Dreissena!

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The Potential Distribution and Abundance of Zebra Mussels in California

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Zebra mussels have not yet been found west of the Continental Divide, and the nearest established populations are nearly 2000 miles away, in the Oklahoma River. However, they have been found on several occasions on trailered boats entering California, which alarmed natural resource managers in the state and precipitated this study. Other potential means of introduction include the bait fish and aquarium plant trade, ships' ballast water, and any number of other routes such as for novelty or for algae control.

Potential impacts of a zebra mussel invasion in California

The zebra mussel could have very significant economic and ecological impacts in California, potentially even more serious than in the American Midwest. In the Midwest, the densest concentrations of zebra mussels are found within the plumbing of water delivery systems and in the cooling water systems for power plants. Should zebra mussels be introduced into California, hundreds of reservoirs and thousands of miles of steel and concrete pipes, water gates, fish screens, water intakes, filter plants, agricultural irrigation systems, and many other water system components could be at risk. The State Water Project and the Central Valley Project alone have over 1600 miles of aqueducts and canals. Virtually every citizen and agency in California is directly or indirectly dependent upon these systems to provide water for households, businesses, and agriculture.

Abundant zebra mussel populations in California could reduce or eliminate populations of rare species, change the composition of biotic communities, and alter the physical and chemical conditions of aquatic habitats. For example, in the San Francisco Estuary, a recently introduced Asian clam (*Potamocorbula amurensis*) has eliminated phytoplankton blooms in the northern part of the estuary, so that many zooplankton and benthic organisms in this region now survive on organic matter carried in from the Sacramento-San Joaquin Delta. If zebra mussels were to become abundant in the Delta and Central Valley rivers, and efficiently filter the organic material out of these waters as they have in parts of the Great Lakes, there might be little left for organisms in the northern Estuary to feed on.

Method of analysis

In this study we analyzed and mapped the colonization potential of zebra mussels at 160 sites around the state, based on a selected set of environmental variables. We also considered how additional factors may affect colonization potential and abundance.

We based our analysis on five environmental variables for which tolerance limits are well-studied and data are available: salinity, dissolved calcium, pH, temperature, and dissolved oxygen. For most variables, we used averaged data for April to September to capture conditions during the zebra mussel's spawning and growth period. We classified waters as having high, moderate, or low-to-no colonization potential based on their habitat suitability across all five variables, giving greater weight to calcium and pH, and mapped the results. In some cases we incorporated other information, such as records of periodic desiccation of shallow lakes, in our assessment.

We chose the sites for analysis to cover most of the state, capture a wide range of water quality conditions, show elevational changes along rivers, and include the large water delivery systems. The primary source of data was STORET, the U. S. Environmental Protection Agency's (EPA) Water Quality Data Clearinghouse, which consolidates and organizes water quality data from federal, state, and local agencies. Eric Wilson, the STORET manager for EPA Region IX, extracted and tabulated the data for this study. We also obtained data from eight other state agencies. [(See Cohen and Weinstein 1998b for a detailed description of methods and data used in this study).]

Results

1. Potential Distribution

The zebra mussel has a wide but not comprehensive potential range in California. Of the 160 sites that we assessed, 54% ranked as having low or no potential for colonization by zebra mussels, 2% ranked as having moderate potential, and 44% ranked as having high. Most of the coastal watersheds, the west side of the Sacramento Valley, and the San Joaquin River and southern Delta, provide suitable water chemistry and temperature for colonization. Suitable waters include many important facilities such as the Delta-Mendota Canal, the California and South Bay aqueducts, the Los Angeles Aqueduct, the Colorado River Aqueduct, the All American Canal, and their associated reservoirs.

Of the 86 sites we ranked as having low or no colonization potential, low calcium was the critical factor in 65% of the sites, a combination of low calcium and low ph in 17% of the sites, high temperature in 12% of the sites, periodic desiccation in 5% of the sites, and low temperature or high salinity at the remaining 1% of the sites. Low calcium, sometimes combined with low pH, will prevent significant zebra mussel colonization in most of the Sierra Nevada and the upper Sacramento River watershed. Warm summer temperatures will prevent colonization at several southern California sites. Freezing, which is thought to limit zebra mussels' range in parts of Europe, may prevent establishment in small or shallow lakes in California that freeze solid in the winter, though no such lakes were included in this assessment.

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Submissions for inclusion in ***Dreissena!*** are encouraged. Please direct correspondence to:

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Periodic desiccation, possibly combined with high or fluctuating salinities, will prevent establishment in some northeast lakes. Zebra mussels can tolerate salinities up to about 8 parts per thousand as long as changes in salinity are gradual, so they may be able to colonize some inland brackish waters, although others, such as Mono Lake and the Salton Sea, are clearly too salty. Zebra mussels' low tolerance for rapidly changing salinities would limit their seaward distribution in estuaries and coastal lagoons. They are abundant in some slightly brakish water portions of estuaries in Europe, but seldom persist where salinity exceeds 2 parts per thousand. We therefore estimate that zebra mussels could colonize in the Bay/Delta Estuary downstream to a tidally averaged, near-bottom salinity of 2 ppt. Here and throughout coastal California, rapidly fluctuating salinity levels would make many tidal regions very unstable habitats for zebra mussels, and their presence would likely depend on an upstream source of larvae to reestablish extirpated colonies.

Several cautions apply to these results:

• Additional factors may limit colonization. For example, zebra mussels are usually not found in very productive (that is, having high levels of phytoplankton) or very unproductive waters. Young zebra mussels also need a hard surface on which to settle when moving from the floating larval to the attached adult stage, so waters with mud, clay, or fine sand bottoms may not support zebra mussels. Also, young zebra mussels cannot settle in fast currents.

• The average values for some variables at some sites were just under or just over the tolerance limits used in the analysis. Where these average values were based on a small number of sampling events, especially for calcium or pH, this could have produced a misclassification.

• Interactions of some of the variables may limit colonization. For example, zebra mussels' salt tolerance and metabolic efficiency decrease as temperatures rise beyond 25-28° C; therefore, zebra mussel distribution may be more restricted in the warm southern areas of the state than indicated by our analysis, which did not take such interactions into account.

• Confounding factors in studies of existing zebra mussel distributions may have given us an unrealistically narrow impression of their environmental tolerances; and introduced populations may become adapted, through natural selection and genetic change, to conditions that earlier generations could not tolerate. These issues could lead to waters being judged environmentally unsuitable which later support thriving populations of zebra mussels, as has happened on occasion.

Finally, our preliminary assessment of some data on zebra mussel distribution that we acquired late in this study suggests that the calcium levels required for reproduction or early development may be higher than the threshold levels cited by most of the literature and researchers, and which we used in this analysis. Should this turn out to be the case, a number of the sites that we classified as suitable habitat may in fact not be able to support in situ reproducing populations. Some of these sites, however, may still be subjected to dense accumulations of zebra mussels resulting from the settlement of larvae produced by upstream populations. We hope to sort this issue out with further analysis.

2. Potential abundance

The aqueducts and many of the reservoirs of California's State Water Project and the Central Valley Project provide optimal chemical and physical conditions for zebra mussels, and thus may support abundances approaching those seen in the Great Lakes. The California Aqueduct, the Los Angeles Aqueduct, and the Colorado River Aqueduct have concrete or steel substrates and flow rates under 1.5 m/sec. Even waters with soft substrates could eventually support high densities of mussels after initially settling on vegetation, sticks, or trash, and then on each other, to form large aggregations. However, flowing water may depress abundance in rivers and streams relative to lakes and reservoirs, and in smaller rivers relative to larger (and generally slower) ones. In Europe, zebra mussels are seldom found in rivers less than 30 meters wide and are generally at least an order of magnitude more abundant in lakes and reservoirs than in large rivers.

Abundance could also be affected by the presence or absence of upstream sources of larvae. Larvae from upstream sources can supplement resident populations and serve to re-inoculate an area should an environmental perturbation, such as a winter die-off, depress or exterminate a population. It is also possible that the settlement of larvae from upstream has created some dense populations in waters that are unsuitable for reproduction.

Finally, abundance may be affected by predation. While it is clear that predation has in some cases significantly depressed the local abundance of zebra mussels, it is not known whether predation could control populations in an entire region and over the long term.

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GLOBAL

"Zebra mussels have arrived in Ireland!" That news, when it came during the Winter of 1997/98, caught the attention of North American zebra mussel researchers — we suddenly weren't alone as the newest home to the mighty mollusc. The mussels were discovered in large numbers in Lough Derg and the lower River Shannon during the summer of 1997. The demography of these populations suggest they have been present undetected for about two years. The discovery prompted the establishment of a research program at the National University of Ireland, Galway, to assess and monitor the ecology and geography of the mussel in Ireland. This work is moving forward as part of a national effort in conjunction with the Irish Marine Institute.

In addition to the extensive zebra mussel populations in Lough Derg, the mussel is now found in the lower River Shannon, in canals serving the Ardnacrusha Power Station, in the Limerick docks area, and in the Upper Shannon. There are concerns that the mussel will spread via the recently re-opened Shannon-Erne Waterway into the Erne lakes.

*Serious problems have already arisen at an ESB [a major generator of electric energy in the Republic of Ireland] owned salmon hatchery located downstream of Lough Derg where zebra mussels settling on screens and intake pipes have drastically reduced the flow of water to salmon rearing tanks. Numerous boat owners in the lower Shannon area are reporting heavy mussel fouling of boat hulls. There are also indications that public domestic water supplies are being affected. There is also the fear that the mussel will have negative impacts on the Lough Derg spawning grounds of the endangered pollan (*Coregonus autumnalis*).*

An international workshop "Zebra Mussels in Ireland," was held on 19 - 21 February 98 in Connemara, Galway, sponsored by ESB, the Ir-Am-Aqua Initiative (an Irish-American aquaculture initiative between Ireland, Northern Ireland, and the Northeast Sea Grant Network), Connecticut and New York Sea Grant, the Marine Institute of Ireland, the Irish EPA, Duchas (the Irish Heritage Service), the Northern Ireland Environment and Heritage Service, the Shannon and Western Regional Fisheries Boards, and the National University of Ireland. More than 120 government, academic, and private sector attendees learned about the zebra mussel, its impacts, and control from a conference faculty made up of North America, Irish, and European researcher. North American presenters included: Ellen Marsden (University of Vermont), Robert McMahon (University of Texas-Arlington), Chuck O'Neill (New York Sea Grant), Nancy Balcom (Connecticut Sea Grant), and Ladd Johnson (Laval University).

*Two of the abstracts from the workshop are presented below. More detailed articles by Irish researchers regarding the invasion will be published in Vol. 9 No. 3 of this newsletter. In the meantime, two main contacts regarding zebra mussels in Ireland are Dr. T.K. McCarthy (*tk.mccarthy@ucg.ie*) and Dr. D. Minchin (*dminchin@frc.ie*). [Chuck O'Neill, Editor.]*

Dispersal of Zebra Mussels in Ireland

Investigator: Dan Minchin, Marine Institute, Fisheries Research Centre, Abbotstown, Dublin 15

Zebra mussels *Dreissena polymorpha* were found for the first time in Ireland during 1997 naturalized in the lower region of the River Shannon between Limerick Dock and the northern end of Lough Derg, a linear distance of about 70 km. The first observation of zebra mussels was from the Limerick Dock in March 1995. This suggests that they had become established in 1994. The zebra mussel has been established in lower Lough Derg at least since 1995. This has been deduced from polymodal frequencies verified from known dates of immersion of boats from which samples have been obtained. Zebra mussels may have come from the UK on the bottom of second-hand boats imported on trailers and were found on one recently imported barge. It is possible that there has been more than one introduction with a further population introduced with discharged ballast, used as trim, from boats carrying timber from the Baltic Sea. It is likely that within a few years boats on the Shannon will extend the present range of zebra mussels to the navigable waterway network to include Lough Erne and the Barrow navigation via the Grand Canal. Leaflets have been distributed to advise boat-owners, lock-keepers, anglers and public bodies as to how movements may take place and what measures to avoid range extensions.

The Zebra Mussel in Ireland

Investigator: T.K. McCarthy, National University of Ireland, Galway

Ireland's fauna exhibits mainly "island" features, with reduced species richness and disharmonic structure being evident in respect of several taxonomic groups. Equilibrium models of island biogeography and knowledge of the effects of the Pleistocene glaciations can assist understanding of the relative importance of environmental condition and barriers to dispersal as determinants of the present day species composition of the Irish aquatic fauna. Species introductions, deliberate or accidental, by man are occurring at a greatly increased rate. The introduction of zebra mussels to Ireland reflects this trend.

Zebra mussels were first recorded scientifically in Ireland in May 1997 during studies in unionacean mussels in Lough Derg, though subsequent enquiries revealed that lock gate operatives on the lower River Shannon had noted them in the previous year. Length frequency analysis of the initial samples indicated that the species had been established for at least two years. Questionnaires were issued to anglers, commercial eel fishermen, boat marinas and a field-sampling programme was undertaken. The results of this study, summarized in a report commissioned by ESB, were communicated widely and increased public awareness of the potential economic and ecological damage that zebra mussels could cause in Ireland led to concern being expressed by various state agencies and by fishery managers, anglers and conservationists. The survey of zebra mussel distribution is on-going and recent field work, including SCUBA dive surveys and underwater video surveys, have shown that, in addition to being firmly established in Lough Derg and the lower Shannon system, the species has been spread by pleasure craft to upper catchment sites such as Lough Ree and above Carrick-on-Shannon. Furthermore the species has recently been shown to have spread to lower Lough Erne in Northern Ireland, via the recently re-opened Shannon-Erne waterway. Details of population structure, growth rates, substrate utilization patterns and general ecology of L. Derg zebra mussels will be presented. The potential effects of the species on Irish unionacean bivalves, fish populations and lake water quality will be outlined. Examples of the damage being caused by zebra mussels as fouling organisms in the Shannon area will be presented.

The need for adequately funded integrated monitoring research programmes, to comprehensively document the ecological and economic effects of zebra mussels in Ireland will be stressed. Development of links with research programs in North America and in other European countries will be important if effective control technologies, consistent with EU directives and environmental constraints appropriate to Irish conditions are to be implemented. Increased public awareness of the danger associated with exotic species introductions will be important in limiting the spread of zebra mussels in Ireland and hopefully reducing the rate of faunal change now occurring at an alarming rate.

POLICY

The 100th Meridian Initiative Introduction

Nonindigenous aquatic nuisance species are causing significant economic and ecological problems throughout North America. Invasive species such as zebra mussels, Asian clam, spartina, and purple loosestrife now threaten western waters. Problems that are caused by exotics in fresh and marine waters include:

a. The Central Arizona Project estimates zebra mussels will increase operations and maintenance costs between $4 - 5 million annually. This figure does not reflect cost to customers, farmers and water treatment plants. Great Lakes water users spend millions of dollars annually to monitor and control zebra mussels.

b. The Japanese oyster drill *Ceratostoma inornatum* has decreased aquaculture net profits by 55%, increased production costs by 17% and caused a 25% mortality in outplanted oyster seed.

c. The invasion of the Asian clam, *Potamocorbula amurensis* has affected food webs in San Francisco Bay by depleting phytoplankton stocks.

d. A 1996 report issued by the Nature Conservancy states that invasive non-native species are one of the leading threats to the ecological integrity of our nation's forests, grasslands, and waterways.

The West has an opportunity to protect its financial and ecological resources from the damage caused by these nuisance species. A rapid and coordinated rapid response on the part of the public and private sector will ensure that the spread of aquatic nuisance species is limited. Research has indicated that most of these species be introduced into the west through recreational boating and angling activity, aquaculture and ballast water.

On November 20, 1997, representatives from resource agencies in CA, CO, KS, ND, NE, OK, TX, WA, WY and Manitoba, the U.S. Fish and Wildlife Service, Bureau of Reclamation, U.S. Army Corps of Engineers, Sea Grant and private industries met to discuss the 100th Meridian Initiative to Prevent the Western Spread of Zebra Mussels and other Nuisance Aquatic Exotics. The program outlined in the 100th Meridian initiative is aimed at preventing or slowing the spread of zebra mussels and aquatic vegetation into the western United States.

Zebra Mussels: A Case In Point

The zebra mussel, (*Dreissena polymorpha*) has rapidly spread across much of the eastern United States and Canada. This nuisance exotic has cost municipal and industrial water facilities millions of dollars to control. Native freshwater mussel populations are being decimated by zebra mussels (Biggins 1992), (Haag, et al., 1993). Their cumulative impact on aquatic ecosystems has yet to be quantified. Most experts believe that in the absence of effective preventative measures, the zebra mussel may spread throughout North America. With the exception of Oklahoma, States and Provinces west of Minnesota, Iowa, Missouri, and Arkansas have not been impacted by the zebra mussel invasion. The scarcity of water in the west makes water delivery systems and aquatic systems particularly vulnerable to zebra mussel fouling. For example, many westerners rely on canals, diversion systems, and dams built by the Bureau of Reclamation to deliver water for a variety of needs. Tens of thousands of miles of canals provide an ideal habitat for zebra mussel colonization. In the event that zebra mussels establish themselves, the probability of reducing the quality or quantity of limited water resources could be devastating to agricultural, industrial and recreational interests. (F. Nibling, Bureau of Reclamation, Personal Communication 1995).

In 1994, the U.S. Fish and Wildlife Service (Service) conducted a study to determine the feasibility of preventing or reducing the further western spread of zebra mussel (Tyus et al., 1994). The study determined that the primary method of zebra mussel transport across the Continental Divide is by recreational boating activity. Many people trailer boats and motors across the country for fishing tournaments, recreational fishing, and pleasure boating. Adult zebra mussels may attached to hulls, motors, or in motor compartments. Larvae can survive in wells, bilge water, or in the internal parts of motors and trailers. Secondary methods for spreading zebra mussel veligers include the use of tank trucks and equipment by bait dealers, State and Federal fish distributors, the aquaculture industry, and the aquarium trade. Zebra mussels can also be spread in irrigation water, introduced with hatchery bait or aquarium fish, or attached to or on various items that are used by anglers, the aquarium trade, and the aquaculture industry.

A Canadian boater survey and California Agricultural Check Stations inspections provide evidence supporting the conclusion that zebra mussels will be transported into the west via recreational boats. During the summer of 1994, Youth Service Canada students, under the supervision of Fish Futures, Inc., and with the cooperation and assistance of Canada Customs, Ontario Ministry of Natural Resources, and Manitoba Environment, conducted interviews and boat inspections at border crossings located between the United States and Canada as well as at other key sites. All interviews and inspections were carried out in watersheds that contribute surface water to Manitoba. Major findings included: 93% of the boats originated from jurisdictions that have waters with zebra mussels, 5% had been in waters with zebra mussels in the last 5 days, 60% had been drained since being in zebra mussel-infested waters, and 32% had been cleaned since being in zebra mussel infested waters (Fish Futures, Inc. 1994).

The California Department of Food and Agriculture inspects boats entering California at border agricultural inspection stations for the presence of zebra mussels. These exotics have been declared injurious species by California law. Since the inception of the inspection program in early October 1993, there have been fourteen records of boats with zebra mussels being stopped at border agricultural inspection stations. Michigan was the point of origin in three cases and these mussels were dead (D.F. Peterson, California Department of Water Resources, Written Communication, 1995).

Despite this evidence of zebra mussels being carried into the west, there are still opportunities to preclude the extensive colonization that has occurred in the east. In the east, barges, large recreational boats and downstream colonization are considered the primary reasons for the rapid spread of zebra mussels. In the west there are a limited number of land and water pathways through which zebra mussels may colonize western waters. The large, relatively unpopulated arid and semiarid territories of western North America may provide the first realistic opportunity to slow or stop the further spread of the zebra mussel.

Goals and Strategies

The goal of the 100th Meridian Initiative is to prevent or slow the spread of zebra mussels and aquatic species west of the 100th Meridian. To determine and reduce the risk of zebra mussel infestation, a comprehensive prevention-exclusion program will be supported by the Service in the six States and Manitoba that straddle the 100th Meridian. Components of this proposed program include; information/education campaigns, strategic placement of voluntary inspection stations and monitoring programs.

Strategy I. Information and Education

The main aspect of an information and education program is to educate the public, particularly boaters and anglers, on what they can do to prevent the further spread of zebra mussels. Information and education programs will be developed by each state in order to meet its individual circumstances. Commercial haulers , recreational boaters and anglers and aquaculturists will be encouraged to utilize techniques that reduce the likelihood of zebra mussels being transported during their respective activities.

Actions

1. Develop a single theme public information campaign targeted at western boaters and anglers. Create templates of educational posters, pamphlets, and billboards for use throughout the western United States. [Lead Agencies: USF&WS, SG]
2. Contact long distance boat transport companies regarding 100th meridian exclusion initiative to request their participation. [Lead Agencies: USF&WS, MA]
3. Post exotics prevention (including voluntary inspection procedures) literature in conjunction with low power radio stations at interstate visitors centers, weigh stations, and rest areas in KS,NE,ND,OK,SD,TX. [Lead Agencies: States]
4. Utilize billboards on major interstates in KS (I-70), NE (I-80), ND (I-94), OK (I-40), SD (I-90), TX (I-20), Manitoba (#1) to convey prevention message. [Lead Agencies: States, USF&WS, MS.]
5. Post zebra mussel advisory signs at public boat access sites in KS, NE, ND, OK, SD, TX. [Lead Agencies: States, SG]
6. Create TV and radio public information spots on prevention message. Distribute these spots throughout States. [Lead Agencies: USF&WS, SG]
7. Contact state and local boat shows and request information be distributed or that USF&WS Western Spread Display be used. [Lead Agency: USF&WS]
8. States will identify fishing tournaments requiring zebra mussel prevention conditions. [Lead Agencies: States]
9. Zebra mussel prevention information will be placed in state boater registration packets or fishing regulations when feasible. [Lead Agencies: States]
10. Aquatic exotic curricula including videos will be developed for elementary and secondary school. [Lead Agencies: USF&WS, SG, States]
11. Contact state Departments of Transportation to determine feasibility of placing low/high power radio stations at selected visitor centers, rest areas or weigh stations in states along the 100th Meridian Highways. These radio stations will be used to notify travelers and commercial haulers of the need to inspect for zebra mussels and other aquatic exotics. The radio spots will identify the closest voluntary inspection station. [Lead Agencies: States]

Strategy II. Inspection and Access Management

This strategy is intended to take management actions which will prevent the inadvertent spread of zebra mussels into the Western United States.

1. Determine existing state and federal laws, regulations and policies governing exclusion of aquatic exotics. [Lead Agencies: USF&WS, States]
2. Identify key east west interstate highways in 100th Meridian states. Locate all visitor centers, weigh stations and rest areas on these highways.(NE; I-80, ND; I-94, KS; I-70, OK; I-40, TX; Dallas Ft. Worth). [Lead Agencies: USF&WS, SG]
3. Identify strategic visitor centers, rest areas and weigh stations for use as voluntary boat inspection sites. Determine strategic times to ensure maximum visitation at boat inspection sites. [Lead Agencies: States]
4. Utilize low/high power radio stations to notify travelers and commercial haulers of the need to inspect for zebra mussels and other aquatic exotics. The radio spots will identify the closest voluntary inspection station. [Lead Agencies: States]
5. Identify strategic marinas and access sites for location of boat wash/inspection sites. [Lead Agencies: States, USACE, BOR]

Strategy III. Monitoring for Zebra Mussels and Exotic Aquatic Vegetation

This strategy will identify areas at specific risk to infestation as well as allow for a rapid response to initial infestation.

1. Develop and conduct assessment of 100th Meridian Initiative efforts including; effectiveness of educational/inspection/ monitoring program. [Lead Agencies: USF&WS, BOR, USACE, SG, States]

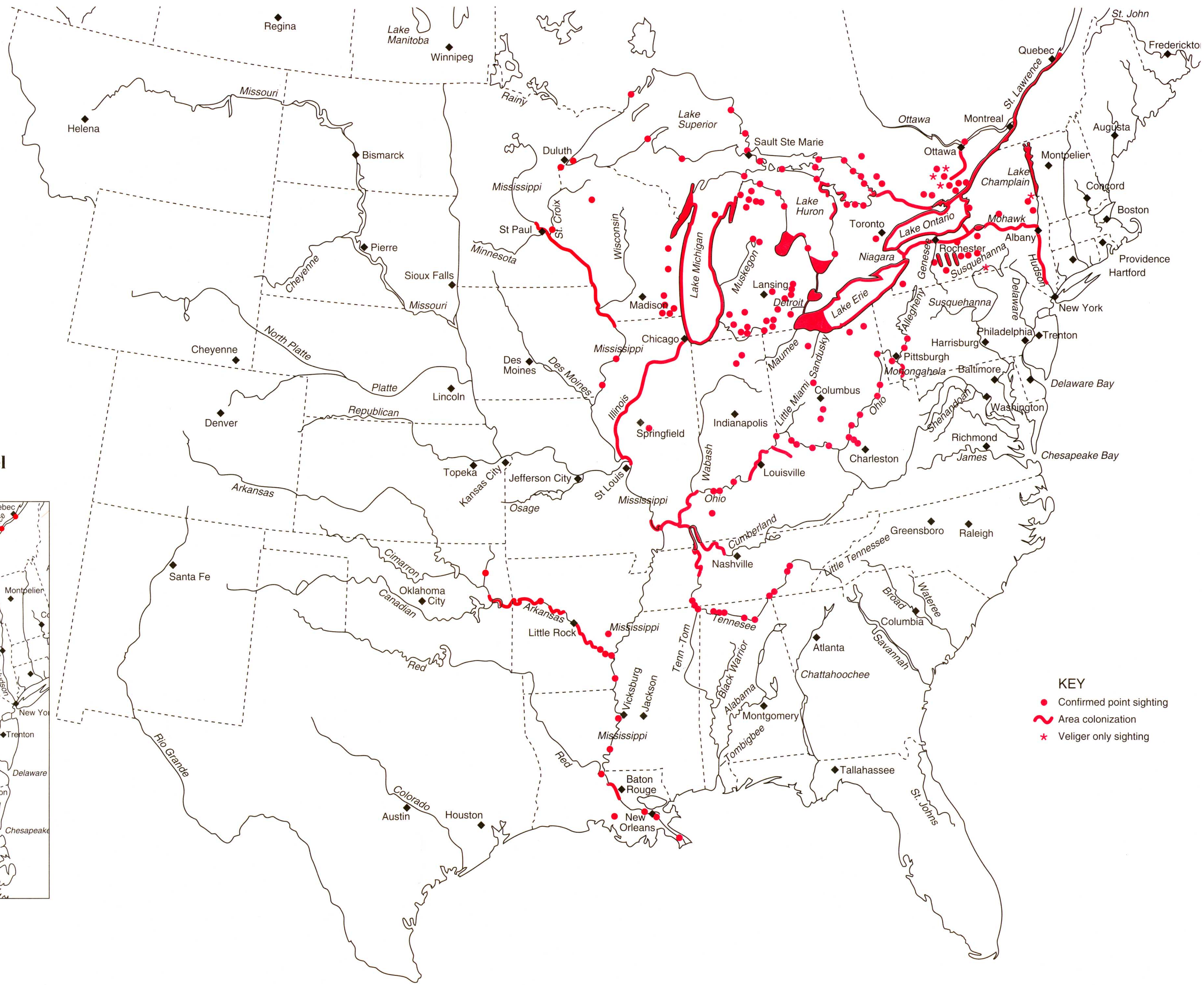
SIGHTINGS

North American Range of the Zebra Mussel

as of 1 May 1998

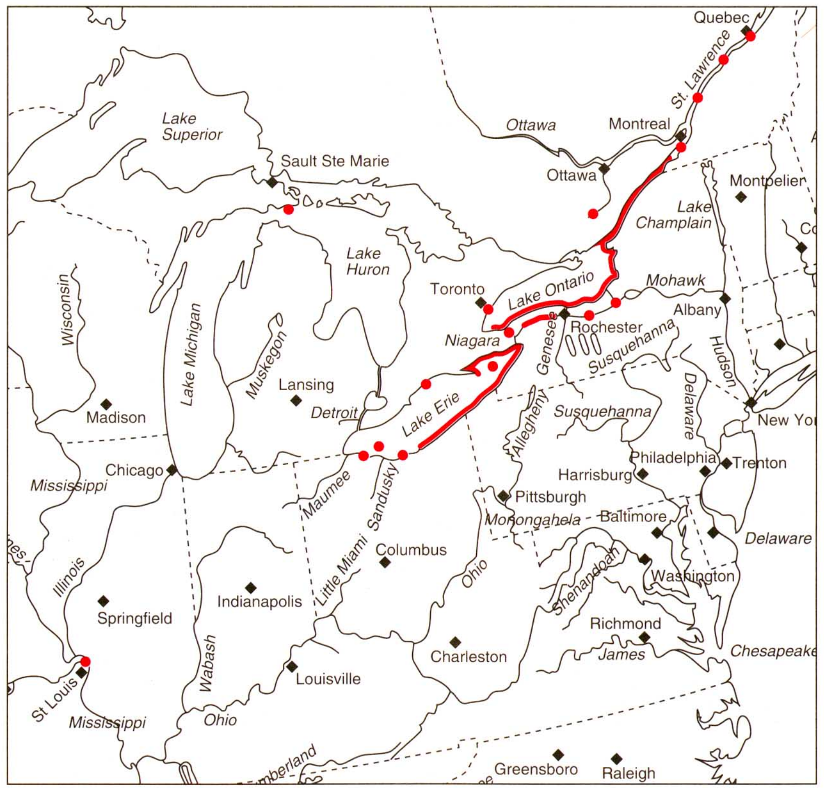
Compiled by New York Sea Grant with information from: Canadian Museum of Nature, Fisheries and Oceans Canada, Great Lakes Sea Grant Network, Illinois Natural History Survey, National Biological Survey, Ontario Federation of Anglers and hunters, Ontario Hydro, Ontario Ministry of Natural Resources, Tennessee Valley Authority, US Army Corps of Engineers, US Fish & Wildlife Service, and Utilities and others throughout North America.

Sightings: No new sightings



North American Range of the Quagga Mussel

as of 1 May 1998



Sightings: No new sightings

2. Continue USF&WS monitoring for zebra mussels at field stations in ND, SD, NE, KS. [Lead Agency: USF&WS]

3. Compile baseline data on boater and angler traffic using existing data bases; creel, Department of Transportation, etc. [Lead Agencies: States, USF&WS]

4. Utilize existing communication and monitoring network (Western Zebra Mussel Task Force and Western Regional Panel) regarding on zebra mussel sightings. [Lead Agencies: USF&WS, USGS/BRD]

5. Conduct risk assessment of western water bodies to determine water bodies at risk for infestation. Map those sites and make available to state resource agencies. [Lead Agencies: USF&WS, BOR, USACE, States]

6. Monitor high risk sites identified in #3. [Lead Agencies: USF&WS, BOR, USACE, States]

7. Develop emergency response/ containment plan to respond to initial infestations. [Lead Agencies: USF&WS, BOR, USACE, States]

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PD0021 de Leeuw, J.J. & Renema, W. 1997. Dwingt kleptoparasitisme kuifeenden *Aythya fuligula* tot nachtelijk foerageren? (Do tufted ducks *Aythya fuligula* feed by night to avoid kleptoparasitism). *Limosa*, 70(1): 1-4. *($0.48)* DUTCH W/ENGLISH SUMMARY

DPEC198 Frischer, M.E., Resto, M., Toro, A., Nierzwicki-Bauer, S.A., Hansen, A.S., Bushnell, T.P., & Toranzo, G.A. 1997. Zebra mussels as possible reservoirs of *Giardia* and *Cryptosporidium*. *Abstracts of the General Meeting of the American Society for Microbiology*, 97(0): 460. *($0.12)* ABSTRACT

DPEC199 Karatayev, A.Y., Burlakova, L.E., & Padilla, D.K. 1997. The effects of *Dreissena polymorpha* (Pallas) invasion on aquatic communities in Eastern Europe. *Journal of Shellfish Research*, 16(1): 187-203. *($2.04)*

DPEC200 Kastner, R., Lutz, G., & Barrett-O'Leary, M. 1997. The zebra mussel and bait fish aquaculture. *(available from Louisiana Sea Grant College Program)*

DPEC201 Kastner, R., Lutz, G., & Barrett-O'Leary, M. 1997. The zebra mussel and catfish aquaculture. *(available from Louisiana Sea Grant College Program)*

DPEC202 Kastner, R., Lutz, G., & Barrett-O'Leary, M. 1997. The zebra mussel and crawfish aquaculture. *(available from Louisiana Sea Grant College Program)*

DPEC203 Kastner, R., Lutz, G., & Barrett-O'Leary, M. 1997. The zebra mussel and hybrid striped bass aquaculture. *(available from Louisiana Sea Grant College Program)*

DPEC204 Kastner, R., Lutz, G., & Barrett-O'Leary, M. 1997. The zebra mussel and tilapia aquaculture. *(available from Louisiana Sea Grant College Program)*

EX0029 Khalanski, M. 1997. Conséquences industrielles et écologiques de l'introduction de nouvelles espèces dans les hydrosystèmes continentaux: La moule zébrée et autres espèces invasives (Industrial and ecological consequences of the introduction of new species in continental aquatic ecosystems: The zebra mussel and other invasive species). *Bulletin Francais de la Peche et de la Pisciculture*, 0(344-345): 385-404. *($2.40)* FRENCH W/ENGLISH ABSTRACT

DPTX101 Lucker, T., Busch, D., & Wosniok, W. 1997. Experiments to determine the impact of salinity on the heavy metal accumulation of *Dreissena polymorpha* (Pallas 1771). *Limnologica*, 27(1): 91-101. *($1.32)*

DPBI247 Medler, S. & Silverman, H. 1997. Functional organization of intrinsic gill muscles in zebra mussels, *Dreissena polymorpha* (Mollusca:Bivalvia), and response to transmitters *in vitro*. *Invertebrate Biology*, 116(3): 200-212. (*$1.56*)

DPTX103 Roper, J.M., Cherry, D.S., Simmers, J.W., & Tatem, H.E. 1996. Bioaccumulation of toxicants in the zebra mussel, *Dreissena polymorpha*, at the Times Beach Confined Disposal Facility, Buffalo, New York. *Environmental Pollution*, 94(2): 117-129. (*$1.44*)

DPTX104 Roper, J.M., Cherry, D.S., Simmers, J.W., & Tatem, H.E. 1997. Bioaccumulation of PAHs in the zebra mussel at Times Beach, Buffalo, New York. *Environmental Monitoring and Assessment*, 46(3): 267-277. (*$0.72*)

DPTX105 Sures, B., Taraschewski, H., & Rydlo, M. 1997. Intestinal fish parasites as heavy metal bioindicators: A comparison between *Acanthocephalus lucii* (Palaeacanthocephala) and the zebra mussel, *Dreissena polymorpha*. *Bulletin of Environmental Contamination and Toxicology*, 59(1): 14-21. (*$0.96*)

ANNOTATIONS

Kraak, M.H.S., Ainscough, C., Fernandez, A., van Vlaardingen, P.L.A., de Voogt, P., & Admiraal, W.A. 1997.
Short-term and chronic exposure of the zebra mussel (*Dreissena polymorpha*) to acridine: Effects and metabolism. *Aquatic Toxicology*, 37(1):9-20. (*$0.84*) **DPTX094**

Potential effects of relatively hydrophilic nitrogen containing polycyclic aromatic hydrocarbons (NPAH) in the aquatic environment were tested under laboratory conditions using zebra mussels (*Dreissena polymorpha*) exposed to acridine (benzol[*b*]quinoline range 0-2.50 mg acridine /l). Filtration rates were measured in both short-term (48 hours) and chronic (10 weeks) experiments by calculation of decreases in algal concentration (*Scenedesmus acuminatus*; 20,000 cells/ml). The filtration response was dose-dependent in the short-term trials with a 50% reduction in filtration rates compared to controls at a calculated concentration of 0.96 mg acridine /l. Filtration rates during chronic exposure trials were comparable to short-term trials after 48 hours, but mortality increased sharply at higher acridine concentrations. In the chronic trials, a degradation metabolite, 9(10H)-acridone, appeared in the medium after 4 weeks with concomitant cessation of mussel mortality. Indications of enhanced metabolic degradation of acridine over time by mussels, periphyton and bacteria in the aquaria were observed. (*bib;fig;tab*)

Klerks, P.L. & Fraleigh, P.C. 1997.
Uptake of nickel and zinc by the zebra mussel *Dreissena polymorpha*. *Archives of Environmental Contamination and Toxicology*, 32:191-197. (*$0.84*) **DPTX093**

Uptake of both dissolved (<0.45 µm) and particulate fractions of zinc and nickel under laboratory conditions by *Dreissena polymorpha* is reported. Dissolved nickel uptake was twice that of particulate nickel uptake, although the latter was also significant. Zinc uptake was highly variable ranging from exclusively particulate uptake in highly turbid waters, to primarily dissolved zinc under less turbid conditions. Differential excretion rates were observed with over half the zinc eliminated within 24 hours of accumulation, compared to no detectable nickel excretion. Zinc removal from the water column exceeded that of nickel, with biodeposition of zinc as feces and pseudofeces and bioaccumulation of nickel. The results suggest element-specific decreases in metal concentrations in the water column with concomitant increases in metal bioaccumulation and biodeposition, and that biomonitoring programs using mussels would reflect changes in both particulate and dissolved metal concentrations. (*bib;fig*)

Cope, W.G., Bartsch, M.R., & Hayden, R.R. 1997.
Longitudinal patterns in abundance of the zebra mussel (*Dreissena polymorpha*) in the upper Mississippi River. *Journal of Freshwater Ecology*, 12(2):235-238. (*$0.48*) **DPSP102**

Abundance of the zebra mussel (*Dreissena polymorpha*) in the Mississippi River four years after the initial reports of colonization is reported. Sampling took place from May to October, 1995 at locks and dam facilities in the upper Mississippi River from Minneapolis, Minnesota to Muscatine, Iowa. Every lock and dam was colonized except the two sites furthest upstream at Minneapolis. The highest mussel density (11,432 /m^2) was observed at Fulton, Illinois. In general, sites 161km or more downstream from Minneapolis had the greatest zebra mussel densities. (*bib;fig*)

Boles, L.C. & Lipcius, R.N. 1997.
Potential for population regulation of the zebra mussel by finfish and the blue crab in North American estuaries. *Journal of Shellfish Research*, 16(1): 179-186. (*$0.96*) **DPEC196**

A series of descriptive and manipulative experiments were conducted in the Hudson River Estuary to quantify the abundance, natural mortality and effectiveness of predator control on the zebra mussel (*Dreissena polymorpha*). Measurements of the mussel population size structure and density on rocks collected along a depth gradient over a season were used to determine distribution and abundance. Natural mortality was examined using cages to exclude or allow access to local predators. Mortality on rocks of known mussel density presented to blue crabs (*Callinectes sapidus*) in field enclosures was compared with enclosed cages containing mussels alone to assess effectiveness of crab predation. Naturally occurring predators, as determined by underwater video observation, were primarily finfish of the genus *Lepomis*. Mortality was an order of magnitude higher in enclosures containing crabs than those exposed to only the local predator guild and approached localized extinction at densities of 0.1 crab/m^2. It was suggested that in the southern portion of the mussels range, where blue crabs are more abundant, predation may serve to regulate zebra mussel populations. (*bib;fig;tab*)

Cope, W.G., Bartsch, M.R., & Marking, L.L. 1997.
Efficacy of candidate chemicals for preventing attachment of zebra mussels (*Dreissena polymorpha*). *Environmental Toxicology and Chemistry*, 16(9): 1930-1934. (*$0.60*) **DPIC243**

Testing conducted on forty-seven chemicals with potential for preventing attachment of zebra mussels (*Dreissena polymorpha*) is reported. Mussels were exposed to candidate chemicals for 48 hours followed by a 48 hour post exposure depuration period in untreated water. Eleven chemicals prevented reattachment during exposure and had sufficiently low effective concentrations to warrant further analysis. Of those, three chemicals were selected for toxicity testing on non-target fish (bluegill, *Lepomis macrochirus*; channel catfish, *Ictalurus punctatus*; rainbow trout, *Oncorhynchus mykiss*) following evaluation of chemical cost, aqueous solubility, anticipated treatment concentrations, and potential hazard to humans or the environment. The chemicals tested, all antioxidants (BHA, butylated hydroxyanisole; *tert*-butylated hydroxyquinone; tannic acid) were generally not toxic for *Dreissena* at concentrations necessary to prevent reattachment, but did affect non-target fish. Exploration of more selective formulations, such as in paints or coatings, was suggested. *(bib;fig;tab)*

High, K.A., Barthet, V.J., McLaren, J.W., & Blais, J.S. 1997.
Characterization of metallothionein-like proteins from zebra mussels (*Dreissena polymorpha*). *Environmental Toxicology and Chemistry*, 16(6): 1111-1118. (*$0.80/$0.96*) **DPBI243**

Characterization and partial purification of metallothionein-like proteins from the zebra mussel (*Dreissena polymorpha*) was undertaken to assess the mechanism of heavy metal binding in the mussel. Metallothionein is a protein capable of binding heavy metals, such as copper (Cu), cadmium (Cd) and zinc (Zn). *Dreissena* were exposed to Cd to stimulate production of the metallothionein-like proteins for study, followed by extraction of the proteins. Two metallothionein-like proteins were identified. Evidence supporting the characterization of the proteins and data on the metal binding affinity of these proteins for Cd, Cu and Zn are presented. Characteristics of these proteins in mammals and other invertebrates are discussed. Wide distribution and large numbers of zebra mussels in the environment coupled with the characteristics of these proteins make them potentially useful biomarkers for heavy metal monitoring. *(bib;fig;tab)*

Karatayev, A.Y., Burlakova, L.E., & Padilla, D.K. 1997.
The effects of *Dreissena polymorpha* (Pallas) invasion on aquatic communities in Eastern Europe. *Journal of Shellfish Research*, 16(1): 187-203. (*$2.04*) **DPEC199**

This review synthesizes information not generally available to the English-speaking scientific community because of language and political barriers. Over 60 years of research, conducted primarily in the former Soviet Union and Eastern Europe, describes the effects *Dreissena polymorpha* on taxonomy, biology, food web ecology, productivity and ecosystem function. The invasion of lakes often precipitates dramatic changes within a waterbody. *Dreissena* becomes quite abundant in a short period of time generally dominating the native benthic community and outcompeting native filter feeders. Native filter feeders decline, accompanied by an increase in the abundance of animals feeding in or on the sediments. Sharp declines are often seen in native unionids, followed by establishment of an equilibrium between unionids and *Dreissena*. Efficient filtration by *Dreissena* results in a loss in pelagic zoo- and phytoplankton productivity with a concomitant increase in benthic production causing a redistribution of resources from the pelagic to the benthic communities. Benthophage fish biomass increases, and a generally greater percentage of primary production is consumed by higher trophic levels than in systems lacking *Dreissena*. Comparisons to data generated in North America are discussed. *(bib;fig;tab)*

Lucker, T., Busch, D., & Wosniok, W. 1997.
Experiments to determine the impact of salinity on the heavy metal accumulation of *Dreissena polymorpha* (Pallas 1771). *Limnologica*, 27(1): 91-101. (*$1.32*) **DPTX101**

Heavy metal (cadmium, lead), zinc) accumulation three salinity levels (1.7, 2.7, 4.7 ppt (parts per thousand)) is reported in *Dreissena polymorpha*. Two experimental sequences were used. The first consisted of natural river water adjusted for salinity and the second, of river water at the same salinity levels enriched with a mixed solution of cadmium, lead and zinc. Increasing salinity generally enhanced metal accumulation, possibly by increasing free ions in the water column. Cadmium accumulation was increased significantly ($p < 0.05$) at all salinity levels compared to controls, zinc accumulation increased significantly at salinities of 2.7 and 4.7 ppt, and lead at 4.7 ppt. Ecotoxicological effects of salinity on metal ion bioavailability are discussed. *(bib;fig;tab)*

Medler, S. & Silverman, H. 1997.
Functional organization of intrinsic gill muscles in zebra mussels, *Dreissena polymorpha* (Mollusca:Bivalvia), and response to transmitters *in vitro*. *Invertebrate Biology*, 116(3): 200-212. (*$1.56*) **DPBI247**

An examination of the role of intrinsic gill muscles and associated connective tissue and their ability to control water flow by adjusting the size of water passageways in *Dreissena polymorpha* is reported. Two sets of muscles with a complementary orientation to each other, are located within the hemocoel and bathed in hemolymph. They function to reduce interfilament distances in the gill, regulating ostial size in both the inner and outer ostia. Interactions of these muscles with surrounding connective tissue are described in detail. The *in vitro* response of these muscles to exogenous application of acetylcholine and FMRFamide which stimulate muscle contraction, reducing ostial area, and serotonin which relaxes contraction, increasing ostial area are presented. Changes in gill dimensions observed during microscopic examination are consistent with a role in regulating water flow. Gill response to neurotransmitters in other bivalve species is discussed. *(bib;fig;tab)*

Metcalfe, C.D., Metcalfe, T.L., Riddle, G., & Haffner, G.D. 1997.
Aromatic hydrocarbons in biota from the Detroit River and western Lake Erie. *Journal of Great Lakes Research*, 23(2): 160-168. (*$1.08*) **DPTX102**

Elevated concentrations of polynuclear aromatic hydrocarbons (PAHs) and PCBs detected in zebra mussels (*Dreissena polymorpha*) collected in the Detroit River are compared to levels of PAH metabolites in the bile of gizzard shad (*Dorsosoma cepedianum*) and freshwater drum (*Aplodinotus grunniens*) collected in the Detroit River and western Lake Erie. The purpose being to compare distribution of PAHs to PCBs from the upper Detroit

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River down the eastern margin of the western Lake Erie basin to Point Pelee, and to determine whether benthic fish show signs of exposure to elevated levels of PAHs. Zebra mussel PCB concentrations are consistent with those reported in a moderately polluted rivers, and demonstrate the influence of the river contamination down the coastline. Both PAHs and PCBs were elevated in tissues of mussels from the heavily industrialized portions of the Detroit River, as were the PAH metabolite levels in the fish. No evidence of contamination by ingesting contaminated biota or exposure to sediments was observed in the fish from the Lake Erie basin.

(bib;fig;tab)

Sures, B., Taraschewski, H., & Rydlo, M. 1997. **Intestinal fish parasites as heavy metal bioindicators: A comparison between *Acanthocephalus lucii* (Palaeacanthocephala) and the zebra mussel, *Dreissena polymorpha*.** *Bulletin of Environmental Contamination and Toxicology*, 59(1): 14-21. (*$0.96*) **DPTX105**

Concentrations of cadmium and lead were determined for zebra mussels (*Dreissena polymorpha*), perch (*Perca fluviatilis*), and an acanthocephalan parasite (*Acanthocephalus lucii*) infesting the perch for a reference site and one contaminated by roadway runoff to investigate the potential advantages of using intestinal parasites as bioindicators of heavy metal contamination. Comparison of muscle, liver and intestinal tissues in the perch, total soft tissue in *Dreissena* and *A. lucii* demonstrated higher burdens in *A. lucii* of both cadmium (22-23 times) and lead (30-38 times) than the host intestinal wall, and 120-230 times the lead and 10-12 times the cadmium burden of *Dreissena*. Variability within the samples, however, was less for *Dreissena*. The levels of both cadmium and lead detected were significantly higher at the roadway site compared to the reference site. *Dreissena* was more suitable for detection of localized contamination than the fish or their endoparasites, possibly due to their lack of mobility. It was suggested that more sensitive detection of heavy metal contamination within an aquatic system may accomplished using acanthocephalans if host mobility is restricted due to their greater accumulation capacity.

(bib;fig;tab)

EDUCATIONAL MATERIALS

US Army Corps of Engineers Zebra Mussel Information System (ZMIS)

ZMIS is an interactive computer program designed to allow easy access to a wide variety of information on zebra mussels. Information in the system includes identification of larval, juvenile, and adult zebra mussels, life history, impact, monitoring and detection, management strategies, contaminant issues, and an extensive bibliography. Information is retrieved via an intuitive expert system graphical interface using standard Windows 3.1 features such as hyperlinked text, illustrations, and full color photographs. Access to the internet is also included. The system is the product of over 3 years of programming and information gathering and was funded primarily by the U.S. Army Engineer Waterways Experiment Station Zebra Mussel Research Program as an aid to technology transfer activities. For information on ZMIS, contact Michael J. Grodowitz, U.S. Army Engineer Waterways Experiment Station, CEWES-ER-A, 3909 Halls Ferry Road, Vicksburg, MS 39180, voice (601) 634-2972, fax (601) 634-2398, e-Mail - GRODOWM@EX1.WES.ARMY.MIL.