The Effects of Strobe Lights on Zebra Mussel Settlement and Movement Patterns

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ABSTRACT

We evaluated the efficacy of strobe lights as deterrents to zebra mussel settlement and migration under laboratory and field conditions. Zebra mussels preferentially settle in darker areas and, in laboratory experiments, moved away from light. Strobe lights effectively repel a number of fish species but have not previously been tested on zebra mussels. If strobe lights proved effective as a zebra mussel repellant, fish repellence may be an additional advantage in some applications. In the laboratory, mussels were exposed to either strobe lights or darkness for one hour. We measured the total distance, linear distance, and direction traveled by zebra mussels by digitizing trails left in a fine layer of sand on aquarium floors. Displacement and direction traveled by the zebra mussels varied significantly with presence of strobe lights; however, total distance traveled did not. Mussels moved away from the strobe source, but moved randomly in darkness. In the field, PVC plates were exposed to strobe lights, strobe light backscatter, or darkness in two locations in Lake Champlain for an average of 37 days. Neither settlement nor migration of zebra mussels was affected by the illumination of plates by strobe lights or by strobe light backscatter. There were no treatment, location, or interaction effects on juvenile or adult density in field experiments. We therefore conclude that the use of strobe lights is not an effective method for controlling zebra mussel populations.

INTRODUCTION

The zebra mussel is a highly invasive, non-native species that was transferred to North America in the ballast water of ships from the Caspian and Black Seas (Johnson *et al.* 1996). Their presence in North America has had enormous impacts both economically (LePage 1993, Kovalak 1993) and ecologically (Griffiths 1993, Hunter and Bailey 1992). Zebra mussel veliger larvae are planktonic and disperse through connected waterways, in bait buckets, and attached to pleasure boats (Ackerman *et al.* 1994). Juveniles and adults attach with byssal threads to a substrate surface, forming a strong connection (Eckroat *et al* 1993).

Due to their preference for settling on hard surfaces, zebra mussels can be found on many man-made structures, such as dams, reservoir pumping stations, electricity generating plants, and industrial facilities, frequently impeding water intake. Any method that could remove zebra mussels or reduce their settling on water intakes and submerged equipment has the potential to be very useful.

Methods used to remove zebra mussels from localized substrates include oxidizing chemicals such as chlorine and chlorine dioxide, thermal radiation from steam injection or hot water flushes, filters, ultraviolet light, and electrical currents (e.g., Edwards *et al.* 1992). Manual removal using a high pressure wash or mechanical "pigging," desiccation through freezing or hot air, acoustical vibrations (Kowalewski *et*

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al. 1993), and the use of a plasma arc have also been tested (Anonymous 1999). Use of toxic coatings such as copper or zinc and non-toxic silicone based coatings deter settlement. Copper, brass, and galvanized metals also seem to be effective in reducing zebra-mussel fouling (Walz 1973, Kilgour and Mackie 1993).

Zebra mussels appear to avoid light and prefer to settle in darker areas, such as the underside of artificial substrates (Walz 1973, Marsden and Lansky 2000, Kobak 2001). For example, shaded surfaces of PVC plates had 7.7 times as many zebra mussels as sunlit surfaces (Marsden and Lansky 2000). In shallow water, zebra mussels are frequently found on the sides of rocks and pilings, but not on sunlit surfaces. In deeper water, zebra mussels densely cover horizontal surfaces. Laboratory work has demonstrated that when detached from a substrate, zebra mussels will move away from a light source (Toomey *et al.* 2002). Voluntary detachment and movement of mussels (termed translocation) in response to light has not been previously examined.

Fish avoidance of submerged strobe lights has been demonstrated (e.g., Nemeth and Anderson 1992). When exposed to either mercury or strobe lights, coho salmon hid or swam around actively, especially during normal nighttime conditions. Vogel and Beauchamp (1999) found that reaction distances of lake trout increased with light intensity. Unnatural light levels seemed to be negative stimuli for fish (Mork and Gulbrandsen 1994, Ferno *et al.* 1995). This has led to the application of strobe light technology upstream of hydroelectric turbines to reduce fish mortality (R. Brown, Flash Technologies, personal communication 1997). To our knowledge, effects of strobe lights on zebra mussels (or any invertebrate) have not been evaluated. Effects of submerged lights of any kind on zebra mussels have not previously been examined in field conditions.

We examined the reactions of detached mussels to strobe light exposure in 38-L aquaria in the laboratory. We also examined the effects of strobe lighting on zebra mussel larval settlement and adult movement in two different locations in Lake Champlain.

METHODS AND MATERIALS

For all of the laboratory experiments we used six 38-liter tanks filled with water from Lake Champlain with a thin layer (2-5 mm deep) of fine sand covering the bottom of each tank. The tanks were completely covered with aluminum foil, leaving a space just large enough for the strobe lights to shine through in the light tanks. Six zebra mussels of approximately equal sizes (7 ± 2 mm), detached from hard substrates in Lake Champlain an hour before running the trial, were placed in a uniform pattern on the sand in two rows approximately 8 cm from each other. In previous experiments, this small size class was noted to move farther and more often than larger individuals (Toomey et. al 2002). The mussels were then exposed to either a strobe light or complete darkness. After one hour, a digital photograph of each tank floor was taken with an Olympus Camedia 3030 digital camera. The trails left in the sand by the mussels were analyzed using Scion Image software (Scion Corp. 2000). Total distance, displacement, and angle traveled from start to end point were measured. Displacement was measured as the shortest distance between the mussel's starting point and its location at the end of the one-hour trial period. Direction traveled was quantified by measuring the angle from the light source location (0°) to the final location of each zebra mussel at the end of one hour. A replicate was considered to be a tank containing six zebra mussels. Each treatment was replicated twelve times in blocks of three tanks run simultaneously. All mussels were used only once.

The field experiments were performed at two locations on Lake Champlain in June, July, and August - the Burlington Boathouse (BBH) in Burlington, Vermont, and

Chipman Point Marina (CP) in Orwell, Vermont. Three 400-watt strobe lights with a frequency of four flashes/second were used at each location; the strobes were submerged at least 2 m underwater, and strapped to wooden pilings approximately 1 – 1.5 m from a piling with sampling plates. Numbered 15 x 15 cm PVC settling plates nailed to pilings served as sample areas to measure settlement and translocation (Marsden 1992). Plates were placed either on a piling directly in line with the strobe light (the light treatment), on the opposite side of the same piling (the backscatter treatment), or approximately 10 m from the lights as unlit controls.

At BBH there were four backscatter plates, three light plates and two unlit control plates. At CP there were five light, four backscatter and three unlit control plates. The zebra mussels adjacent to the plates at both locations were videotaped underwater (Sony DCR110 mini-DV format digital video camera) when the plates were deployed and when they were removed. Still images were captured from the videotape and analyzed to see if the zebra mussels in the treatment area had moved. In the absence of obvious changes in zebra mussel locations, comparison was made by visual inspection only. The lights operated continuously from June 18 to Aug 12 with the exception of two nights the first week of the experiment and from 29 June to 8 July at BBH. Due to boater disorientation, the lights at CP on were operated for 12 hours during daylight only from 13 July to13 August.

At the termination of the field trials, the plates were carefully removed from each location and placed individually into bags of ethanol. In the laboratory, the numbers of juveniles and translocated adults present on the exposed side of each plate were tallied.

Data analysis

Total distances traveled and total displacements of mussels in laboratory experiments were compared between light and dark treatments using a two-tailed t-test. To quantify direction traveled, we divided a circle into six 60° segments and compared the observed number of individuals found in each section to an equal distribution among all segments using a chi-square test. The field data were analyzed using a factorial ANOVA, with treatment and site as the factors. The response variables were juvenile density and adult density.

RESULTS

Laboratory trials

There was no significant difference in the distance traveled by zebra mussels in darkness and when exposed to strobe light ($t = 0.263$; d.f. = 77; $p > 0.793$). The zebra mussels traveled an average distance of 14.2 ± 1.7 cm (SE) in the presence of strobe lights and 13.3 ± 1.5 cm (SE) in darkness (Fig. 1). Reported means do not include the individuals that did not move during the one-hour period. The farthest distances traveled by individual mussels were 38.1 cm in the presence of strobe light and 34.6 cm in the darkness.

Due to non-linear movement of the mussels, distance traveled was always longer than the displacement. There was significantly greater displacement in light (11.43 ± 1.3 cm) than in the absence of light (7.39 ± 0.88 cm; $t = 2.422$; d.f. = 77; $p < 0.018$; Fig. 1). The greatest displacement of a mussel in the light was 25.6 cm and 26.5 cm in the dark. Because some individuals moved up the side of the tank during the one-hour period, accurate distance and displacement measurements could not always be obtained. Distance and displacement were measured from starting point to the edge of the tank where they began traveling up the wall. This occurred in 17 out of 108 cases.

Direction traveled by the zebra mussels in the presence of light varied significantly from a random pattern ($\chi^2 = 4.88$; d.f. = 5; $p < 0.001$). There was no significant

difference between directions traveled by mussels in dark conditions and a random distribution ($\chi^2 = 10.68$; d.f. = 5; $p > 0.08$; Fig. 2). The mussels in the light all moved at angles from 50° to 240° away from the light source at 0°. Only four mussels migrated toward the light out of the 33 that moved. The proportion of the mussels that moved in the light (56%) was less than the number of mussels that moved in the darkness (70%).

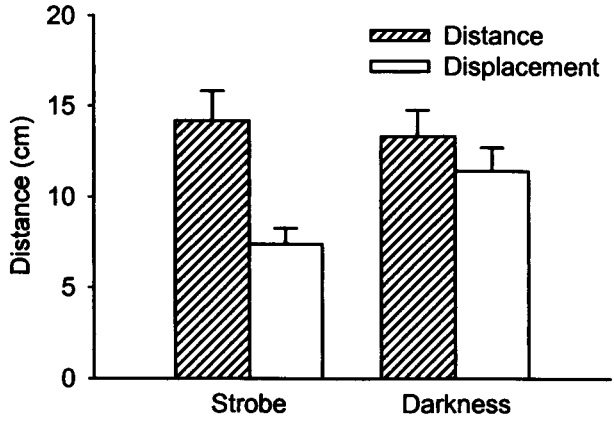

Figure 1. Mean (± standard error) distance and displacement of zebra mussels in the presence of a strobe light or in darkness after one hour.

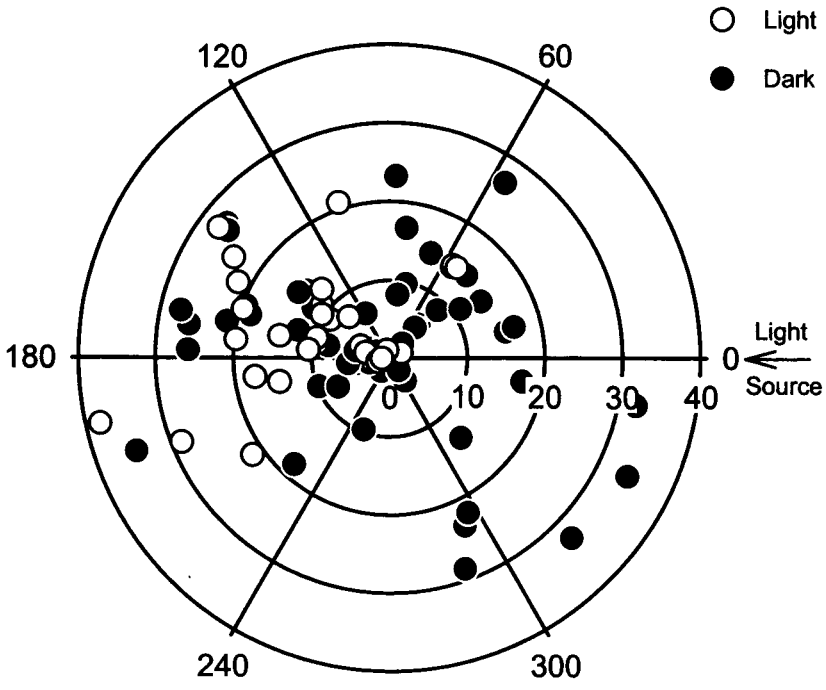

Figure 2. The final location of mussels after one hour in an aquarium. Open circles represent mussels exposed to strobe light; solid circles represent mussels kept in total darkness. All mussels started in the center of the circle.

Field trials

There were no treatment, location, or interaction effects on juveniles or adults ($p > 0.05$ in all cases; Fig. 3). Fewer translocators and juveniles were found on the control plates than on the backscatter plates in either location, and fewer juveniles were found on the control plates than the light plates at Chipman Point. However, neither of these differences was statistically significant.

The average number of juvenile mussels found on plates directly in front of strobe lights was 120 ± 79.6 at CP and 233 ± 93.8 at BBH. The average number of juveniles on backscatter plates was 129 ± 58.6 at CP and 267 ± 110.6 at BBH. On control plates an average of 82 ± 10.7 juveniles was found at CP and 87 ± 10.5 at BBH (Fig. 3A). The number of juveniles found on plates in the light ranged from 67 to 392 at BBH and from 4 to 420 at CP.

The average number of adult translocators found on plates directly in front of strobe lights was 4.0 ± 3.0 at CP and 3.0 ± 1.45 at BBH. An average of 7.0 ± 3.7 translocators was found on backscatter plates at CP and 8.0 ± 2.9 at BBH. On control plates an average of 6.0 ± 3.8 translocators was found at CP and 3.0 ± 2.0 translocators at BBH (Fig. 3B). Numbers of translocators on plates in the light ranged from zero to five at BBH and zero to 16 at CP.

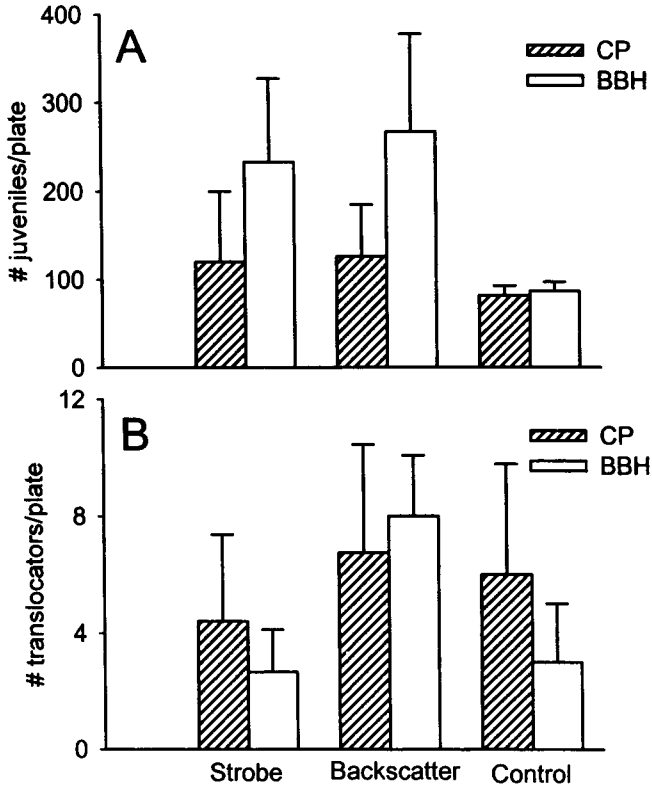

Figure 3. A. The average number (± standard error) of juvenile mussels found on experimental plates at both Chipman Point Marina (CP) and Burlington Boat House (BBH) in strobe, backscatter, and control situations. B. The average number (± standard error) of translocator mussels found on experimental plates.

DISCUSSION

In the laboratory, zebra mussels in the presence of strobe lights had significantly greater displacement than those in darkness; however, the total distance traveled did not significantly differ between treatments. This combination of results implies that zebra mussels exposed to strobe lights turned less, and followed a straighter path. This conclusion is confirmed by direct observation of mussel trails. In addition, the direction traveled by zebra mussels along the tank floors was significantly different than a random pattern, and 88% of the time they traveled away from the light source. Furthermore, mussels in darkness sometimes traveled along corkscrew-like paths, whereas strobe-light-exposed mussels frequently traveled along straight or almost sine-wave-like paths. These results make it clear that detached mussels tend to flee strobe lights under the described laboratory conditions.

Translocators are the closest field analog of our laboratory experiments. Once an adult mussel has settled, it can detach its byssal threads and move using its foot. Surprisingly, adult mussels in the field did not avoid strobe lights. One reason for this may be that zebra mussels are responding more to conspecifics than strobe lights. Populations have grown in Lake Champlain to such densities that most surfaces are covered with several layers of mussels. The mussels are likely in a fierce competition for space, food, and oxygen, so they will take advantage of available empty space, as represented by our plates. Clearly the strobe lights do not threaten their survival, and may represent a less noxious stimulus than intraspecific competition.

Unlike adults, juvenile mussels are actively mobile for a period of time after settling, thus affording them time to choose a settling location. Previous observations of small mussels showed a strong negative response to light (Toomey et al. 2002). Our prediction was that this phenomenon would extend to newly settled zebra mussels in the presence of strobe light. That we did not find supporting evidence for this may in part be explained by the major differences between the field and laboratory environments. We manually detached mussels in the laboratory, thus eliminating a step in their relocation process. Densities in the laboratory were unnaturally low, so competition for space was not an issue. Finally, substrates in the laboratory and field were different; zebra mussels most commonly attach to hard substrates, and may have been seeking hard substrates when they moved in the tank experiments.

Although strobe lights have worked to deter fish from dam turbines (Vogel and Beauchamp 1999, Mork and Gulbrandsen 1994), fish are far more mobile organisms than zebra mussels. It is possible for zebra mussels to pull up their byssal threads and move using a foot, however, little is known regarding the specifics of their mobility (Toomey et al. 2002). Perhaps strobe lights are not strong enough stimuli to produce this movement. Though we had a low number of replicates in the field, an effect spectacular enough to have a practical application would have been detectable even with low numbers. However, we do know that detachment was occurring in our study due to the presence of adult translocators on the illuminated plates, but strobe lights did not discourage their colonization.

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