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Impacts of zebra mussel invasion on offshore sediments of Western Lake Erie

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IMPACTS OF ZEBRA MUSSEL INVASION ON OFFSHORE SEDIMENTS OF WESTERN LAKE ERIE

by

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Management perspective

Title: IMPACTS OF ZEBRA MUSSEL INVASION ON OFFSHORE SEDIMENTS OF WESTERN LAKE ERIE

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Issue:

The invasion of the Great Lakes by the exotic zebra mussel (Dreissena, ZM) has caused great concern for lake managers. These prolific benthic organisms have taken over most of the shallow-water hard substrates in the Lower Great Lakes, greatly altering the benthic ecology and community structure. Of particular interest is the recent spread of ZM into soft substrates in western Lake Erie formerly deemed hostile to them. Lakewide Management Plans (LAMPs) require quantitative data on their distribution, density of colonization, and colonization behaviour in order to anticipate problems and design possible controls on their future impacts.

Current Status:

Combined digital sidescan sonar, underwater video imagery, and diver surveys in western Lake Erie showed colonization levels of up to 10,000 ZM per m^2 in soft sediments. Colonization patterns were not random, ranging from 30-m-long parallel stripes, to ovate, football-shaped masses. Total population of ZM (> 0.84 mm) for the basin was calculated at 10^{14} individuals. This figure will be useful in modelling the effect of ZM on the nutrient dynamics of western Lake Erie.

Presence of ZM had no apparent effect on sediment grain-size. However, colonized areas have significantly higher organic carbon content than non-colonized areas, as well as sharply lower concentrations of Co, Cr, Cu, Ni, Pb, and Zn, and slightly lower Fe and Mn. This suggests that the presence of ZM might be a factor in the re-mobilization of metals in bottom sediments.

Next steps:

The above preliminary results must be verified by further analysis. Following this, they will be shared with aquatic biologists of Great Lakes Laboratory of Fisheries and Aquatic Sciences to promote interdisciplinary insights and recommendations useful for lake management.

Abstract

Zebra mussels (Dreissena) have expanded rapidly throughout most of the Laurentian Great Lakes since their release in 1986. These exotic mollusks now occur in great numbers on the bottom of western Lake where they are now found increasingly in deeper areas of the basin Erie (average depth: 10 m), on soft, muddy substrates. This study is aimed at quantifying the density and the distribution patterns of mussel colonization in the basin as a first step in investigating the effect on key sediment properties of such an abrupt change in benthic community structure. By linking their distribution with substrate properties, we hope to identify key processes and controls on colonization.

Underwater video imagery and diver-collected samples taken from five representative offshore areas (seven sites) in western Lake Erie showed colonization levels of up to 10,000 live and dead mussels per m^2 in soft sediments (adults with shells >10 mm comprised 20 - 50 %). Digital side-scan sonar records confirmed that colonization patterns were not random, but showed distinctive spatial signatures ranging from 30-m-long parallel stripes, to ovate, football-shaped masses. Broad irregular mats were found in association with hard bottoms (bedrock, boulders, or wrecks and large debris). From the four representative areas, relationships were assumed between major substrate type and mussel quantities. Colonization density of each of the major bottom types was combined with digitized percentage of areal coverage for these bottom types in western Lake Erie, producing a first-order approximation figure of 10^{14} individuals for the total population of mussels in the basin. This figure includes mollusks of all sizes > 0.84 mm.

Sediment sample pairs collected from colonized and non-colonized areas of the four sites showed there was no granulometric difference; however, colonized areas have significantly higher organic carbon content than non-colonized areas. Also, colonized areas show sharply lower concentrations of Co, Cr, Cu, Ni, Pb, and Zn, and slightly lower Fe and Mn.

Cont 96-77

COLONIZATION PATTERNS AND DENSITIES OF ZEBRA MUSSEL Dreissena IN MUDDY OFFSHORE SEDIMENTS OF WESTERN LAKE ERIE, CANADA.

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Abstract. Zebra mussels (Dreissena) have expanded rapidly throughout most of the Laurentian Great Lakes since their inadvertent release in 1986. These exotic molluscs now occur in great numbers on the bottom of western Lake Erie where they are found increasingly in deeper areas of the basin (average depth: 10 m), on soft, muddy substrates. This study is aimed at quantifying the density and the distribution patterns of mussel colonization in the basin as a first step in investigating the effect on sediment properties of such an abrupt change in benthic community structure. Underwater video imagery and diver-collected samples taken from representative offshore areas (seven sites) in western Lake Erie showed colonization levels of up to 20,000 live mussels per m^2 in soft sediments (adults with shells >10 mm comprised 47 %). Digital side-scan sonar records confirmed that colonization patterns were not random, but showed distinctive spatial signatures ranging from 30-m-long parallel stripes, to large ovate masses. Broad irregular mats were found in association with hard bottoms (bedrock, boulders, or wrecks and large debris). Mussel densities were averaged from the sites, assuming consistent relationships with substrate type and were combined with digitized percentage of areal coverage of major bottom types in western Lake Erie. This resulted in the first population figure of 10^{13} in the basin. This figure includes molluscs of all sizes > 0.84 mm.

KEY WORDS: Dreissena, zebra mussel, side-scan sonar, western Lake Erie,

1. Introduction

Since their inadvertent introduction into Lake St. Clair (Fig. 1) in 1986, the zebra mussel (Dreissena sp.) has expanded its range at an alarming rate throughout the Great Lakes and into adjacent watersheds.

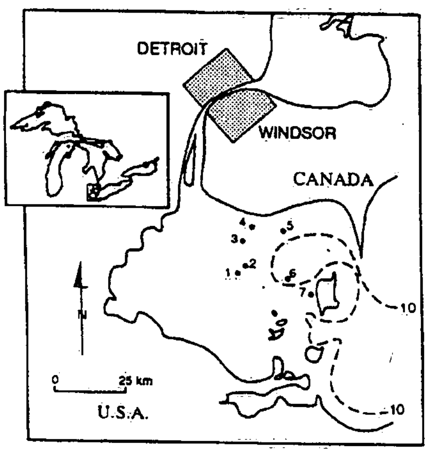

Fig. 1. Location map of western Lake Erie showing sites surveyed: (1) Bret; (2) Footballs; (3) Stripes; (4) Susan; (5) Barge; (6) Zebra; (7) Pelee. Position of 10 m depth contour is also shown.

In recent years, colonies of zebra mussels have established themselves outside the Great lakes watershed. Thriving populations now exist in the Mohawk / Hudson River systems of western New York, the Ohio River, and as far south as the Tennessee and Arkansas Rivers of the southern U.S.. They have been observed in the lower Mississippi River as far south as Baton Rouge (New York Sea Grant, 1993). In addition, the smaller Canadian lakes to the north of the Great Lakes and the Trent - Severn waterway now also are sites of growing zebra mussel infestation.

Initially, zebra mussels colonized hard substrates (bedrock and boulder deposits) and man-made coastal structures located in waters 2 to 12 m in depth. These are the common depths they inhabit in European ecosystems (Stanczykowska, 1964; Binelli *et al.*, 1997, this volume). The impact of zebra mussels is most pronounced in the lower Great Lakes, especially in western Lake Erie where, the combination of relatively warm, shallow water and eutrophic conditions provides ideal conditions for population growth. Mussel densities exceeding 342,000 mussels per m^2 have been recorded (Leach 1993; Fitzsimons *et al.*, 1995). In recent surveys, dense mats of mussels were observed in deeper waters on soft muddy sediments (Hunter and Bailey, 1992; Dermott and Munawar, 1993; Berkman *et al.*, 1995). The expansion of zebra mussels into such habitats that were once considered inhospitable is cause for concern, as such a move would open up for colonization the largest surface areas of the lakes (Table 1).

TABLE I

Proportions of various substrates and first-order estimate of live mussel population, western Lake Erie

Substrate type	Area (sq.km)	% of total	Representative site	Rep. density mussels x m-2	Total Population	Est. substrate Coverage (%)	Adjusted Population
Mud (with isolated druses)	2000	42.6	Midbasin 1	0	0.00E+00	95	0.00E+00
Mud (stripes & footballs)	580	12.3	BARGE	13000	7.54E+12	1	7.54E+10
Bedrock	200	4.3	(Fitzsimons et al.)	340000	6.80E+13	60	4.08E+13
Sand & gravel	930	19.8	PIPPE	20000	1.86E+13	5	9.30E+11
Mixed substrates (till)	990	21.1	ERIE	13000	1.29E+13	5	6.44E+11
TOTAL	4700	100.0					4.24E+13

Some researchers (MacIsaac *et al.*, 1992) have suggested that by their filtering activity, these mussels have permanently affected the nutrient dynamics and spawning success of higher, more commercial aquatic species such as walleye . Fitzsimons *et al.* (1995) disagree. Furthermore, material filtered from the water column that they do not ingest, is expelled as pseudofeces to the adjacent sediment surface. The effect of such transfers on sediment properties and contaminant cycling could be important, especially if zebra mussels are in fact invading new substrates and depths in Lake Erie.

This paper seeks to supplement the little that is known about how zebra mussels are spreading into areas of muddy sediment in western Lake using a combined geophysical and geologic approach. to map the distribution of population densities in the basin as a first step in identifying trends and patterns of their infestation.

2. Methodology

2.1 SIDE-SCAN SONAR SURVEYS

The survey began in the summer of 1994, using a digital side scan sonar system manufactured by Marine Sonics Technology of Virginia, U.S.A.. The side scan sonar transmits a 300 kHz acoustic pulse at right angles to the direction of the moving survey vessel; the returning echoes is collected and processed by computer to build an image of the bottom surface topography, including mussel beds (Carey, 1978). Sonar surveys focused on several areas in the western basin (Fig. 1), characterized by different substrates. In 1995 and 1996 we returned to the sites and remapped target areas. For the 1994 surveys, positioning was by GPS, with an accuracy of about 100 metres. In 1995 and 1996 we used differential GPS with an accuracy of about 1 metre. To coordinate the surface and diver surveys in the 1996 surveys, we placed distinct acoustic reflectors on the bottom at the study sites.

2.2. DIVER SURVEYS AND BOTTOM SAMPLING

Scuba divers, equiped with video and still-cameras, were used to "ground-truth" the side-scan data and to collect bottom samples. Two types of bottom samples were collected by divers. Quadrat samplers 0.0625 m^2 in area (25 cm x 25 cm x 4 cm) were used to collect surface samples of zebra mussels from areas deemed representative. The samplers were placed by the diver onto the sediment surface and pressed into the sediment. All the sediment and mussels within the quadrat were collected in a plastic bag and brought to the surface. The sample was washed on the boat through a 1 mm brass sieve and the mussels stored for later counting in the laboratory. The other samples consisted of short (10 - 15 cm long) plastic cores pushed by the diver into the sediment. Core samples were taken in pairs, one below a mussel mat, the other in bare sediment within 1 m of the first. These cores were kept cool until they were freeze-dried in preparation for later grain-size and chemical analysis.

2.3. ZEBRA MUSSEL COUNTING PROCEDURE

More than 100 selected video frames were chosen from the underwater video imagery collected during the surveys. For each frame, the number of living or dead mussels (disarticulated or bleached shells were counted as dead) were visually counted. In addition, the altitude of the camera and the surface area covered by the frame were calculated (Ioannou *et al.*, 1996). These numbers were then used to generate values representing mussels . m^{-2} for the different sites sampled. Regression of the video-based and the quadrat counts provided a conversion factor of approximately 10. This was used to gross-up the values to a 4 cm active mussel layer.

The technique was dependent on defining an accurate value for the median mussel size. This value was obtained from collected (quadrat) mussel samples in addition to an "on-screen" scaling method which made use of the video camera's protective frame as a size reference.

3. Results

3.1. VIDEO-CAMERA IMAGING OF ZEBRA MUSSEL DISTRIBUTIONS

Zebra mussel infestation of varying densities was observed on the underwater video footage taken at all the sites. Bottom coverage ranged from sparse (<1% of video frames) to dense (>90%). The densest coverage was noted in areas of rough bottom (bedrock, boulders, cobbles and wreck debris). At these sites we estimate that there were approximately 5000 mussels.m^{-2} at the surface, for an active total of 50 000.m^{-2} down to

4 cm. Less dense, patchy coverage was noted in areas of mud bottom (silty clay). Large expanses of bare sediment cover were noteed in the mussel distribution.

3.2 SIDE-SCAN IMAGING OF ZEBRA MUSSEL SITES

Over the past three years, a total of seven different sites have been investigated with the side-scan sonar (Fig. 1). Many of these sites have been revisited on an annual basis. The sonar records readily enabled distinction of the various major substrate types making up the sites: hard bedrock and boulder / cobble (very dark expanses, or stippled, irregular patterns, often with light-coloured shadow haloes indicating relief), granular sand (alternating dark and light linear bands suggesting dune and ripple forms), and soft mud (monotonous contrast). Representative images from the sites are presented in Figure 2.

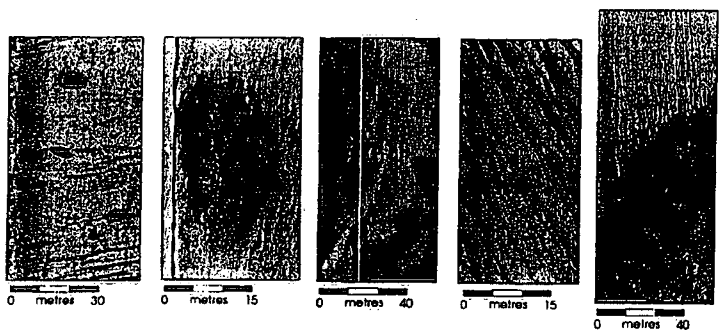

Fig. 2. Side scan records from five representative substrates in the western basin of Lake Erie. Left to right: A. Ovate masses ("footballs") with strong backscatter; B. Enlargement of ovate masses mussel mounds, C. Bedrock (mussel encrusted); D. Parallel linear bottom features with mussels in depressions ("stripes"); E. Transition from densely colonized bedrock (bottom) to stripes in adjacent soft sediments (top).

Because the estimated resolution of the technique was approximately 50 cm (depending on swath-width setting), it was impossible to image individual mussels. However, examination of surveys carried out over video-verified areas of muddy sediment allowed the identification of distinct density reflection patterns on the sonograph records that corresponded to mussel colonization. These patterns were classified into two major types: sub-parallel, linear "stripes" and rounded, ovate "footballs".

The former (Fig. 2D) is the name given to large areas of the sites whose side-scan record consisted of parallel, linear dark reflectors at a consistent angle to the boat track. They could be resolved out to a distance of up to half the swath width (up to 50 m). They apparently extended further, but could not be observed beyond this distance because of recording limitations. They are aligned consistently in a direction of N40 ^{o}E to N85 ^{o}E, averaging around N60 ^{o}E) and were observed at most of the sites associated with a visible hard substrate or object (bedrock reef outcrop or a shipwreck) and extended to both sides. They were also found in association with the ovate patterns ("footballs") described below. The greatest elongation was consistently toward the NE, suggesting association with prevailing directional forcing processes, such as basin-wide circulation and sediment transport. Zebra mussels occupied the troughs of these features in dense colonies, although the divers noted often the presence of distinct demarcation borders or "fronts" of mussel coverage. A schematic of the perceived relationship between the "stripes" and the hard bottom areas is presented in Figure 3.

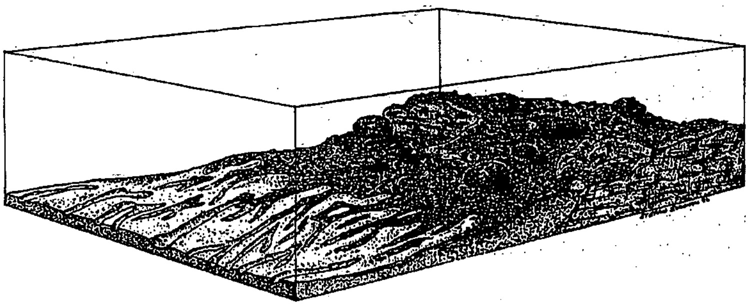

Fig. 3. Schematic of relationship between "stripes" pattern of zebra mussel colonization and nearby hard substrate. Note the expanding "apron" between the stripes and the bedrock nucleus.

The ovate "football" pattern (Fig. 2A, B) was observed less frequently and consisted of patches of dark reflectors (no shadow, indicating a lack of relief) with rounded margins. These patches were often ovate in shape and ranged in diameter from 10 to more than 50 m. Diligent search for "football" areas noted in previous years often failed to relocate them, suggesting that, unlike the "stripes", they appeared to be somewhat ephemeral and subject to alteration in form and location with time. These features, like the "stripes", were almost always associated with areas of hard bottom, but were formed in adjacent areas of muddy sediments. Diver descriptions, however, generally noted hard sediment close to the surface. Zebra mussel patterns were patchy and less dense than in the troughs of the stripes pattern.

Divers confirmed that the patterns were in fact due to zebra mussel colonies. The "stripe" patterns were caused by dense colonization of mussels within linear trough-like bottom features (Fig. 3). These troughs ranged from 0.25 to 1 metre in width and could be followed by the diver for more than 100 m. They were usually 5 - 15 cm deep, often with steep, at times undercut or excavated walls. The mussels occurred in concentrated mats along the bottom; disarticulated or empty shells could also be felt in the soft sediment to depths exceeding 10 cm.

The "football" patterns were observed by divers to correspond to areas where mussels occurred as partially buried, discontinuous patches. Like the "stripes" areas, they were consistently associated with areas where hard bottoms were nearby and within 20 cm of the surface. Also worthy of note was the fact that "footballs" observed and precisely located in previous years were absent or greatly modified in form in 1996.

3.3 ESTIMATION OF ZEBRA MUSSEL POPULATIONS

Measurements of zebra mussel colonization densities were taken using two techniques: Direct image analysis of the video frames, and by extrapolation of the spot quadrat samples. The video-based counting technique is detailed in Ioannou *et al.*, (1996). Individual videotape frames (105 in all), meeting criteria of high resolution and camera height above the bottom, were magnified and individual mussel and mussel shells (dead) were visually counted. The accuracy of the technique was dependent on defining an accurate value for the median mussel size. This value was obtained from size distribution measurements done on the quadrat samples (Fig. 4). Values ranged from 1000 to 2000 mussels / m^2 for soft sediment areas, but reached 5000 mussels / m^2 in rocky areas. These figures are most likely an underestimation, as they are based on only a 2-D picture of the mussel coverage, neglecting those below the surface layer.

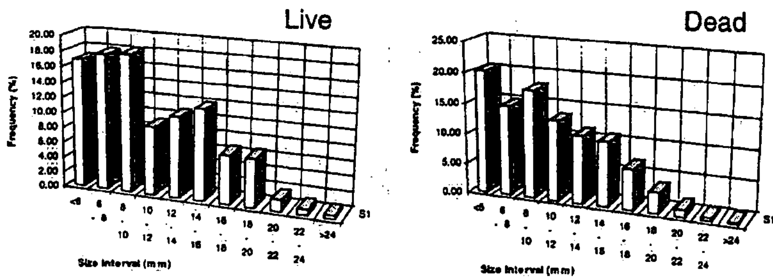

Fig. 4. Representative size frequency histogram of zebra mussel samples (both live and dead) based on a combined total of over 4000 shells from various locations.

Seven quadrat samples were counted manually and also provided size distributions for the zebra mussels sampled (Fig. 4). The size distributions were all bimodal, reflecting populations of different ages. Median size of the mussels sampled in the quadrats ranged between 10 and 14 mm, with maximum values up to 25 mm. Percentages of live mussels ranged from as low as 14% to as high as 82%. Using these values we obtained live mussel figures of as high as 20 000 mussels . m^{-2} (Table 1).

Both techniques offer advantages, predominantly that of speed and wide coverage for the video technique versus better resolution of the smaller (e.g. < 10 mm) individuals in the size distribution and better live / dead ratios for the quadrat sample technique. In the extrapolation of the counts for these representative areas to the lake as a whole, we decided to use the live counts from the quadrat measurements. A major factor was that these counts were more compatible with those on hard substrates (Fitzsimons et al. (1995).

A map of bottom substrates in the western basin (Fig. 5; Rasul *et al. 1996*, in prep.) was used to calculate the total area of the bottom covered by each of 4 types represented by the survey sites: mud, bedrock and hard ground, sand, and mixed sand and cobbles (Table 1). Combining these areas with the mussel per unit area counts described above, we arrived at a first-order approximation of 10^{13} for the entire western basin. It is difficult to assign an error margin for such an estimate (all of the components have considerable uncertainties), however, we would place the figure as within an order of magnitude of the true value.

Fig. 5. Generalized substrate map of western Lake Erie.

4. Discussion

For the first time it was shown that regular patterns of colonization exist (ovate masses and linear features). This suggests that studies of mussel coverage in muddy sediments using random grab or dredge samples could be of doubtful validity unless a large number of samples were taken. Another factor not addressed here (and to our experience, of lesser importance) is the colonization of individual live or dead unionid clams in muddy offshore sediments.

4.1 HYPOTHESES FOR ORIGIN OF STRIPE AND FOOTBALL PATTERNS

It is noteworthy that with the exception of unionid clam colonization, zebra mussel colonies in muddy sediment substrates occur close to areas of bedrock outcrops. This coincidence leads to the hypothesis that the zebra mussels occupying soft substrates were physically derived from these hard-bottom nuclei.

STRIPES

The most likely origin of these features is through bottom scouring related to natural processes. Although deep-rooted ice keels can reach the bottom in the <10 depths of the basin, they tend to be much wider (several metres wide) than the stripes, and show no bifurcation. Sediments are also scoured by the activity of fishing boats, that commonly pull nets and anchors in the sediments. However, the resulting excavations would be more variable in direction and width, and show levees of ploughed material on the sides. In the absence of any direct studies of the stripe features, the most likely mode of formation for these linear troughs is by long-term exposure to leeside currents and eddies downstream from a bedrock exposure (reef). The steepness and undercut nature of the walls could be due to subsequent reworking by fish.

If this hypothesis is correct, it leads to the conclusion that the zebra mussels occupying soft substrates could have been physically exported from these hard-bottom nuclei by storm-induced current- or ice-scour processes. Dead mussel shells previously deposited in the troughs would then serve as attachment sites.

FOOTBALLS

The football patterns are interpreted as smaller, isolated hard-bottom areas that have a dense cover of mussels. They owe their rounded shape to the absence of relief and current scouring, which makes them vulnerable to periodic sedimentation. Their shape and precise location can thus change depending on whether they have been recently covered or exposed by erosional / depositional processes. Dead mussel shells at these sites could also serve as attachment sites for locally-derived veligers, causing the feature to grow outward..

SUMMARY MODEL OF ZEBRA MUSSEL COLONIZATION

Veligers carried along in the water column settle onto the bottom in a random manner. Those that settle onto hard substrates can attach their byssal threads firmly and thrive. This is the case in bedrock or cobble areas. If the veligers settle onto soft sediments, their only hope of surviving there is to attach themselves to hard objects, such as the shells of clams or zebra mussels, living or dead. In only a few cases were the zebra mussel clumps observed in soft sediments attached to clam shells; most were attached to disarticulated zebra mussel shells.

The association of the stripe pattern of zebra mussel colonization with current-mediated transport over densely colonized bedrock exposures suggests that the source of the shells used to initiate colonization were derived from the bedrock "reef" and deposited in the linear vortex-scours downstream. Veligers spawned from the reef would thus find settling sites nearby to form druse clumps. Patches of druses can join together over time to fill up the troughs, then infilled troughs would coalesce to form an apron adjacent to the bedrock nucleus, and thus the colonies would outward along the troughs (Figures 2E, 4). Enhanced current flow through the troughs would also prevent the colonies from being sedimented over.

4.3 ESTIMATION OF ZEBRA MUSSEL POPULATION OF WESTERN LAKE ERIE

One of the prime benefits of this study is that it provides an estimate of total zebra mussel populations in western Lake Erie that takes into account colonization in soft sediments. Estimation of impacts on phytoplankton stocks caused by zebra mussel filtration (MacIsaac et al. 1992) were based on on a figure for mean population density of zebra mussels and average clearance rates per mussel. They assumed densities averaging 270 000 individuals . m^{-2}, i.e. that measured for hard substrates (15% of bottom surface in western Lake Erie).

The new quantification technique applied here, i.e. direct counting from video footages calibrated by diver-collected quadrat samples, is still being tested and improved. Nevertheless, when combined with the updated and detailed map of the various substrates in the basin it is an improvement on earlier estimates of total colonization. Estimates of the statistical error is virtually impossible given the patchy distribution, the wide range in size of the individual mussels, and the difficulty in differentiating between live and dead individuals. These aspects will be improved as more areas are sampled. Our estimate of 10^{13} individuals for the entire basin provides an overall population density of approximately 10 000 mussels . m^{-2}. Such a reduction would make a considerable difference in the ecosystem impacts previously estimated.

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