Factors Limiting Colonization of Western New York Creeks by the Zebra Mussel *(Dreissena polymorpha)*

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Abstract

The New York State Erie Barge Canal was first colonized by the zebra mussel (*Dreissena polymorpha*) in 1989. Canal water supplements flows in many creeks in western New York, including six creeks in Monroe County that have not been colonized by zebra mussels. We chose Salmon Creek to study why zebra mussels have not colonized regional creeks because the rocky substrate of the creek appears ideal for colonization, yet 100 meters downstream from the input of canal water to the creek adult zebra mussel densities drop to less than one mussel m^{-2}. In the summer of 1993 veliger counts in the canal averaged 52 times greater than they were in Salmon Creek, yet water quality, current velocity, and particulate organic carbon concentrations in the creek and the canal were very similar. Chlorophyll a in the canal was higher than in the creek. Given the appropriate physical habitat and water quality conditions and an abundant source of veligers, the factors limiting zebra mussel colonization in Salmon Creek remain unknown, but three factors appear important: 1) Partial retention of zebra mussel veligers by the wetland through which the canal discharge flows, 2) Filtering of phytoplankton and veligers by the dense bed of adult zebra mussels at the beginning of the outfall channel from the canal to the creek, or 3) Inappropriate food quality (e.g., lack of phytoplankton with important fatty acid constituents) in the creek.

Introduction

The zebra mussel (*Dreissena polymorpha*) was first reported in the Great Lakes in 1988 (Hebert *et al.*1989), and by the end of 1989 it had spread throughout the region (Hopkins 1990). The New York State Erie Barge Canal, with a direct connection to Lake Erie, was colonized in 1989. Many of the creeks and rivers crossed by the canal receive water from the canal from late April through November (NYSTA 1985). Salmon, Moorman, Brockport, Northrup, Larkin, and Allens Creeks, located in Monroe County, New York, all receive canal water through siphon tubes, sluice gates, or fixed crest dams. Zebra mussels were observed at canal water outfalls to these creeks as early as 1990.

Despite nearly continuous inputs of canal water and zebra mussel veligers for seven months each year since 1990, none of the six creeks has zebra mussels more than 100 m downstream from where the canal discharges enter (Miller 1994). Dense populations of zebra mussels occur on rocks immediately below canal outfalls, but very few mussels are found in the streams. Even rocky substrates are not colonized.

Salmon Creek was chosen for this study because there is no apparent reason why zebra mussels should not successfully colonize the creek, an 11 km reach of which was carefully searched for zebra mussels in June 1992 (Miller 1994). Rocky

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substrates suitable for attachment are abundant, and invertebrate and fish communities indicate a reasonably healthy environment (Haynes, unpublished data). Aside from agricultural and suburban run-off common to all streams in Monroe County, there is no evidence of point source pollution in the watershed (NYSDEC, Division of Regulatory Affairs, Avon, NY, personal communication).

Given apparently suitable water quality and substrate conditions, why have zebra mussels not become established in Salmon Creek? Factors likely to influence zebra mussel survival in the creek are water quality (temperature, pH, calcium carbonate concentration), physical conditions (current, substrate), and biological conditions (food availability, predation). We examined these parameters in Salmon Creek to learn why the zebra mussel has not become established.

Study Site

Salmon Creek originates from a wetland south of the NYS Erie Barge Canal; the creek passes under the Erie Canal and flows northeast to Braddock Bay on Lake Ontario (Figure 1). Canal water flows through three sluice gates into a 50 m channel to Salmon Creek. Five sampling sites were selected to monitor zebra mussel density, veliger density, chlorophyll a levels, and selected physical and chemical conditions in Salmon Creek (Figure 1). Site 1 was farthest downstream near the location of the last observed zebra mussel in the creek. Site 2 was downstream from the confluence of the creek and the canal outfall channel after creek and canal water mixed. Site 3 was 40 meters upstream from the canal outfall channel. Site 4 was located in the canal just in front of the discharge to the outfall channel to Salmon Creek. Site 5 was located 15 m downstream from the dense bed of adult zebra mussels immediately below the canal discharge.

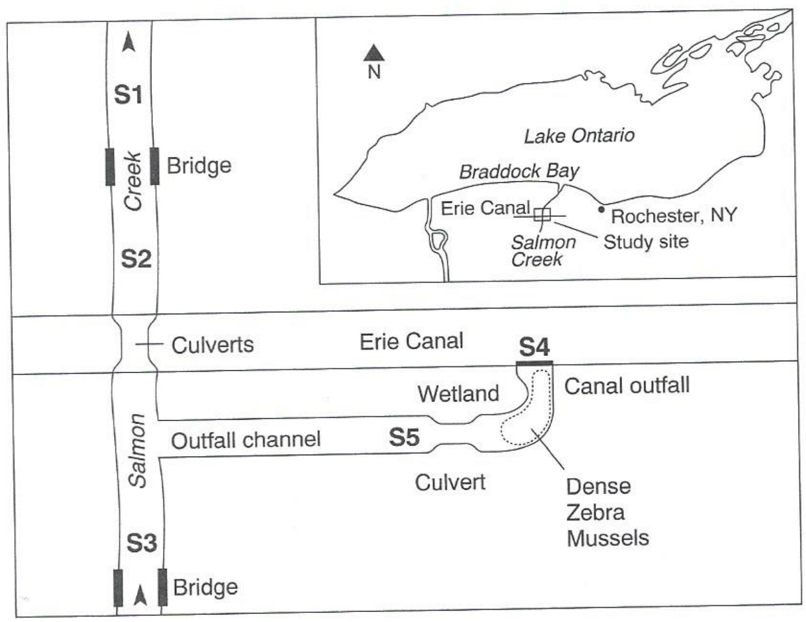

Figure 1. The study was conducted in Adams Basin, NY where discharge from the Erie Barge Canal enters Salmon Creek. Samples were collected a five sites, indicated as S1, S2, S3, S4, and S5.

Methods and Materials

Water samples for physico-chemical analyses were collected once each week beginning on May 11 and ending on September 7, 1993. Surface temperatures were measured at sites 1, 3 and 4 with a hand thermometer. Samples for calcium and pH determinations were collected at sites 1 and 4 by pumping water into brown plastic bottles. The pH was measured electrometrically and calcium was determined with a Perkin Elmer 3030 flame atomic absorption spectrophotometer. Calcium analysis ended on July 20.

Particulate organic carbon (POC) and chlorophyll a samples were collected at all sites biweekly. POC samples were placed on ice and returned to the lab for analysis. When analyses could not be performed immediately, samples were frozen. Chlorophyll a was analysed immediately. POC and chlorophyll a were determined using methods described in Wetzel and Likens (1991). The wet oxidation method for POC was modified by using a standard curve to determine POC concentrations. Based on new information published more than two years after sampling ended in 1993, chorophyll a was analysed from May 16 to July 25, 1995.

Current velocity of Salmon Creek was measured with a pygmy Gurly meter at sites 1 and 3. However, from mid June through August the velocity at upstream site 3 was so slow that we used the classic method of floating an orange as an alternative. Discharge was determined under bridges near sites 1 and 3 by measuring depths of the stream across the channel and multiplying the cross sectional area by current velocity. Subtracting the upstream discharge from the downstream discharge estimated the discharge from the Erie Barge Canal.

Veligers were sampled by pumping 200 L of water through a 64 μm plankton net. Samples were placed on ice, returned to the lab, and counted live under 40X magnification. To assess potential settling and growth of zebra mussels in the creek, bricks were placed in the stream at sites 1, 2 and 3 in early May and examined bi-weekly through September.

Fish were collected by electrofishing upstream from site 1 and in the canal outfall channel to site 5 (Figure 1) in mid-July in 1992 and 1993. In both locations, two to four fish of each species were collected, fixed in formalin, and returned to the lab. Stomach contents of fish were examined for zebra mussels.

Data were analyzed using two tailed, paired comparison t-tests or nonparametric sign tests ($\alpha = 0.05$). Most comparisons between the creek and the canal were made from the data collected at sites 1, 3 and 4. Site 2 was used only to sample veliger abundance and particulate organic carbon to determine whether dilution occurred after the canal outfall channel and Salmon Creek merged. Site 5, added midway through the 1993 sampling period, was used to determine more precisely where veligers were being lost in the system.

Results and Discussion

Water temperatures, pH and calcium concentrations in the Erie Canal and Salmon Creek did not differ significantly during the sampling period (Table 1). Temperatures in the creek never exceeded 30 °C, the maximum temperature tolerable for zebra mussel growth, and temperatures remained above 20°C from June 15 until September 7, a period in which the temperature of Salmon Creek was mostly in the optimal temperature range, 20°C to 25°C, for growth of zebra mussels (Kovalak 1989, Sprung 1989; Table 2). Winter temperatures were not measured in this study, but there is no reason to believe zebra mussels are unable to survive winter conditions in the flowing creek when they do survive harsher conditions in the canal which is mostly drained each winter. Zebra mussels are capable of growth and reproduction at temperatures which exceed 3°C, and become dormant at temperatures less than 3°C (Smit et al. 1993). These temperatures are typical of western New York streams in the winter.

The pH was variable in the canal (7.5 to 8.7) and in the creek (7.3 to 8.3). Although pH in the creek was below the ideal for zebra mussels (Morton 1971), the range was well within published tolerances (Table 2). Calcium concentrations in the creek (range: 48.8 to 118.2 mg/L) were never below the minimum concentration of 40 mg/L needed for veliger survival and growth and were consistently above the 50 mg/L level required to sustained normal larval growth rates (Kovalak 1989). Calcium concentrations in the canal ranged from 46.8 to 83.8 mg/L.

On average, the Erie Canal contributed 86% (range = 74 to 97%) of the flow in Salmon Creek. The current velocity of Salmon Creek upstream from the canal outfall channel (site 3) ranged from a high of 0.008 m/sec in May to a low of 0.002 m/sec in August. The discharge at site 3 had a similar pattern of decline from 0.014 m^3/sec to 0.002 m^3/sec. Current velocity downstream at site 1 ranged from 0.16 m/sec in May to 0.03 m/sec in August, and discharge ranged from 2.54 m^3/sec to 0.32 m^3/sec in the same months. Differences between discharge at sites 1 and 3 resulted from canal water flowing into the creek (range: 2.11 m^3/sec to 0.02 m^3/sec).

Current velocities in the creek were well below 1.5 m/sec that impairs growth (Smirnova and Vinogradov 1990) and 2.5 m/sec that prevents settling (O'Neill and MacNeill 1991) of zebra mussels. Although velocities in the creek were often less than the suggested ideal for zebra mussels (0.1 to 1.0 m/sec; Table 2), they overlapped with velocities in the canal (0.09 to 0.25 m/sec; T.W. Lewis, SUNY College at Brockport, personal communication) where zebra mussels were abundant.

Veliger densities in the canal ranged from 0 to 55 individuals/L. In the creek at downstream site 1 many fewer veligers were found, ranging from 0 to 2.3 veligers/L, a maximum of 3.6 % of the veligers counted in the canal samples. In the 10 week period that veligers were sampled in the outfall channel at site 5, 50 percent or fewer of the canal totals were counted, ranging from 0 to 12.0 veligers/L. No zebra mussels colonized the bricks placed in the stream.

Table 1. Comparison of mean physical, chemical and biological conditions most relevant to zebra mussel biology in the Erie Barge Canal and Salmon Creek.

Parameter	Erie Canal	Salmon Creek	t-value	P-value
Temperature (°C)	19.6	19.4	0.704	0.50
pH	7.9	8.0	0.945	0.37
Calcium (mg/L)	62.9	72.5	1.887	0.10
POC (mg/L)	21.5	21.6	0.137	0.92
Veligers (#/L)	14.3	0.2	(a)	<0.01
Chlorophyll a (mg/L)	7.9	3.0/4.6 [(b)]	(a)	<0.05
Velocity (m/sec)	NA	0.005/0.05 [(b)]	NA	NA
Discharge (m^3/sec)	0.07	0.01/0.08 [(b)]	NA	NA

NA = not applicable
(a) = Sign Test
(b) = First value is from Salmon Creek upstream at site 3; Second value is from Salmon Creek downstream at site 1 after confluence of creek and canal waters

Fish of 11 species were collected from Salmon Creek and the canal outfall channel. One fish, a hornyhead chub (*Nocomis bigutattus*) taken from the outfall channel below site 5, had eaten one zebra mussel, the soft tissue of which remained in the broken shell. Although crayfish abundance in Lake Ontario increased after colonization by the zebra mussel (Stewart 1993) and predation on zebra mussels by crayfish has been observed in controlled settings (Piesik 1974; Miller, personal observation), the abundance of crayfish in Salmon Creek does not appear to have changed in the past 10 years (Haynes, personal observation). Predation does not appear to be a likely factor limiting zebra mussel abundance in Salmon Creek.

Particulate organic carbon levels in the creek and in the canal were not significantly different (Table 1) and ranged from 17.9 mg/L to 24.5 mg/L in the creek and from 18.1 mg/L to 25.7 mg/L in the canal. Chlorophyll a concentrations in the canal ranged from 3.7 to 21.0 mg/L and were significantly higher (Table 1) than levels at all other sites (e.g., at downstream site 1, chlorophyll a ranged from 2.4 to 7.3 mg/L). Most significant was that chlorophyll a levels dropped by an average of 87% from canal site 4 to site 5 immediately after the dense bed of adult zebra mussels in the canal outfall channel to Salmon Creek. There were no differences in chlorophyll a concentrations among sites 1, 2, 3 and 5.

Because zebra mussels are abundant and grow in the canal, which contributes >75% of the flow in Salmon Creek and has water quality and current conditions indistinguishable from the creek, temperature, pH, calcium and current can be eliminated as factors limiting zebra mussel colonization in the creek. However, 80% of annual flow in Salmon Creek typically occurs during only a few seasonal storm events (J.C. Makarewicz, SUNY College at Brockport, personal communication); it is possible that zebra mussels colonizing the creek are scoured off during events. That this may occur is supported by the locations of the few zebra mussels that are found in Salmon Creek. They are attached to the sides of rocks or in cracks between rocks, not on the top surfaces of the rocks. However, zebra mussels also are not found on the top surfaces of rocks in the canal, where no event scouring occurs, suggesting that other factors, as well as scouring, may play roles in habitat selection in the creek.

The physical habitat of Salmon Creek and the similarity of water quality in the creek and the canal, where zebra mussels are abundant and reproducing, indicate no reason for zebra mussels not to colonize Salmon Creek. At the beginning of our study,

Table 2. Tolerated and optimal ranges of important environmental parameters for zebra mussels. Makarewicz (1989) reported water quality data for nearby Larkin, Buttonwood and Northrup Creeks. This study reports data for Salmon Creek.

Parameter	Tolerated Range	Optimum Range	Makarewicz (1989)	Salmon Creek
Temperature (°C)	0 - 30 [a]	20 - 25 [a]	1- 27	9 - 27
pH	4.6 - 9.5 [b]	8.2 - 8.6 [b]	7.5 - 8.5	7.3 - 8.3
Calcium (mg/L)	> 40 [a,c]	> 50 [a,c]	61 - 68	49 - 118
Current (m/sec)	> 0 - 2.5 [d,e]	0.1 - 1 [d,e]	< 1	0.03 - 0.16
Food Particle Size (µm)	1 - 450 [b,f,g]	15 - 45 [b,f,g]	not reported	not examined

[a]Kovalak 1989, [b]Morton 1971; [c]Sprung 1993, [d]Smirnova and Vinogradov 1990, [e]O'Neill and MacNeill 1991, [f]Sprung and Rose 1988, [g]Ten Winkel and Davids 1982

we hypothesized that POC would decrease as canal water moved over existing zebra mussel colonies in the outfall channel and was diluted by Salmon Creek, but POC did not differ between the canal and the creek. Thus, food quantity, as measured by POC, can be eliminated as a factor limiting zebra mussel colonization of Salmon Creek. Our data do show that the abundance of veligers and the concentration of chlorophyll a drop sharply in the first 15 meters after canal water enters the outflow channel.

Our initial literature review in 1993 indicated that food particle size, not composition, is the critical aspect of diet for zebra mussels; 15 to 45 μm is the preferred size range, but 1 to 450 μm particles can be filtered and ingested (Ten Winkel and Davids 1983). Studies published two years after our study ended suggest that food quality also is important (Liebig and Vanderploeg 1994). Stoeckman and Gerton (Ohio State University, Columbus, OH, personal communication) found better survival among cultured zebra mussels using a commercially prepared diet of marine algae higher in fatty acids than the control diet. Vanderploeg *et al.* (1996) reported that the key to raising *Dreissena* in culture is providing the right algae, particularly freshwater *Chlorella minutissima* and marine *Rhodomonas minuta*, both about 3 μm in diameter and rich in long chain polyunsaturated fatty acids. However, Wright *et al.* (1996) reported that two *Dreissena* species survived and grew better on small phytoplankton high in saturated fatty acids. Clearly, small food size is important to veligers (Morton 1971), but more work is needed to precisely define key components of the *Dreissena* diet and how diet requirements may influence where mussels can colonize successfully.

The Erie Barge Canal has many of the physical and biological properties of a lake, among which is the presence of phytoplankton and bacteria suitable for zebra mussel feeding. Chlorophyll a levels in the canal in the summer of 1993 suggested moderate to high abundance of phytoplankton (G. Lampman, SUNY Brockport, personal communication), and measurements in the summer of 1995 showed that chlorophyll a concentrations in the canal are consistently higher than levels in Salmon Creek. The high abundance of zebra mussels in the canal is undoubtedly related to its rich food supply. Because phytoplankton do not readily occur in streams and 87% of canal phytoplankton (measured as chlorophyll a) is filtered by adult zebra mussels in the outfall channel before reaching Salmon Creek, it is quite likely that the POC of Salmon Creek does not meet the qualitative nutritional requirements of zebra mussels.

Also, veligers are not reaching the Salmon Creek successfully. Slightly more than 1% of the veligers coming out of the canal were counted 100 m downstream. These results prompted the addition of a veliger sampling station in the outfall channel (site 5, Figure 1). Even at this location, 15 m from the canal outfall, veliger counts decreased by more than 60%. Obviously, something immediately after the canal outfall reduces veliger counts and chlorophyll a concentration.

Near the base of the canal outfall to Salmon Creek is a dense colony of adult zebra mussels and a small wetland. Part of the water flowing out of the canal to the channel leading to Salmon Creek forms a back eddy that flows through the wetland before moving to the creek. Some adult zebra mussels were observed attached to vegetation in the wetland, thus it is possible that some veligers become trapped and settle in the wetland. That this may occur in Salmon Creek was supported by sampling in Brockport Creek in the summer of 1995. The canal discharge to Brockport Creek meanders through a wetland before reaching the creek. No adult zebra mussels were found in the creek, but chlorophyll a levels were much higher after water passed through the wetland than they were in the canal. This suggests that the wetlands associated with canal outfall channels produce phytoplankton but prevent veligers from reaching the creeks.

Just as adult zebra mussels at the base of the canal discharge to Salmon Creek appear to filter most phytoplankon out of the water (87% reduction), it is likely they are also feeding on the veligers (Smirnova and Vinogradov 1990) coming from the canal and create the 60% reduction in numbers we observed between sites 4 and 5 (Figure 1). The dense population of adult zebra mussels in the discharge channel appears to be a "biotic sponge" which removes veligers and phytoplankton from the canal water flowing into Salmon Creek, thus depriving the creek of appropriate quality food (phytoplankton) and a source of veligers to support zebra mussel colonization of the creek.

Why have zebra mussels not colonized other creeks in the local area? The physical habitat of the Salmon Creek outfall channel was compared to the habitats at the outfalls of Brockport, Northrup and Allens Creeks. The wetland between the canal and Brockport Creek apparently prevents veligers from reaching the creek. Near their outfalls, Allens and Northup Creeks have predominately muddy bottoms unsuitable for zebra mussel attachment and filter feeding. Thus, it appears that zebra mussels are having a difficult time colonizing streams fed by the Erie Barge Canal in Monroe County, NY, which is good news considering the impacts they have on lake ecosystems.

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