Whenever any differences were found, a Student–Newman–Keuls test was performed to determine whether the difference was between the dead and live mussels, between treatment groups, or both. The level of significance was set at $\alpha = 0.05$.

RESULTS

The water quality parameters (Table 1) in the treatment tanks and the holding tank all stayed within the range shown to be tolerated by zebra mussels in the literature during each experiment (Nichols 1992, McMahon 1996, Mackie & Claudi 2010, Claudi et al. 2012).

Sodium Chloride

The mean length of mussels in this study group was 13.98 mm with an SD of 2.96 mm. The mean length of the dead mussels

TABLE 2.

Estimated LD_{50} and LD_{99} for adult zebra mussels exposed to sodium chloride with 95% CI for exposure durations of 4, 6, 12, and 24 h and the sample dose(s) that caused 100% mortality during the experiment.

Exposure time (h)	LD_{50} (95% CI) (mg/l)	LD_{99} (95% CI) (mg/l)	SD_{100} (mg/l)
4	43,607 (36,552–52,023)	70,082 (58,744–83,608)	None
6	40,028 (35,057–45,705)	62,585 (54,812–71,461)	None
12	50,512 (31,022–34,4269)	55,2045 (142,657–381,190,827)	None
24	11,405 (10,607–12,263)	15,646 (14,551–16,823)	30,000

SD_{100} indicates the sample dose (concentration) that caused 100% mortality for a given exposure time.

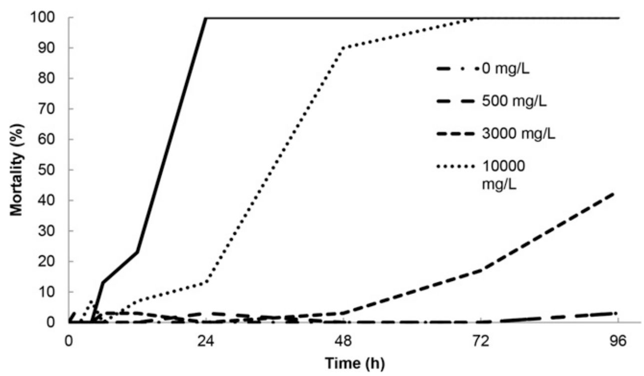

Figure 2. Average mortality (%) of adult zebra mussels (N = 3 groups with 10 mussels in each group) from Otsego Lake after exposure to iodized table salt of varying concentrations in Fall 2014.

was significantly different from the mean length of the live mussels ($F = 12.15$, $P < 0.0001$) when mussels in the control group were taken into account. The mean length of the control group was 15.03 mm compared with the other four concentrations (range 13.60–13.89 mm). The control group was removed and the mussels from the treatments were used to compare the mean lengths of the live and dead mussels. No difference was found with the control group removed ($F = 3.35$, $P = 0.0674$). Dead mussels' average shell length was 13.41 mm and live mussels' average shell length was 13.79 mm.

No exposure time less than 24 h caused complete mortality (Fig. 1). Higher concentrations of sodium chloride resulted in higher mortality than lower concentrations for the exposure periods longer than 6 h. The fastest exposure period that resulted in complete mortality was a 24-h exposure at 30,000 mg/l. Exposure periods longer than 24 h at the same concentration caused complete mortality. The only other concentration that caused 100% mortality was 10,000 mg/l with a 96-h exposure. The other treatments that caused more than 50% mortality were the 72- and 48-h exposures at 10,000 mg/l. The highest mortality caused by any other treatment was 3,000 mg/l with a 96-h exposure, which caused 20% mortality.

The estimated LD_{50} value varied greatly depending on the exposure period (Table 2). For an exposure of 4 h, it would require a concentration of over 43,000 mg/l to kill half of the mussels, whereas, the concentration needed to kill half the mussels at a 24-h exposure was 11,405 mg/l. There was also a large range in the concentration required to cause 99% mortality. The concentration range for the LD_{99} was 70,082 mg/l at 4 h to 15,646 mg/l at 24 h.

Iodized Table Salt

The mean length of mussels in this study group was 14.30 mm with an SDof 2.95 mm. The analysis of variance indicated a difference in mean lengths of the groups. The control group and the 10,000 mg/l concentration were found to be different from each other and the remaining concentrations. The concentrations of 500, 3,000, and 30,000 mg/l were found to have similar mean lengths. The mean length was not different between dead and live mussels ($F = 3.31$, $P = 0.0685$). The average shell lengths of the dead and live mussels were 14.61 and 14.24 mm, respectively.

Similar to the laboratory-grade sodium chloride, higher concentrations of table salt resulted in higher mortality than lower concentrations. The fastest exposure period that resulted in complete mortality was a 24-h exposure at 30,000 mg/l (Fig. 2). Exposure periods longer than 24 h at that same concentration also caused complete mortality. The other concentration that caused 100% mortality was 10,000 mg/l at 72- and 96-h exposures. More than 50% mortality was caused by the 48-h exposure at 10,000 mg/l. The highest mortality caused by any other treatment was 3,000 mg/l with a 96-h exposure, which caused 43% mortality. The control group had two total mortalities, one each at the 1- and 96-h exposures.

The LD_{50} and LD_{99} concentrations for table salt showed a wide range (Table 3). The concentration needed to cause 50% mortality at the 4-h exposure was 2.54282E10 mg/l and the 24-h LD_{50} was 12,698 mg/l. The LD_{99} for a 24h-exposure was 42,173 mg/l.

Water Softener Salt

Adults in this test had a mean shell length of 15.38 mm with an SD of 2.86 mm. There was no difference in shell lengths by concentration ($P = 0.37$) or between dead and live ($P = 0.26$) mussels. The average shell length of dead mussels was 15.20 mm and the average shell length of live mussels was 15.42 mm.

The fastest exposure period to cause complete mortality was 48 h at 30,000 mg/l (Fig. 3). Exposures longer than 48 h also caused complete mortality at the concentration of 30,000 mg/l. The 10,000 mg/l concentration caused complete mortality at exposures of 72 and 96 h. Concentration and exposure periods that led to at least 50% mortality were 30,000 mg/l for 12 and 24 h and 10,000 mg/l for 24 and 48 h. The control groups had complete survival at all exposure periods.

TABLE 3.

Estimated LD_{50} and LD_{99} for adult zebra mussels exposed to iodized table salt with 95% CI for exposure durations of 4, 6, 12, and 24 h and the sample dose(s) that caused 100% mortality during the experiment.

Exposure time (h)	LD_{50} (95% CI) (mg/l)	LD_{99} (95% CI) (mg/l)	SD_{100} (mg/l)
4	2.54282E10[a]	6.14127E16[a]	None
6	126,012[a]	2,686,409[a]	None
12	115,168 (40,612–19,198,530)	12,180,309 (702,349–7.61489E13)	None
24	12,698[a]	42,173[a]	30,000

[a] Indicates that no 95% CI was generated. SD_{100} indicates the sample dose (concentration) that caused 100% mortality for a given exposure time.

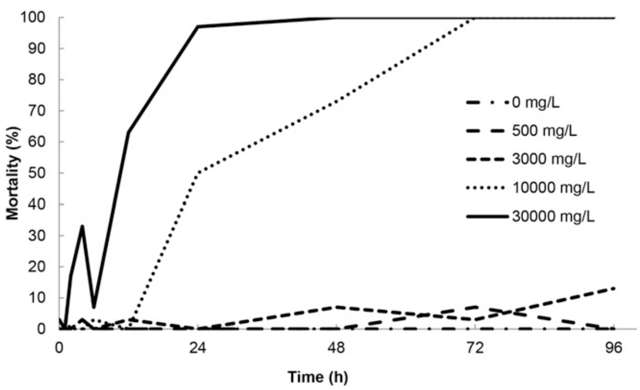

Figure 3. Average mortality (%) of adult zebra mussels (N = 3 groups with 10 mussels in each group) from Otsego Lake after exposure to water softener salt of varying concentrations in Fall 2014.

The LD_{50} and LD_{99} values for water softener salt varied greatly as well (Table 4). The LD_{50} for a 40-h exposure was 170,851 mg/l and the LD_{50} for 48-h exposure was 6,963 mg/l. The LD_{99} value for a 4 h exposure was 43,228,644 mg/l and for a 48-h exposure it was 24,836 mg/l. The exposure period of 48 h was added because it was the first exposure period that had complete mortality for any concentration.

DISCUSSION

The results of this study suggest that sodium chloride–based chemicals could be used for adult zebra mussel decontamination. Both the laboratory-grade sodium chloride and the iodized table salt caused complete mortality at the 30,000 mg/l concentration at the 24-h exposure period (Fig. 4). The 24h-exposure would be useful for when the user could wait a full day before using their equipment or watercraft. This could also be a reasonable use for people, companies, or agencies with multiple boats so that they can have access to a boat everyday if they follow an every-other-day rotation of their boats to allow enough time for full mortality of mussels. The use of sodium chloride–based water softener salt resulted in a 97% mortality after 24 h, compared with complete mortality in the other two sodium chloride–based chemicals in this test. This may be due to the impurities in the water softener salt compared with the high-grade sodium chloride and the iodized table salt. These results also show sodium chloride, table salt, and water softener salt caused complete mortality faster than in another study conducted by Ellis and MacIssac (2009). Both sequential and simultaneous changes in salinity were tested over a 48-h exposure period to mimic ballast water exchange and zebra mussel adults survived both forms of salinity change in the study (Ellis MacIssac 2009). The maximum salinity obtained during both tests was 30,000 mg/l. In sequential salinity exchange, mussels were placed in the 30,000 mg/l concentration solution from the start and left in it for the length of the study period. In simultaneous salinity exchange, the salinity of the water was slowly increased from 4,000 mg/l to 30,000 mg/l over 4 h. The sequential salinity exchange is similar to the methods used in this study, so the results can be generally compared. The lengths of mussels used by Ellis and MacIssac are not available, so direct comparisons of the sample populations cannot be made relevantly. Another possible source of variation between studies is that saltwater was created using Instant Ocean (Spectrum Brands Inc., Atlanta, GA), a salt used for creating salt water in aquariums (Ellis MacIssac 2009). This synthetically made product may contain other ionic compounds in addition to sodium chloride, leading to a lower amount of sodium chloride present in the water for the same salinity measurement based on ionic measurement. Zebra mussels have been found to have a wide salinity tolerance that is unique to the water body they are in (McMahon 1996). So it may be possible to use the 10,000 mg/l concentration when the disinfecting watercraft after exposure to bodies of water that have mussels with low levels of salt intrusion, but it may not work in water bodies with higher salinities because the mussels may have acclimated to more saline conditions. It is also worth noting the solubility of sodium chloride in water compared with the values calculated for the LD_{50} and LD_{99} values. At 20°C, 35.6 g of sodium chloride cause 100 ml of water to become saturated. That is equivalent to 356,000 mg/l.

Iodized table salt was found to cause mortality at levels similar to the laboratory-grade sodium chloride. This can be beneficial from a cost standpoint. Laboratory-grade sodium chloride can cost around US$40/kg. To create 20 l of chemical solution, as was used in this study, it would cost more than $20. Iodized table salt for the study was purchased for US$0.86 for 737 g. This is a rate of US$1.17/kg. The savings caused by using iodized table salt would allow someone to create almost 18 times more of the solution compared with laboratory grade sodium chloride for the same cost. The size of the container that iodized table salt was sold in also allows for easy conversion for the lay person. One 737-g container can be poured into 5 gallons of water to create a solution that is slightly more concentrated than the highest concentration used in this study. Water softener salt may

TABLE 4.

Estimated LD_{50} and LD_{99} for adult zebra mussels exposed to water softener salt with 95% CI for exposure durations of 4, 6, 12, 24, and 48 h and the sample dose(s) that caused 100% mortality during the experiment.

Exposure time (h)	LD_{50} (95% CI) (mg/l)	LD_{99} (95% CI) (mg/l)	SD_{100} (mg/l)
4	170,851[a]	43,228,644[a]	None
6	484,351[a]	42,534,723[a]	None
12	29,004[a]	158,103[a]	None
24	10,434 (8,254–12,936)	35,484 (24,542–76,468)	None
48	6,963 (5,520–8,716)	24,836 (17,148–50,470)	30,000

[a] Indicates that no 95% CI was generated. SD_{100} indicates the sample dose (concentration) that caused 100% mortality for a given exposure time.

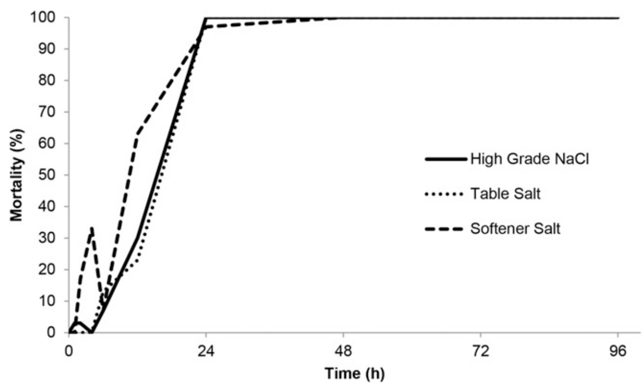

Figure 4. Average mortality (%) of adult zebra mussels (N = 3 groups with 10 mussels in each group) from Otsego Lake after exposure to sodium chloride solutions at 30,000 mg/l in Fall 2014.

be an alternative for boaters who do not plan on using their boat for a longer period. Water softener salt is typically even cheaper (~US$0.28/kg) than iodized table salt. It is sold in much larger quantities, usually about 40 lbs or 18.14 kg. This size package would certainly last longer, but would require one to measure the salt out for decontamination every time. There are 273 g of table salt in one U.S. cup. Assuming that the density is not extremely different between the table salt and softener salt, it would require less than 2.25 cups of softener salt to create 20 l of solution.

The use of sodium chloride to disinfect watercraft exteriors would be difficult because it would require a pond or holding tank where watercraft would have to be left for 24 h to cause complete mortality of adult mussels. Adult mussels are macroscopic and can be removed from a boat hull with a scraper, as long as they are in a location that can be physically reached. Sodium chloride–based solutions would be useful for the treatment of gear such as ropes, chains, and anchors that can be completely immersed in the chemical treatment. Also, areas in watercraft that can hold water for extended periods of time, such as livewells and anchor boxes, could be disinfected by these solutions. The high salinity of these solutions could be corrosive to sensitive areas of watercraft so they may not work in all situations. It may be possible to rinse the area with either tap or well water to remove any mineral buildup after the needed exposure period is complete.

It has been suggested that zebra mussel adults have seasonal differences in filtration rates (Diggins 2001, Costa et al. 2008). Because of this, it was found that mussels may vary by a factor of up to 22 times between summer and winter, in susceptibility to chemical treatments based on those changes in filtration (Costa et al. 2008). Therefore, it would be beneficial to repeat this study at least once, in June, to determine if the zebra mussels in Otsego Lake are more susceptible to given concentrations of sodium chloride than they had been in the previous fall. A seasonal difference in susceptibility would allow for the use of fewer chemicals during a portion of the year that would decrease the prices of disinfection treatments. The change in susceptibility over time could explain the lower mortality caused by the softener salt. A test that examined the results of all three chemicals at the same time was not possible due to limited laboratory space. A concurrent test of all three chemicals in the future would be beneficial to eliminate any possible variation in susceptibility due to the difference in sample dates.

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