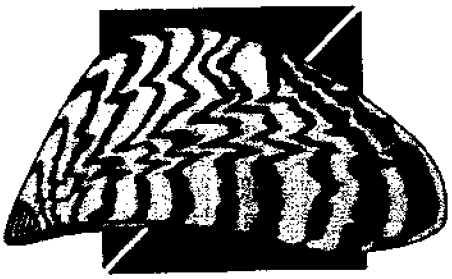


Second International Zebra Mussel Research Conference

19-22 November 1991 • Rochester, New York

CONFERENCE PROCEEDINGS

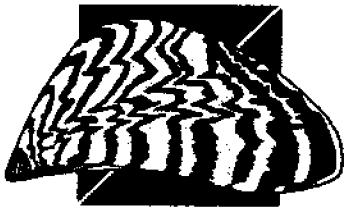
Sponsored by:

Great Lakes Sea Grant Network

Environment Canada/ Fisheries and Oceans

Hosted by:

New York Sea Grant



Second International Zebra Mussel Research Conference

19-22 November 1991
Rochester, New York

Sponsored by:

Great Lakes Sea Grant Network
(Illinois/Indiana, Michigan, Minnesota, New York, Ohio, Wisconsin)

Environment Canada

Fisheries and Oceans Canada

Hosted by:

New York Sea Grant

The conference was planned to facilitate the dissemination of important new information resulting from current research into the biology, impact, and control of the Zebra mussel (*Dreissena polymorpha*) in North American waters, and to enhance international cooperation and coordination in research on the Zebra mussel.

$ 8.00

CONTENTS

SESSION ONE:

ZEBRA MUSSEL BIOLOGY, PHYSIOLOGY, BEHAVIOR AND POPULATION DYNAMICS

MacNeill, David B.
New York Sea Grant

PHYSIOLOGICAL AND MORPHOLOGICAL COMPARISONS OF *DREISSENA POLYMORPHA* AND *MYTILOPSIS LEUCOPHAETA* (BIVALVIA: DREISSENIDAE)

The introduction of the zebra mussel, *Dreissena polymorpha*, into North America may have serious economic and ecological ramifications. Within the next ten years, *Dreissena* is predicted to spread into several estuarine areas along the eastern seaboard of the U.S., potentially resulting in a range overlap with the dark false mussel, *Mytilopsis leucophaeta*, a euryhaline dreissenid native to North America. Like other dreissends, *Mytilopsis leucophaeta* has biofouling tendencies, although believed to be of lesser consequence than *Dreissena*. Results of a literature review indicate partially overlapping salinity tolerances and habits of *Dreissena* and *Mytilopsis* in Europe. Because of their related phylogenies, these two bivalve species display close morphological similarities, particularly as juveniles, leading to probable field misidentification as their populations become sympatric. This presentation reviews physiological and morphological descriptions of *Dreissena polymorpha* and *Mytilopsis leucophaeta* and provides an abbreviated guideline for their definitive identification.

Garton, David W., and Ann M. Stoeckmann
Department of Zoology, The Ohio State University

GENOTYPE-DEPENDENT METABOLISM AT THE PHOSPHOGLUCOSE ISOMERASE LUCUS AT AMBIENT AND ELEVATED TEMPERATURES

Recent electrophoretic studies have shown that *Dreissena* populations in North America possess remarkably high levels of genetic variation at many enzyme loci. The locus coding for the glycolytic enzyme phosphoglucose isomerase (PGI, EC 5.3.1.9) is the most variable, with seven alleles present in the *Dreissena* population at our study site in western Lake Erie. Studies on variable loci in other invertebrate species have identified fluctuating environmental factors as primary agents responsible for maintaining genetic variation. In several marine and terrestrial species, environmental gradients of temperature result in corresponding clinal variation in PGI allele frequencies. Accordingly, we performed a series of experiments during the summers of 1990 and 1991 to determine if metabolic rate was genotype-dependent at ambient and elevated temperature in *Dreissena*.

Oxygen consumption of individual mussels was determined in a Gilson differential respirometer and expressed as ul h^{-1} std $mussel^{-1}$ at STP. Following oxygen consumption measurements, PGI genotypes were determined for each mussel using cellulose acetate electrophoresis. In 1990, metabolic rate was determined at ambient temperature (23.8°C) and 2 and 5 days following transfer to 31.2°C (N = 120 for ambient and Day 2, N = 80 for Day 5). In 1991, experiments were performed four times (May, July, August and October), with metabolic rate measured at ambient lake temperature, and 3–4, 8–11 and 15–16 days following transfer to 30°C (N = 40 for each sample date; total N = 480). All experiments were performed at Ohio State University's F.T. Stone Laboratory in western Lake Erie. Analysis of the 1991 series of experiments is currently in progress.

There were three common and four rare alleles at the PGI locus, numbered 1–7 in reverse order of electrophoretic mobility. Although nine genotypes were detected, the six genotypes of three common alleles (homozygous genotypes 33, 44 and 55; heterozygous genotypes 34, 35 and 45) comprised 87.5% of the population. Data analysis was restricted to common genotypes in order to maintain a balanced experimental design. Average oxygen consumption of heterozygotes was significantly less than homozygotes (21.8 vs 25.0 ul hr^{-1}, respectively, ANCOVA $p < 0.025$). Heterozygous genotypes 34 and 35 had much lower average metabolic rates than all other genotypes, whereas the rarest homozygous genotype (55) had significantly higher average metabolic rate. Average metabolic rates of genotypes 33, 44 and 45 were intermediate between genotypes 34 and 35, and 55. Genotype-dependent differences in metabolic rate were temperature sensitive, with significant differences between heterozygotes and homozygotes occurring at elevated temperature (2 and 5 days post-transfer to 31.2°C) and not at ambient lake temperature (23.8°C).

Increasing water temperature has been hypothesized as a factor limiting southern expansion of *Dreissena* in North America. Our results provide evidence that *Dreissena* possesses considerable genetic variation, and that variation at PGI can respond to selection via elevated temperature. This implies that zebra mussels have the ability to adapt to local temperature regimes, and that thermal tolerance measured on "northern" populations may not accurately predict ultimate thermal tolerances of "southern" populations of *Dreissena*.

Eckroat, Larry R., and Louise M. Steel
The Pennsylvania State University at Erie, The Behrend College

STRUCTURAL CHARACTERISTICS OF THE BYSSUS OF THE ZEBRA MUSSEL, *DREISSENA POLYMORPHA* (PALLAS), WITH COMPARISONS TO THE BYSSUS OF THE BLUE MUSSEL, *MYTILUS EDULIS* (LINNAEUS)

To better understand the morphology of the byssus of the zebra mussel (*Dreissena polymorpha*), the surface and internal structures of the stem, threads, and plaques were examined with a scanning electron microscope. The information provided adds to the current understanding of the morphology of the byssus of *D. polymorpha* and shows that the byssuses of *D. polymorpha* and *Mytilus edulis* are markedly dissimilar.

Micrographs indicated that the byssus of *D. polymorpha* was a continuous structural unit that was attached to the inside of the mussel's shell by retractor muscles. In some specimens, cuffs were present on the stems at the bases of the threads. Because these cuffs seemed to be lost by specimens from which the byssus was manually pulled, the process by which the mussels voluntarily detach from a substratum may not involve pulling forces. The thread-branching pattern suggested that the stem remains the same length when new threads are formed. Information concerning the interior of the threads was obtained using the freeze-fracture method. Although the appearances of the cross-sectional fracture faces were variable and provided little detail, longitudinal fracture faces indicated that the thread had two parts: an interior cortex containing longitudinal fibers embedded in a matrix and an exterior sheath, which was a separate layer that is likely to form as a result of an enzyme-catalyzed tanning process. In addition, it was observed that the outer surfaces of the threads were smooth proximally and became increasingly ridged distally. This thread topography may result because the thread material is molded to the walls of the ventral groove of the mussel's foot. Plaques, which are likely to be filled with an adhesive, were attached to substrata in rows, which could increase the stability of the mussel's anchorage.

It has been reported that the byssus of *D. polymorpha* is similar to the byssal apparatus found in *M. edulis* and other marine bivalves. Although there are many similarities between *D. polymorpha* and *M. edulis*, differences in their byssuses were distinguished using the scanning electron microscope. For instance, in these two biofouling species, differences exist in the anchorage of the stem, the pattern in which the threads branch from the stem, the thread surface topography, and the morphology of the region of the thread that extends into the plaque. These differences in byssus morphology are likely to be related to how the byssus is formed.

Because byssal attachment is fundamental to the success of mussels that colonize hard substrata, morphological differences between the byssuses of various biofouling mussels should be recognized as researchers develop and adapt control mechanisms.

Nichols, Susan Jerrine, and B. Kollar
U.S. Fish and Wildlife Service, National Fisheries Research Center—Great Lakes

REPRODUCTIVE CYCLE OF ZEBRA MUSSELS (*DREISSENA POLYMORPHA*) IN WESTERN LAKE ERIE AT MONROE, MICHIGAN

The reproductive cycle of zebra mussels was investigated to determine length of veliger production, length of ripe gamete production, percentage of females present, and size of sexual maturity. This study was conducted weekly since May 1990 at the Detroit Edison plant in Monroe, Michigan. Basically, veligers are present in the water column for 6 months. In 1990, veligers first appeared May 30 at densities of 75/L, peaked July 26 at 187/L, and were last found October 3 at 4/L. In 1991, veligers appeared on May 12 at 30/L, and by June 18 were at 179/L. Although veligers were present in the water column for only 6 months of the year, zebra mussels carried ripe gametes every month of the year. In May, June, and July 1990, over 85% of the mussels were carrying ripe gametes. This percentage dropped to 8% by January 1991, increased to 19% by February and was at 92% by May 1. Zebra mussels showed seasonal variation in sex ratios and size at sexual maturity. In samples collected from May 1990 to May 1991, the proportion of females increased from 52% to 74%. The mussels also showed a decrease in size at sexual maturity, from 13 mm shell length in May 1990 to 5 mm by May 1991. These seasonal changes indicate that the reproductive cycle of zebra mussels is readily affected by local environmental conditions, and therefore may vary considerably from site-to-site.

Conn, David Bruce, Soo-Jin Lee, and Kimberly A. Shoen
Department of Biology, St. Lawrence University

ULTRASTRUCTURAL CHARACTERISTICS OF THE DEVELOPING AND OVULATED OOCYTES OF THE ZEBRA MUSSEL, *DREISSENA POLYMORPHA*

The explosive population growth and widespread dissemination of the zebra mussel, *Dreissena polymorpha*, in the Laurentian Great Lakes system is partly a result of its very high reproductive potential. Despite the obvious importance of this reproductive potential, virtually nothing is known about the cellular and subcellular aspects of reproduction in *D. polymorpha*. The present study was undertaken to elucidate the basic ultrastructural features of the oocytes in this species.

Adult female *D. polymorpha* were collected in July, 1991 from a well-established population in the St. Lawrence River near Massena, New York. Within 5 minutes of collection, each mussel was dissected and its visceral mass removed and processed for light and transmission electron microscopy.

Oocytes concurrently occupying each gravid ovarian acinus were divisible into two basic groups: developing (pre-ovulated) oocytes which were closely attached to the acinar epithelium, and ovulated oocytes that were free in the acinar lumen. All oocytes contained numerous free ribosomes and mitochondria, heterogeneous membrane-limited vesicles, scant granular endoplasmic reticulum (GER), and a few myelin figures. Each possessed a single nucleus with a prominent nucleolus, abundant closely-spaced nuclear pores, and little heterochromatin. The plasma membrane of each oocyte was folded into a dense brush border consisting of numerous cylindrical microvilli of uniform length and diameter supporting a prominent glycocalyx. Homogeneous membrane-limited cortical granules occupied the cortex of each oocyte. Ovulated oocytes differed from developing oocytes in having cytoplasm of lower electron density, cortical granules of higher electron density, fewer free ribosomes, more dilated GER cisternae, and a more spherical nucleus. Between the oocytes, each acinus was completely filled by a somewhat granular, moderately electron-dense material.

The presence of a large nucleus with large nucleolus and abundant nuclear pores suggests a high level of maternal RNA transcription and ribosome production with export to the cytoplasm. Protein synthesis resulting in numerous cytoplasmic granules and vesicles may be associated with autosynthetic vitellogenesis and/or cortical granule production; the latter may be a provision for polyspermy prevention. The close physical association between developing oocytes and ovarian acinar cells may suggest a mechanism for heterosynthetic vitellogenesis as described previously for other mollusc species. The well-developed glycocalyx associated with oocyte microvilli may play an important role in gamete recognition and fertilization.

These data provide vital baseline information for understanding the process of oogenesis in *D. polymorpha*. This information will be crucial to our understanding of many aspects of reproduction in this species, and might prove useful in the development and evaluation of new technologies for control based on interference with reproductive output.

This study was supported by grants from the Pew Charitable Trusts and St. Lawrence University.

Otter, Tim
Department of Zoology, University of Vermont

BIOLOGY OF ZEBRA MUSSEL SPERM

I have sought to establish some baseline information on the reproductive effort of male zebra mussels and the viability and motility of zebra mussel sperm. These data should be of interest in two ways: 1) to comprehend the physiology of normal sperm and the process of external fertilization in zebra mussels, and 2) to identify potential targets for the control of zebra mussel reproduction.

Spawning was induced by immersing each animal in Millipore-filtered lakewater (FLW) containing 0.1–1.0mM 5-hydroxytryptamine (5HT) buffered at pH 8.4 (4–6mM Tris-HCl). Lower doses of 5HT were ineffective, but all doses of 5HT ≥0.1mM induced spawning in ca. 20% of the mussels. In some cases spawning could be seen directly as a cloudy plume being discharged from the excurrent siphon, as soon as 4 min. after exposure to 5HT. In other cases no plume was visible and the water became noticeably cloudy with sperm some 30–60 min. after addition of 5HT. Because females appear relatively unresponsive to 5HT (Ram & Nichols, '90) and the sex ratio is ~1:1 (Garton & Haag, '91), I conclude that the non-spawners were immature mussels, females, or males that had recently spawned in nature. Shell length varied from 13mm–27mm, and sperm count (hemocytometer) ranged from 7.3 million to 350 million, with larger mussels releasing proportionately more sperm, assuming that a constant percentage of body volume is gonad. Roughly half of the mussels in this population are 5–15mm long and capable of producing gametes, whereas less than 10% of mussels are larger than 15mm. Taken together, these data suggest that during an episode of mass spawning, over half of the sperm in the water would have been released by small (5–15mm, probably 1 yr.-old) mussels.

Sperm swimming paths and sperm morphology were recorded on videotape using darkfield or phase-contrast microscopy and then analyzed by computer-assisted methods. The average sperm length is 54.7 ±3.1 μm (50μm flagellum; 4.5μm long bullet-shaped head). In some sperm, phase-dense regions were observed at the base of the tail (swollen mitochondria?) and near the tip of the head (acrosome?). A more detailed analysis of swimming path parameters is in progress, but sperm movement can be grouped into five basic categories: immotile; erratic twitching; intermittent swimming; slow smooth swimming in circular paths; fast smooth circular swimming. In the best preparations, the initial percent motility approached 90%. Sperm became progressively less motile within minutes to hours after spawning, with the time course of loss of motility highly dependent on temperature (range 15°C–27°C). These results imply that at the peak summer temperatures in Lake Erie, fertilization must occur within minutes after spawning while in cooler waters fertilization might be delayed considerably. One major question that needs to be investigated is whether 5HT has any direct (stimulatory) effects on sperm motility, as it does in certain other bivalve molluscs.

Support: Lintilhac Foundation, Univ. of Vermont.
Location: F.T. Stone Laboratory, Put-in-Bay, OH.

Ram, Jeffrey L., Gary W. Crawford, and James U. Walker
Department of Physiology, Wayne State University

ZEBRA MUSSEL SPAWNING: RELEASE OF EGGS AND SPERM IN RESPONSE TO EXTERNAL APPLICATION OF SEROTONIN

One approach to controlling zebra mussels (ZMs) is to find weak points in their life cycle that can be exploited in developing a species specific control method. We have been focussing on reproductive mechanisms. Previously, this laboratory (Ram and Nichols, 1st Int. Zeb. Muss. Res. Conf., 1990) reported that injection of serotonin (5-HT) induced ripe males (but not females) to spawn. We now report that 5-HT can stimulate spawning in both males and females and can be applied either externally or by injection. ZMs, maintained in a closed system, responded to injection of 10^{-3} M 5-HT initially (May, 1991) with only male spawning, as previously reported. However, after maintenance in our system for 2 weeks, identical experiments elicited spawning from both males and females. Furthermore, 5-HT could be applied either by injection or external application (no significant difference between injecting 0.1 ml 10^{-3} M 5-HT or immersing animals in 10 ml of 10^{-3} M 5-HT). Spawning responses with 10^{-3} M 5-HT could be elicited from ZMs maintained in this system for more than two months (and continuing), with on average 43 ±2% producing sperm and 28 ±4% spawning eggs (n = 8 expts., total 440 animals; females are significantly different from males, $p<0.025$). Of 120 controls, given identical election and handling, but no 5-HT, none spawned. The shortest latency observed for spawning in response to external 5-HT application was 15 min for males and 1.5 hr for females at ambient temperature (about 22°C). In response to a range of [5-HT], the lowest concentration to produce spawning by external application was 10^{-4} M, which elicited spawning at approximately half the frequency as 10^{-3} M ($p<0.05$). Upon retesting previously spawned animals, 70% of both males and females responded again when tested one day later. 5-HT can, thus, be used as a non-invasive means for identifying ripe males and females. Furthermore, ZMs appear to give environmental chemicals access to their reproductive system, a property that may be exploited for purposes of control. (We gratefully acknowledge the assistance of S. J. Nichols in obtaining animal and doing initial experiments, and J. J. Mojares in analyzing spawn.)

Stoeckmann, Ann M., and David W. Garton
Department of Zoology, The Ohio State University

METABOLIC RESPONSES TO INCREASED FOOD SUPPLY AND INDUCED SPAWNING.

Metabolic responses of *Dreissena polymorpha* to increased food supply and induced spawning were measured during July and August, 1991. Zebra mussels were maintained under ambient conditions of food and temperature in running lakewater aquaria at F. T. Stone Laboratory located on South Bass Island in western Lake Erie. Mussel diet was supplemented from 20 May to 28 August by adding 5 X 10^9 cells of a preserved algal mixture twice a day to a 40 l aquarium. The supplemented diet consisted of a concentrated mixture of cultured marine algae (*Tetraselmis* and *Thalassiosira*, Coast Oyster Co., Diet A). Ingestion of the artificial diet was confirmed by histological analysis and increased fecal production. Recently collected mussels were induced to spawn by adding serotonin (10^3 M 5-hydroxytryptophan) to filtered lakewater in the respirometer flasks. Spawning was detected by visual inspection. All mussels were preserved for histological analysis to determine stage of gametic maturation ("readiness" for spawning). Oxygen consumption of mussels under increased food and induced spawning conditions, measured using a Gilson Differential Respirometer and expressed as ul h^{-1} std $mussel^{-1}$ at STP, were compared to oxygen consumption of mussels maintained under ambient conditions. All metabolic rates were standardized to a dry weight of 15.5 mg.

Preliminary results show metabolic rate increased significantly following increased food and induced spawning. Average oxygen consumption of food supplemented mussels was 1.3 times that of ambient mussels (42.68 vs. 33.51 ul O_2 h^{-1}, respectively). Similarly, average adjusted dry weight of food supplemented mussels was nearly twice the average dry weight of mussels under ambient conditions (24 vs 14 mg, respectively). Average oxygen consumption of mussels exposed to serotonin, but not spawning, was significantly greater than for ambient mussels (43.20 vs 33.51 ul O_2 h^{-1}, respectively). After correcting for the effects of serotonin, mussels induced to spawn increased average oxygen consumption 1.7 times that of ambient mussels (56.45 vs 33.51 ul O_2 h^{-1} respectively).

Significant increases in metabolic rate and length-standardized dry weight of mussels in the food supplemented experiment are evidence that *Dreissena* is food-limited in western Lake Erie. This observation supports the conclusion that growth and reproductive output of *Dreissena* will be proportional to the availability of phytoplankton. Elevated metabolic rate indicates spawning is a physiologically stressful event. Reduced resistance to additional stressors during active spawning may have application for mitigation and control strategies for *Dreissena*.

Ackerman, Joseph Daniel[1], and Renata Claudi[2]
[1]Department of Mechanical Engineering, University of Toronto, [2]Ontario Hydro

THE EARLY LIFE HISTORY OF ZEBRA MUSSELS: OVERWINTERING JUVENILES AND POST-SETTLEMENT MOVEMENTS

Currently, there is no generally accepted nomenclature for the larval and post-larval stages of *Dreissena polymorpha*. This has led to confusion in the enumeration and reporting of zebra mussel occurrence and abundance. Morphological and behavioral observations of *Dreissena* larval and post-larval stages are, however, similar to marine bivalves. Based on these conserved traits, we have chosen to extend standard life history descriptions (e.g., Carriker, 1961) to *Dreissena*.

The pediveliger and plantigrade are considered the most relevant planktonic post-larval stages from the perspective of mussel settlement. It is in the pediveliger stage that mussels are found swimming in plankton and crawling on hard substrates. Movement can occur between these two modes of existence until byssal attachments (primary settlement) are achieved in the plantigrade stage. Plantigrade post-larvae are not entirely sedentary and active movements occur on hard surfaces and in the water column following initial attachment (secondary settlement).

Post-larval zebra mussels can overwinter on hard surfaces and were collected during February and April of 1991 in Lake Erie. Moreover, pediveligers and plantigrades were detected in the plankton and on freshly developed substrates in the spring of 1991. There is reason to believe that these observations represented the movement of post-larvae from overwintering populations rather than the spawn of the 1991. This complexity in life history has implications for the understanding and control of zebra mussels.

Greenberg, Alan[1], Gerald Matisoff[2], Gerald Gubanich[1], and Julius Ciaccia[1]
[1]City of Cleveland Division of Water
[2]Department of Geological Sciences, Case Western Reserve University

ZEBRA MUSSEL VELIGER DENSITIES AND WATER QUALITY PARAMETERS IN LAKE ERIE AT THE CLEVELAND WATER INTAKES

Zebra mussel (*Dreissena polymorpha*) veliger densities were measured in the open waters of Lake Erie near the Kirtland water intake in Cleveland in order to identify times and depths of veliger settling to optimize chemical and mechanical control procedures. A small number of veligers first appeared in the water in late May when the surface water temperature was about 22°C. A small density maximum (27/L) was recorded on May 29, 1991. There was a second, larger density maximum (316/L) which occurred on July 30, 1991. There has been more than an order of magnitude increase in peak veliger densities in the Cleveland area since 1988. Maximum veliger densities increased each year from just a few per liter in 1988 to well over 300/L in 1991. Maximum veliger densities in the Cleveland area are lower than those reported from the western basin of Lake Erie in previous years. The highest veliger density is usually found in the epilimnion just above the thermocline. Somewhat lower densities are found at the surface and almost no veligers are found in the hypolimnion. The water intakes receive water from a depth of about 35 feet, within the zone of high veliger densities. However, almost no veligers survive transport to the Kirtland water plant at the other end of the intake pipe. Mechanical pumping was employed on August 13–14, 1991 to dislodge zebra mussels from the intake pipes. This resulted in 35 yd^3 of zebra mussel debris collected at the Kirkland shore shaft and well screen. Monthly average summer turbidity data and Secchi disc measurements from 1985 to present support the premise that zebra mussels are "cleaning up the lake" and lowering turbidity in the central basin near Cleveland. In fact, the Cleveland Division of Water is now investigating coagulating agents other than alum because of alum's inefficiency in low turbidity water.

SESSION TWO:

ZEBRA MUSSEL BIOLOGY, PHYSIOLOGY, BEHAVIOR AND POPULATION DYNAMICS

(CONTINUED)

Martel, Andre
Canadian Museum of Nature

OCCURRENCE OF POST-METAMORPHIC DRIFTING IN ZEBRA MUSSELS: IMPLICATIONS ON DISPERSAL AND RECRUITMENT

Field experiments conducted along the north shore of the central basin of Lake Erie using off-bottom collectors have revealed that post-metamorphic drifting may play a significant role in the life history of the zebra mussel, *Dreissena polymorpha*. These collectors, made of rectangular pieces of fibrous material (11.7 X 12.0 cm, 0.8 cm thick), were deployed for short time periods, 24–48 hours, thus preventing colonizing zebra mussels from growing significantly while on the collectors. For each zebra mussel recruiting to the collectors, the examination of the larval (prodissoconch II) and juvenile shell (dissoconch), including the distinct demarcation between these two regions of the shell, made it possible to determine the stage at which each individual colonized the collectors: (1) as a free-swimming planktonic veliger (colonizers of 240–270 um shell length or less), or (2) as a drifting juvenile, namely individuals that had already metamorphosed (310–330 um shell length and above). The occurrence of early juvenile stages drifting in the water column was also confirmed by their common presence in horizontal near-shore plankton samples taken near the collectors (10–100 m from the shore; water depth: 2–7 m). Moreover, much higher numbers of juveniles were drifting and recruiting to collectors during periods of high wave action (commonly over 30 juveniles/collector/24 hours).

Mechanisms involved in the drifting of newly-metamorphosed zebra mussels that would enable early juveniles (mostly 300–900 um shell length) to drift in the water column may include the secretion of drifting mucous threads or the adhesion of individuals to detritus particles. Such mechanisms would make small juvenile zebra mussels virtually neutrally buoyant during transport by water currents and are currently being investigated. The occurrence and the high numbers of drifting juveniles recruiting to off-bottom collectors suggest that post-metamorphic drifting has significant implications on the dispersal and recruitment processes of zebra mussels.

Bailey, John F., and R. Douglas Hunter
Department of Biological Sciences, Oakland University

FACTOR INFLUENCING *DREISSENA* RECRUITMENT AND BIOMASS ACCUMULATION ON AN ARTIFICIAL SUBSTRATUM

Studies on *Dreissena* recruitment were done in 1990 at two locations in Lake St. Clair and one in northwestern Lake Erie. Artificial substrata consisting of 11 x 11 cm ceramic tiles were installed on racks at each site and subsequently examined according to one of two treatment protocols. One treatment "settlement rate tiles" (SETT), involved replacement of existing tiles every two weeks. The intent was to measure recruitment of larvae onto tile surfaces without the presence of settled adults. A second treatment, "cumulative tiles" (CUM), involved biweekly removal, measurement, and return of the same tiles to their site, providing an accumulating population of juveniles and adults over the entire summer. Each treatment had three replicates.

No settlement occurred on any of the tiles at the CR site (Clinton River, Lake St. Clair, Michigan) although a few individuals were observed on nearby surfaces. Settlement at the PM site (Pt. Mouillee, Lake Erie, Michigan) was very light with peak densities on CUM tiles reaching a maximum of only 337/m^2 and settlement averaging about 5/m^2 day. In contrast, settlement at the TR site (Thames River, Lake St. Clair, Ontario) was heavy, with a maximum density of 354,035/m^2 and settlement rates averaging 5,058/m^2 day. The SETT results at TR indicated one major recruitment on about July 10–24, and a lesser one on about September 4–17. Light recruitment occurred at other times beginning June 26. The last recorded recruitment was on November 13, after which the experiment was terminated.

The CUM tiles at TR showed a similar recruitment pattern to the SETT tiles but had densities that were about four times greater. This difference is likely due to the SETT tiles not having been aged (i.e., they were initially devoid of periphyton) hence they were less preferred substrata. A further difference was the growing presence of larger-sized mussels on the CUM tiles, which not only increases the surface area but provides optimal settling surfaces.

Evidence that tile removal, handling, and replacement is detrimental to growth was obtained from a subset of CUM tiles (CUM6) at TR which were left *in situ* for ten weeks before sampling (i.e., undisturbed from June 12 to August 21). These CUM6 tiles had *Dreissena* densities that were between one and two orders of magnitude higher than those on the biweekly sampled CUM tiles. For example, on September 4, the CUM tiles averaged 1,822/m^2 whereas the CUM6 tiles averaged 242,265/m^2. Lack of disturbance had positive consequences for recruitment as well.

Data from 1991 tiles indicate a major recruitment occurred around June 10–24, resulting in densities averaging 239,000/m^2, and consisting mostly of spat less than 1 mm. Based on density distribution of these newly-settled spat, a variety of natural surfaces (stone, bivalve shells, zebra mussel shells, etc.) are preferred surfaces compared to tile. It appears not to matter whether *Dreissena* shells on which the spat settle are live or empty.

Bitterman, Angela M.[1], Robert C. Haas[2], and R. Douglas Hunter[1]
[1]Department of Biological Sciences, Oakland University
[2]Michigan Department of Natural Resources

COMPARATIVE GROWTH AND MORTALITY RATES OF *DREISSENA POLYMORPHA* FROM TWO SITES IN LAKE ST. CLAIR

We measured growth and mortality rates of zebra mussels, *Dreissena polymorpha*, at two sites in Lake St. Clair during June, 1990 to May, 1991, to look for factors which might influence their success in colonizing the Great Lakes. Mussels were held in individual compartments in Plexiglass cages which were suspended one meter above the bottom. Growth measurements were taken on half of the cages at biweekly intervals, whereas the other half were measured only at the beginning and end of the 11 month period. Length, width, height, and weight were determined for each mussel for each sampling period. Nutrient conditions were assessed at cage sites by measurement of temperature, secchi depth, suspended organic carbon, and density of planktonic algae.

There were not measurable growth rate differences initially at the two sites (t-test; $P > 0.05$). However, the relatively small compartment size (13 mm radius, 10 mm thick) restricted growth after 10 weeks (mean length 12.8 mm). Lengths of individuals of widely different size at the start converged by the 12th week. Growth in width, height, and weight were not as constrained by compartment size indicating that these zebra mussels had compensated for limited growth in length. After being transferred to larger-holed cages, the mussels at the Clinton site responded faster to the change than the mussels at the Thames site (t-test; $P<0.05$).

Zebra mussels were well established in the vicinity of the Thames River site; however, they were essentially absent in the vicinity of the Clinton River site. Thames River cages were continually being invaded by post-veliger migration and veliger settlement with as many as 10 additional mussels present in one compartment. Almost all compartments had at least one additional mussel. The cage size did inhibit the length of the zebra mussel. The mussel transferred to the larger-holed cages grew significantly greater at both sites than the mussels kept in the small-holed cages (t-test; $P< 0.001$).

Mortality of caged zebra mussels was not related to site location or growth conditions but was increased by greater sampling frequency (Binomial Test; $P < 0.014$). Mortality of mussels sampled only twice was 21% at the Clinton site and 13% at the Thames site. Mortality for the frequently sampled mussels was 45% at the Clinton site and 31% at the Thames site.

Physical, chemical, and nutrient sampling indicated that growth conditions differed between the two sites. Phytoplankton samples at the Thames site had an average of 99 cells/ml for greens and 586 cells/ml for diatoms. The Clinton site had 97 cells/ml for greens and 337 cells/ml for diatoms. The greens were not significantly different between the two sites but the diatoms were. Temperature increased and decreased at the same time for both sites. Secchi depths were greater at the Clinton.

Marsden, J. Ellen[1], and Bernie May[2]
[1]Illinois Natural History Survey
[2]Cornell Laboratory for Ecological and Evolutionary Genetics, Department of Natural Resources, Cornell University

GENETIC POLYMORPHISM AMONG DISJUNCT POPULATIONS OF ZEBRA MUSSELS IN THE GREAT LAKES

Information about the population structure of zebra mussels is critical for the development of effective, long-term management and control. High juvenile mortality in combination with the broad dispersal of larvae could result in a small group of zebra mussels producing the majority of the subsequent year class in a given area. The potential therefore exists for genetic drift to separate zebra mussels into genetically distinct sub-populations with divergent life history characteristics, and possibly different responses to control methods. Even a cursory examination of zebra mussel morphology reveals wide variation in body shape and color pattern. Zebra mussels also have very high levels of genetic variability as detected by starch-gel protein electrophoresis. We examined the genetic structure of multiple populations of zebra mussels from geographically disjunct locations throughout the Great Lakes and inland waterways using protein electrophoresis. Fifty enzyme systems were examined; 21 polymorphic loci were detected which had bands that could be reliably interpreted. We have also initiated measurement of a set of morphological characters in each population. These data permit determination of (1) whether zebra mussels within the Great Lakes represent a single, genetically uniform population or multiple discrete sub-populations, and (2) whether disjunct populations of zebra mussels within the Great Lakes represent separate introductions from Europe. The results will be discussed in relation to the need for basic biological information on non-indigenous pest species before large-scale control strategies are implemented. We will also present data which suggest that there is a second species of *Dreissena* in the Great Lakes system.

Rose, Jennifer L., and Larry Eckroat
The Pennsylvania State University at Erie, The Behrend College

GENETIC COMPARISON AND CHARACTERIZATION OF FIVE ZEBRA MUSSEL POPULATIONS IN THE GREAT LAKES

Dreissena polymorpha (Pallas), first observed in the Great Lakes in Lake St. Clair, is spreading rapidly throughout the Great Lakes Basin. The original of the various Great Lakes populations is still open to speculation, as they may be colonists from Lake St. Clair or stem from separate ship ballast water discharges. Analysis of the allozyme polymorphisms present in several Great Lake populations provides information regarding the genetic relationship of these populations.

Approximately one hundred zebra mussels were sampled from each of five populations in Lakes Erie, St. Clair, and Ontario and their shell length recorded. Individual mussels were then genetically characterized by examining allozyme variation of whole body extracts using starch gel electrophoresis. Eight enzymes (G-6-PDH, EST, IDH, LAP, LDH, MDH, ME and PGI) revealed thirteen interpretable loci.

The five populations sampled had variation similar to that found in other organisms with respect to polymorphic loci (100%), average heterogeneity/locus (30.7–34.4%), and alleles/locus (3.9–4.2). All populations demonstrated heterozygote deficiency; three of the populations exhibited this deficiency at all 13 loci whereas the other two populations exhibited heterozygote deficiency at 11 and 12 loci, respectively, as is characteristic of previously analyzed mussel populations. This heterozygote deficiency is reflected by non-conformity to Hardy Weinberg expectations; however, one locus (EST-6) was in Hardy-Weinberg equilibrium in all five populations. While there are numerous potential explanations for the widespread occurrence of heterozygote deficiency in molluscs, the most plausible suggestion may be selection due to reduced fitness. As shell size is proportional to the age of the mussel, a correlation of shell size with heterozygosity provided information regarding the relationship of mussel fitness and genetic heterozygosity.

The use of F statistics to allocate genetic variability to the population, subpopulation, or individual demonstrated genetic differentiation between subpopulations for some of the 13 loci analyzed. Tests for interpopulational heterogeneity indicated a significant difference at one locus (PGI); the differences at the other loci were not significant.

The genetic identity and genetic distance values between four of the five populations suggested uniformity and therefore supports the idea that colonization occurred from one original population. This uniformity is presumably due to the pelagic dispersal of zebra mussel larva. However, one population (Lampe Marina, Lake Erie) was significantly different from each of the other four, and may be a result of restricted larva dispersal in the sheltered marina environment.

Mackie, Gerry L., and Bruce W. Kilgour
Mackie & Associates Water Systems Analysts

EFFECTS OF SALINITY ON GROWTH AND SURVIVAL OF ZEBRA MUSSELS (*DREISSENA POLYMORPHA*)

Previous studies that describe the tolerance of zebra mussels to saline waters indicate ranges in the LC_{50} between 1.84 and 12.3 ppt. The variability may be due to differences in salts used. There have been no studies conducted to describe the influence of salinity on growth of zebra mussels. The objectives of this study were: (1) to describe the salinity tolerance of zebra mussels to different salts (Instant Ocean, road salt, potassium chloride); (2) to describe the growth of zebra mussels in different salinities (with Instant Ocean); and, (3) to explore the possible interactions between temperature and salinity on survival and growth. The growth experiments were conducted at three different temperatures (3–4, 10–12, and 19–22°C). The 96h bioassays were conducted at 4 and 19°C. Experiments to determine the salinity tolerance to different salts are in progress.

The 96h LC_{50} for Instant Ocean at 19°C was 7.6 ppt. During the six week growth test at 4 and 10°C, mortality in the treatments with 8.0 ppt did not exceed 15%. Differences in mortality between the 96h test and the six week growth experiment may be due to differences in the acclimation time of the mussels. In the 96h test, mussels were not acclimated to the different salinities whereas in the six week growth test, mussels were acclimated to test concentrations (0 to 8.0 ppt) by increasing salinities by 1.0 ppt per day. Zebra mussels appear to be able to adapt to slowly changing saline concentrations.

During the six week growth tests, there were no significant effects of salinity on maximum shell length or ash free dry weight (AFDW) of mussels at 4°C. There was a statistically significant, but not substantial, effect of salinity on survival at that temperature. Mortality ranged between 0.8% at 0 ppt to 4.1% at 8.0 ppt. At 10°C there was no significant effect of salinity on maximum shell length, but there was a significant effect on AFDW. A linear contrast showed that the change in AFDW was linearly related to salt concentrations. The effect of salinity on mortality at 10°C was not as large as at 4°C. At 10°C, mortality ranged between 0.6% at 0 ppt to 1.4% at 8.0 ppt. Results are not available for tests conducted at 19°C due to high mortalities observed in control treatments.

Results to date indicate that above 6.0 ppt there are significant effects of salinity on zebra mussel growth and survival. Survival was reduced at 8.0 ppt at all temperatures, whereas growth (i.e., changes in AFDW) was also impaired at 8.0 ppt at 10°C.

Ramcharan, Charles, Dianna K. Padilla, and Stanley T. Dodson
Department of Biology, Mount Allison University

MATHEMATICAL MODELS TO PREDICT THE DISTRIBUTION AND ABUNDANCE OF *DREISSENA POLYMORPHA* IN NORTH AMERICAN LAKES

Useful estimates of the ecological and economic impacts of *Dreissena polymorpha* rely on accurate predictions of its potential distribution (where it will or will not be present) and abundance (mussel density). We constructed mathematical models that predict the distribution and abundance of *Dreissena* based on correlations between mussel abundance and limnological characteristics of the lakes they inhabit. Data on *Dreissena* populations and limnological variables were collected from published studies of European lakes. Over the last 200 years, *Dreissena* has colonized many types of European lakes that are found in a wide range of latitudes, providing the best dataset in which to search for environmental constraints on mussel growth. Our analyses show that physical and morphological characteristics of lakes do not affect their suitability for *Dreissena*. On the other hand, *Dreissena* is often absent from lakes that have low levels of calcium and low pH. A model developed by Discriminant Function Analysis is 90% successful at predicting presence or absence of *Dreissena* based only on calcium and pH levels in a lake. *Dreissena* reaches higher population densities in lakes that have low levels of the algal nutrients PO_4 and NO_3. Our study indicates that hard-water, mesotrophic lakes with rocky substrates are ideal habitats for *Dreissena*.

SESSION THREE:

ECOSYSTEM EFFECTS, FISHERY IMPACTS, NUTRIENT/CONTAMINANT CYCLES, PREDATOR/PREY INTERACTIONS

KEYNOTE PRESENTATION: Dr. Norbert Walz

Zoologisches Institut der Universität München

NEW INVASIONS, INCREASE, AND ECOLOGICAL EQUILIBRIUM OF *DREISSENA POLYMORPHA* POPULATIONS IN CENTRAL AND SOUTHERN EUROPE LAKES AND RIVERS

Dreissena invaded Central Europe in two steps, first in the beginning of the 19th century, second after 1960. The River Rhine, for instance, was invaded in the first period. Stocks declined with saprobic pollution between 1950–70 and recovered by river sanitation measures after 1980. In the Northern Alps (e.g. Austria, Germany, Switzerland, France) many prealpine and alpine lakes were invaded in the middle of the 1960s. In the 1970s prealpine lakes in Southern Europe followed. Spreading to other than prealpine lakes in Yugoslavia, Italy and Spain was very rare. Stocks in the prealpine Lake Constance increased up to >10000 macroscopic visible individuals m^{-2} after about 5 years of colonization. *Dreissena* populations decreased further after 2 years because of predation by overwintering diving ducks (*Aythya ferina* and *A. fuligula*) and coots (*Fulica atra*). Mean consumption by waterfowl every winter is 97%. Young mussels (0+) are protected by their small size until the next autumn, when they gain high biomasses again. Regular counts of larvae show fluctuations without a special trend on a low level, elucidating a predator controlled equilibrium. The same scenario takes place also in other lakes.

Dermott, Ronald[1], and David Barton[2]
[1]Great Lakes Laboratory for Fisheries and Aquatic Sciences, Fisheries and Oceans Canada
[2]Department of Biology, University of Waterloo

BENTHIC COMMUNITY ASSOCIATED WITH ZEBRA MUSSEL COLONIES

The establishment of mussel colonies along the shores of the Great Lakes is expected to increase the amount of algal production consumed by the benthic fauna. To examine any changes in the nearshore benthic community due to *Dreissena*, sampling was conducted in 1990 and 1991 on the rocky northeast shore of Lake Erie, and in sandy substrates in Lake Ontario off the Niagara River. Due to the additional interstices, mussel colonization of rocky shoals increases the habitat available to epibenthic invertebrates which normally inhabit the attached algae and crevasses among the rubble. Other than the detrimental competition for space and food that occurs between *Dreissena* and native clams on sandy substrates, no direct exclusion was observed between the invertebrates on rocky shoals. Like the Unionidae in soft sediments, exposed *Sphaerium* can be colonized by small mussels.

Although poorly studied, the composition of the major taxa along the north shore of Lake Erie has not changed in areas colonized by mussels. Depending on the season, the caddis *Hydropsyche, Helicopsyche;* the midges *Crictopus, Rheotanytarsus;* and naidid worms remain common after two years of colonization. However, total abundance of invertebrates has increased within the mussel colonies as well as an overall increase since the late 1970's. Species that are benefiting most from the association with *Dreissena* are the amphipod *Gammarus* (to 41,000 m^{-2}), with increases also occurring for the leeches, *Erpobdella, Dina* and *Helobdella* (460 m^{-2}). Abundance of invertebrates is greatest among the mussel beds, where biomass excluding the *Dreissena* attained 21 g m^{-2} (dry shell-free).

Bunt, Christopher, Hugh J. MacIsaac, and W. Gary Sprules
Department of Zoology, University of Toronto

PUMPING RATE CAPACITIES OF JUVENILE GREAT LAKES *DREISSENA POLYMORPHA* (PALLAS)

Zebra mussel (*Dreissena polymorpha*) filtering activities may have a profound impact on water clarity, phytoplankton density and food availability to young, commercially important fish (e.g. perch and walleye). In order to predict these impacts, it is important to know the amount of water that the mussel population is capable of processing, thus diverting the flow of energy from pelagic to benthic food webs. While clearance rates are known for individuals >10 mm, these mussels only compose between 5 and 21% of settled populations in western Lake Erie. Pumping rates of individuals between 2 and 11 mm were determined by injecting an inert dye into the inhalant flow of filtering mussels and measuring the velocity of the exhalant flow with high resolution video. Exhalant siphon dimensions were measured in conjunction with flow velocities to determine pumping rates. Preliminary data indicate that individuals between 2 and 11 mm are able to pump between 0.06 and 19 ml/h. At these rates, the juvenile zebra mussel populations in western Lake Erie (mean depth = 7 m) are capable of processing between 5.2 $m^3/m^2/d$ and 10.5 $m^3/m^2/d$ (i.e. the entire water column may be processed 1.5–3.6 times each day by these individuals). Comparisons with independently measured clearance rates using microspheres were used to estimate gill retention efficiency of entrained particles.

SESSION FOUR:

ECOSYSTEM EFFECTS, FISHERY IMPACTS, NUTRIENT/CONTAMINANT CYCLES, PREDATOR/PREY INTERACTIONS

(CONTINUED)

Malloy Desormeaux, Eileen, and Joseph C. Makarewicz
Department of Biological Sciences, State University of New York College at Brockport

THE RELATIVE IMPORTANCE OF *DREISSENA* FILTRATION AND *DAPHNIA* GRAZING ON PHYTOPLANKTON ABUNDANCE AND WATER CLARITY

Microcosm experiments evaluated the relative impact of *Dreissena* filtration and *Daphnia* grazing on phytoplankton abundance and water quality. Experimental vessels contained levels similar to abundance in Lake Erie:

Phytoplankton only (80,000 organisms/ml)
Phytoplankton and *Daphnia* (30,000/m^3)
Phytoplankton and *Dreissena* (30,000/m^3)
Phytoplankton, *Daphnia* and *Dreissena*

Data from four experiments in which temperature was maintained at a uniform 20°C indicated a 30–50 percent reduction in phytoplankton abundance over a 72 hour period for both *Daphnia* and *Dreissena*. Turbidity levels decreased in vessels containing *Dreissena* and increased in vessels with *Daphnia*. SRP values increased significantly in *Daphnia* vessels but not in *Dreissena* vesaels.

Although both *Daphnia* and *Dreissena* reduced phytoplankton abundance, *Daphnia* released phosphorus thus providing a continuous nutrient source for phytoplankton. SRP levels decreased in vessels containing *Dreissena* consequently reducing the availability of a necessary nutrient for phytoplankton growth and reproduction.

MacIsaac, Hugh J., and W. Gary Sprules
Department of Zoology, University of Toronto, Erindale College

FILTERING IMPACTS OF LARVAL AND ADULT ZEBRA MUSSELS IN WESTERN LAKE ERIE

Filtering rates of larval and adult zebra mussels (*Dreissena polymorpha*) must be known in order to predict the impact of this exotic species on Lake Erie phytoplankton stocks. We determined filtration rates of *Dreissena* veliger larvae using solutions of fluorescent 2.87 µm polystyrene beads, and compared them to rates derived from the literature (Kryger and Riisgård 1988) for settled mussels. Mean filtration rates of veligers ranged between 10.2 and 17.4 µL individual^{-1} hour^{-1} between bead concentrations of 10^3 and 10^5 beads mL^{-1}; at very high bead densities (> 2 x 10^5 beads mL^{-1}) filtration rates were very low (< 2 µL individual^{-1} hour^{-1}). Large veligers have higher filtration rates than small individuals, and some are capable of ingesting particles as large as 11 µm. Filtration rates of settled mussels (2–29 mm) are between 10 and 13446 times greater than those of veligers on an individual basis, and 440 times greater on a population basis for the Hen Island reef population in western Lake Erie. Settled zebra mussel filtering impacts also greatly exceed those of other zooplankton species in western Lake Erie. Based on 1990 Hen Island reef population densities, settled mussels filter up to 132 m^3 m^{-2} day^{-1} (i.e. they potentially filter the water column >19 times per day).

Fitzsimons, John D.[1], Joseph Leach[2], S. Nepzy[2], and V.W. Cairns[1]
[1]Fisheries and Oceans, Canada
[2]Ontario Ministry of Natural Resources

ZEBRA MUSSELS AND THEIR EFFECTS ON FISH SPAWNING IN LAKE ERIE

The rapid colonization by zebra mussels of shallow rocks substrates in Lake Erie has dramatically altered their physical appearance. This colonization, along with associated chemical and biological changes, may reduce the potential for successful reproduction on these substrates. We are examining the effects of mussels on spawning by three lithophils—walleye, white bass and lake trout.

Both walleye and white bass continue to spawn on historic spawning shoals despite high numbers of mussels averaging 150,000/m^2. Spawning by walleye appears to be random, with no apparent selection for areas rendered devoid of mussels by ice scour. Viability of walleye eggs and the dissolved oxygen levels under which they incubate were unaffected by the presence of mussels.

Work underway at potential lake trout spawning areas indicates that mussels are primarily associated with the top layer of multilayered cobble substrates where they don't appear to affect interstitial dissolved oxygen. Observations on lake trout spawning this fall will be discussed.

Graham, D.M.[1], W. Gary Sprules[1], and S.J. Nepzy[2]
[1]Department of Zoology, University of Toronto, Erindale College
[2]Ontario Ministry of Natural Resources

EFFECTS OF ZEBRA MUSSELS ON THE DIETS AND GROWTH OF JUVENILE YELLOW (*PERCA FLAVESCENS*) AND WHITE PERCH (*MORONE AMERICANA*) IN LAKE ERIE

Since their appearance in 1987 in western Lake Erie, zebra mussels have depleted algal resources and likely altered the zooplankton community. Since young fish rely on certain species and sizes of zooplankton, we hypothesize that these changes in community structure will have a negative effect on their condition and growth. Our results indicate a reduction in growth rate for young-of-the-year yellow perch. Weight increased by a factor of 1.04 per day for YOY yellow perch in 1988, when zebra mussel densities were low, and only by a factor of 1.013 per day in 1990 when zebra mussel densities were high. No difference in growth rate were evident for YOY white perch. The diet of 1990 yellow perch may explain this apparent reduction in growth. Early in the season they consumed mostly *Daphnia* but a the summer continued *Daphnia* were no longer consumed and diet diversified as the fish consumed a greater number of taxa. White perch have a broader diet and are therefore less likely to be adversely affected by the reduction of a single prey taxon. Diet and growth rates of 1991 yellow and white perch will be compared to that of 1988 and 1990 to determine whether trends in growth reduction continue.

Masteller, Edwin C.[1], and Donald W. Scholesser[2]
[1]The Pennsylvania State University at Erie, The Behrend College
[2]U.S. Fish and Wildlife Service, National Fisheries Research Center—Great Lakes

INFESTATION AND IMPACT OF ZEBRA MUSSELS ON THE NATIVE UNIONID POPULATION AT PRESQUE ISLE STATE PARKE, ERIE, PA

In June, July, and September 1990 and July 1991 a capture-recapture study of unionid mussels was initiated at four sites near a recurved sandspit of eastern Lake Erie known as Presque Isle. This area is a unique geological feature that has substantial numbers of unionids with over 21 species, including eight species of endangered Pennsylvania unionids. Based on the evidence observed in western Lake Erie, it is believed that the unionid populations of Presque Isle are in danger of increased mortality or extinction due to infestations by the exotic zebra mussel, *Dreissena polymorpha*. To date, over 1,000 unionid have been collected by SCUBA divers, marked, and returned to their collection sites. Zebra mussels were counted and measured from a representative sample of unionids. Dead shells of unionids were also collected. The most abundant unionid species were *Lampsilis siliquoidea, Potamilus alatus, Anodonta grandis, Leptodea fragilis* and *Amblema plicata*. The capture-recapture methodology of Lincoln-Peterson indicates that the Presque Isle population of unionids is composed of approximately 6,000 individuals. The infestation of unionids by zebra mussels at Presque Isle is occurring at a rapid rate and parallels that observed in western Lake Erie with a time lag of about two years. In early 1990, one-year-old zebra mussels were present at only one of the sites at Presque Isle. By the end of 1990, young-of-the-year zebra mussels were found on unionids at all four of the study sites. In July 1991, zebra mussels were found on 484 of the 485 unionids collected. In addition, infestation rates increased from 121 zebra mussels per unionid in 1990 to 234 per unionid in 1991. Similar data of infestation of the unionids in western Lake Erie occurred in 1989 just prior to exponential increases in numbers of zebra mussels throughout the basin. Fortunately, observations indicate that as of late July, few young-of-the-year zebra mussels were settling in unionids near Presque Isle. However, dramatic increases in densities of zebra mussels is occurring in the area and it is believed that it is only a matter of time before the zebra mussels will begin to have a negative influence on the unionid populations near Presque Isle.

Kreis, Russell G., Jr., Michael D. Mullin, Ronald Rossmann, and Laurie L. Wallace
U.S.E.P.A., Large Lakes Research Station, ERL—Duluth

ORGANIC CONTAMINANT AND HEAVY METAL CONCENTRATIONS IN ZEBRA MUSSEL TISSUE FROM WESTERN LAKE ERIE

Zebra mussels were collected from rock substrates in a nearshore zone of western Lake Erie at Sterling State Park, Monroe, Michigan. Mussel soft tissues were removed from shells and four samples were analyzed for organic contaminants, heavy metals, and other standard parameters.

Total lipids and moisture averaged 1.5% and 87%, respectively. Total PCB concentrations averaged 520 ug/kg wet weight, where the prevalent homolog groups were tetra-, penta-, and hexachlorobiphenyls. The distributions of PCB homologs and congeners were similar in all tissue samples. PCB congener #52 was the dominant, comprising 5.6% of the total PCB concentration. Several congeners quantified in the analyses have MFO- and AHH-inducer potential. Hexachlorobenzene, the sums of DDT analogs, and chlordane components averaged 0.83, 22, and 14 ug/kg wet weight, respectively.

Elemental analysis indicated that carbon, hydrogen, and nitrogen averaged 42%, 6%, and 6.5% respectively. Heavy metal analyses were conducted using ICP-AES and AA; results indicated good agreement between the two methods. Cadmium, chromium, lead, and mercury concentrations were either below 5.3 mg/kg dry weight or the limit of detection. Copper, nickel, and zinc averaged 15, 19, and 160 mg/kg, respectively.

A comparative examination of organic contaminants and heavy metal concentrations in zebra mussels and the native unionid, *Lampsilis radiata*, was conducted for the Huron-Erie corridor. Based on limited data, total PCB concentrations in zebra mussels varied by an order of magnitude and in some cases, were an order of magnitude greater than concentrations in *Lampsilis*. Of particular interest was the observation that lipids were 3 to 10 times greater in zebra mussel than in *Lampsilis*. Generally, PCB concentrations increased in all bivalve samples in a southward direction through the corridor. Heavy metal concentrations did not exhibit a spatial distribution or a difference between bivalve types. Lead and cadmium concentrations were below 10 mg/kg dry weight in all bivalve samples and exhibited moderate variation.

Results of this study indicate that zebra mussels can accumulate organic contaminants and heavy metals. Limited data suggest that PCB concentrations are considerably greater than concentrations in native unionids, exhibit a spatial distribution in the Huron-Erie corridor, and have potential for contaminant transfer to higher trophic levels. Conversely, the very limited heavy metal and other organic contaminant data do not suggest concentration differences in bivalves or spatial distributions.

Bruner, K.A., Susan W. Fisher, and P.F. Landrum
Department of Zoology, The Ohio State University

BIOACCUMULATION OF HYDROPHOBIC CONTAMINANTS BY THE ZEBRA MUSSEL, *DREISSENA POLYMORPHA*

The prodigious filtering capacity of the zebra mussels, its large population numbers and its preference for littoral areas and outfalls which may have high toxicant loads, makes it likely that the mussels will be exposed to hydrophobic xenobiotics such as PCBs and PAHs. In addition, the mussels have a relatively high lipid content which facilitates partitioning of dissolved contaminants and assimilation of sorbed materials into the zebra mussel. Storage of PCBs and PAHs in zebra mussel tissues may be one significant way in which mussels can alter contaminant cycling in the Great Lakes. In this study, the ability of zebra mussels to accumulate highly lipophilic compounds through several routes of exposure was assessed using toxicokinetic models. In addition, the effect of mussel size and lipid content on accumulation was measured. We found that adult zebra mussels can accumulate significant amounts of PCBs and PAHs from contaminated water and seston. The accumulation of compounds from water was rapid with significant uptake of the chemicals occurring during the uptake clearance phase of the experiments. In contrast, elimination of these materials was comparatively slow although the presence of an organic sorbent in the guts of the animals did facilitate elimination. BAF values determined in this study indicate that zebra mussels can be expected to accumulate significant levels of these contaminants. The implications of these findings for contaminants cycling in the Great Lakes will be discussed.

Brieger, Gottfried[1], and R. Douglas Hunter[2]
[1]Department of Chemistry and [2]Department of Biological Sciences, Oakland University

UPTAKE AND DEPURATION OF HEXACHLORBENZENE, 3,3',4,4'–TETRACHLORO– AND 3,3',4,4',5,5'–HEXACHLOROBIPHENYL BY ZEBRA MUSSELS

Zebra mussels from two western Lake Erie sites, one near Monroe and one near Luna Pier, were analyzed for specific contaminants. Initial levels of PCBs representative of Aroclor 1242 were found at levels of 121ng/g wet tissue and Aroclor 1256 at 33ng/g at the Monroe site and 157ng/g 1242 and 184ng/g 1254 at the Luna Pier site. The water content of the test animals averaged 86%; lipids averaged 1.1%. Analysis of material from other Great Lakes field sites is in progress.

Zebra mussels were exposed in the laboratory to *Chlorella* food separately containing 500 ppm of hexachlorobenzene, 3,3',4,4'–tetrachloro–, and 3,3',4,4',5,5'–hexachlorobiphenyl. Within 10–13 days, the concentration of HCB rose from an initial level of 1.3μg/g wet tissue to 7.5μg/g, then leveled off to approximately 2μg/g. The hexachlorobiphenyl levels rose from undetectable initial levels to 5μg/g, then gradually leveled off to approximately 1μg/g. The tetrachlorobiphenyl concentration rose from undetectable initial levels to approximately 3.5μg/g, then leveled off around 2μg/g. These studies will be repeated at lower feed levels. Levels of selected other chlorinated hydrocarbons were also determined.

McNabb, Cal D., T.G. Coon, and T.R. Batterson
Department of Fisheries and Wildlife, Michigan State University

SUBMERSED MACROPHYTES IN THE LITTORAL OF LAKE HURON'S SAGINAW BAY

Five locations in the shorezone of Saginaw Bay were used in 1991 to establish baseline data on distribution and abundance of submersed macrophytes. Our intention is to document changes that may occur during the next few years if zebra mussels become abundant and clarify water in the bay. Sites were selected to obtain a range for principal determinants of macrophyte distribution; namely, light penetration and sediment type. Measurements of these parameters, turbidity, and macrophyte abundance were obtained on corridors (transects with 50 m width) at each location. Maximum depth boundaries for submersed macrophytes varied among corridors. Boundaries were located at depth contours 0.5, 0.6, 0.9 and 2.8 m at sites near Au Gres, Bay City State Park, Quanicassee and Pinconning respectively. No plants were observed along a corridor on Sand Point. Absence of plants at Sand Point, and shallow maximum depth boundaries at Au Gres and State Park, appear to be associated with sediment type rather than turbidity or light penetration. Boundaries at Quanicassee and Pinconning appeared to be related to turbidity and light penetration rather than sediment type. Abundance of submersed plants shoreward of maximum depth boundaries was calculated from frequency of occurrence of macrophytes ($\%F_M$) in random grab samples taken along corridors. Macrophyte beds were poorly developed at Au Gres and State Park; $\%F_M$ was 32 and 12 at these sites respectively. Plant abundances at Quanicassee and Pinconning were higher, reaching 82 and 52 $\%F_M$ respectively. Species abundance at sites was taken from $\%F_S$; percent frequency of individual species in grab samples. Most commonly occurring species were the charophyte, *Nitella flexilis*, the filamentous algae, *Cladophora glomerata*, and *Najas flexilis, Potamogeton pectinatus, Potamogeton richardsonii*, and *Vallisneria americana*. We expect in year-2 to relate annual production of common macrophyte species (maximum seasonal standing crop), and abundance of microfaunal food resources developed from common plants via detrital food webs, to potential standing crops of larvae (egg–25 mm) of littoral spawning fish (e.g. yellow perch, common carp). We intend to develop quantitative data regarding the hypothesis that shifts in water clarity caused by zebra mussels will increase macrophyte biomass and increase the capacity of the macrophyte-occupied littoral to support early life stages of fish that spawn there.

Charlton, Murray N.
National Water Research Institute, Environment Canada

DEPTH DISTRIBUTION OF COLONIZATION OF ARTIFICIAL SUBSTRATES IN HAMILTON HARBOUR AND LAKE ONTARIO

In stratified lakes, the vertical distribution of *Dreissena* should be related to depth and temperature due to the requirement for moderately warm water for spawning. If mussel colonization is strongly reduced in deep cold water, problems with water intakes may be avoided. To test this hypothesis artificial substrates were placed in Hamilton Harbour and Lake Ontario. Clear results have been obtained from Hamilton Harbour where there is a summer oxygen depletion in the hypolimnion. Results from both locations related to temperature, oxygen, and turbidity profiles will be presented.

CASE STUDIES: ZEBRA MUSSEL CONTROL IN PUBLIC DRINKING WATER FACILITIES

McTigh, Thomas C.[1], Ford J. Ritz[2] and John R Amend[2]
[1]Monroe County Water Authority, [2]Malcom Pirnie, Inc.

RESPONDING TO THE ZEBRA MUSSEL THREAT: A CASE HISTORY

Dreissena polymorpha, the zebra mussel, is a species of freshwater clam native to the Black and Caspian Seas of northeastern Europe. Since its accidental introduction into the Great Lakes in 1986, this non-native mollusk has caused tremendous problems for water users and suppliers throughout the lower Great Lakes and adjacent waterbodies.

In light of the severe problems encountered by water users in Lake Erie during 1989 and 1990, the Monroe County Water Authority (MCWA) viewed the possibility of zebra mussel infestation of its sole water intake as a critical planning issue. MCWA's concerns were heightened by peak summer water demands which routinely required production approaching the nominal capacity of the intake. Knowing that it had little capacity to spare and cognizant of the speed at which these mollusks were migrating, MCWA decided that the zebra mussel threat required a proactive and aggressive response.

San Giacomo, Richard, and Mona Cavalcoli
R & D Engineering

CASE STUDIES FOR THE ENGINEERING OF MUSSEL CONTROL FACILITIES IN RAW WATER INTAKE SYSTEMS

The threat of potential capacity reduction, head loss, deterioration of pipes, and taste and odor problems caused by zebra mussel infestation prompted municipalities and water suppliers in the United States and Canada, including the Niagara County Water District, Erie County Water Authority, Regional Municipality of Hamilton-Wentworth, Township of Kingston, Town of Deseronto, and City of Buffalo, to seek assistance in implementing effective yet cost-efficient methods to eliminate existing zebra mussels and prohibit future infestation. Case studies were done to evaluate, design, and install zebra mussel control facilities for raw water intake systems. R&D Engineering, P.C. provided the necessary engineering services.

The first step undertaken was to conduct underwater investigations of intake structures to determine present mussel growth and assess structural integrity of the raw water facilities. Chemical control alternatives were then evaluated, including chlorine and its various derivatives, potassium permanganate, and ozone. Present facilities were also evaluated (size, location, capacity, storage capability) for compatibility with the various chemical control methods. Recommendation was then made as to which type of control system to implement to effectively kill zebra mussels but minimize costly additions and/or alterations to the existing facilities. Design components included layout of the proposed solution line and diffuser assembly, to effectively dose the chosen chemical. In addition, weighting systems were designed to aid installation of the application line.

The Niagara County Water District's zebra mussel control system is installed and on-line. Other projects are currently under construction or scheduled to begin construction during the summer of 1991.

SESSION FIVE: MECHANISMS AND RATE OF SPREAD; RANGE EXPANSION; MONITORING

Lowther, D.R.[1] and D. Barker[2]
[1]Ontario Hydro and [2]J.J. Downs Industrial Plastics Inc.

DEVELOPMENT AND TESTING OF AN AUTOMATIC PLANKTON SAMPLER FOR USE IN ZEBRA MUSSEL MONITORING

Ontario Hydro has seventeen facilities on the Great Lakes and connecting waterways as well as sixty seven inland hydraulic facilities. There is a need to accurately establish the seasonal presence of zebra mussel veligers at these diverse locations, to optimize the individual zebra mussel control regimes. Hand sampling was considered to be too labour-intensive based on the distance between facilities. As an alternative, an automated plankton sampler was commissioned by Ontario Hydro from a local supplier.

The sampler has the capability of collecting seven discrete samples at intervals determined by the researcher. Samples are strained through a mesh size of choice and the final sample is preserved.

This paper outlines the physical features of the plankton sampler, method and flexibility of operation as well as some practical considerations for installation and use.

Haag, Kim H., James H. Thorpe, and Fang Wei
University of Louisville, Water Resources Laboratory

MONITORING THE INTRODUCTION AND SPREAD OF ZEBRA MUSSELS IN THE OHIO RIVER: PROTOCOLS AND PROBLEMS

Monitoring the invasion and dispersal of zebra mussels in rivers poses a unique set of problems for investigators. Current velocity and the amount of suspended sediment are the most obvious parameters distinguishing lakes from rivers, and they can severely limit methods for sample collection of veligers, post-veligers, and adults. Commonly used devices will not close properly, cannot withstand the stress exerted by even moderate currents, or clog rapidly. Even when heavily weighted gear is employed, it is difficult to position at specified depths under high current conditions. In addition, fluctuating water levels due to artificial regulation and precipitation can strand or inundate samplers left tethered in place. Alternative approaches to sampling rivers for zebra mussels are proposed.

We initiated a zebra mussel monitoring study on the Ohio River in January 1991. The study encompasses 280 river miles including the Cannelton, McAlpine, and Markland Pools. We have devoted our efforts this first year to monitoring the water column for the presence of veligers. Monthly vertical plankton tows are stratified by river reach within each pool. One set of samples is taken at a site in the lower reach near the downstream dam. In the upper reach of each pool, a major tributary has been selected (Salt, Kentucky, and Miami Rivers, respectively), and one set of samples is collected in each tributary two miles upstream of its confluence with the Ohio. Additional sets of samples are gathered at sites in the Ohio River two miles upstream and two miles downstream of the mouth of the tributary. In addition to vertical tows, replicate quantitative plankton samples are collected at the surface both in the channel and near the bank. Ten to 20 liters of water are filtered through a 63 um mesh net, preserved on our boat, and returned to the laboratory for later enumeration and identification of zooplankton and phytoplankton. To date, no zebra mussel veligers have been found. Routine examination of channel buoys in the three pools have also failed to reveal the presence of adult *Dreissena* in this portion of the Ohio River.

Dustin, Donna L., Edward L. Mills, Mindy M. Gardner, and Thomas Greig
Cornell Biological Field Station, Department of Natural Resources, Cornell University

DEMOGRAPHY AND DISPERSAL OF THE ZEBRA MUSSEL (*DREISSENA POLYMORPHA*) IN UPSTATE NEW YORK WATERS

Zebra mussel (*Dreissena polymorpha*) collections have been made June through October in the Erie-Barge Canal, the Oswego River, and Oneida Lake in 1990 and 1991. At all sampling sites, secchi disc measurements and samples for zebra mussels (both veligers and adults) were taken as was water for chlorophyll, dissolved oxygen, and selected nutrient analyses. In 1990 veliger densities were highest at the western end of the canal and declined steadily eastward. By early fall adult densities were observed as far east as Palmyra. No mussels, including veligers, were observed in the Oswego River and Oneida Lake in 1990. Sites with abundant mussels showed a marked decrease in chlorophyll and an increase in water clarity and soluble reactive phosphorus compared to sites with few or no mussels. In May 1991, adult zebra mussels were first observed on native unionid clams in Oneida Lake. Rapid warming of canal waters in spring of 1991 allowed swift growth and early reproduction of adults surviving over winter. Veliger densities of over 70,000/m^3 occurred in mid-June at Palmyra, with veligers detected at all sites (including Oswego River and Oneida Lake) by mid-July. In contrast to 1990, early summer veliger densities in the eastern waters of the Erie Canal were higher than those in western portions. The Erie Canal system is a major vector through which zebra mussels will infest inland waters of New York State.

Marsden, J. Ellen[1], Lidia Bardygula[2], and Jan Savitz[2]

STATUS OF ZEBRA MUSSELS IN LAKE MICHIGAN—TEMPORAL AND SPATIAL DISTRIBUTION OF VELIGERS AND ADULTS

Most of the information about zebra mussels in North America has come from Lakes Erie, Ontario, and St. Clair. Lake Michigan, in contrast to these lakes, is generally colder and has a north-south orientation. This latter feature has important consequences for the distribution of organisms which are affected by temperature or other latitude-dependent variables. Two simple hypotheses are proposed for zebra mussel populations in Lake Michigan: their density and growth rates should decline from south to north, and their reproduction and settling should be progressively delayed from south to north. The testing of these hypotheses will provide useful information for utilities who need to know how soon they will face "critical" densities of mussels in their intake systems. We report the results of veliger monitoring and adult sightings along the western Lake Michigan shoreline, and SCUBA assessments of adult densities in the near-shore waters of Lake Michigan.

Lange, Cameron L., and Roberta K. Cap
Acres International Corporation

THE RANGE EXTENSION OF THE ZEBRA MUSSEL (*DREISSENA POLYMORPHA*) IN THE INLAND WATERS OF NEW YORK STATE

Through 1990, the zebra mussel (*Dreissena polymorpha*) extended its range into the inland waters of New York State via the State Barge Canal System from the Niagara River near Buffalo, New York to Palmyra, New York, located about 120 miles inland. This rapid rangeextension exceeded the expectations of many investigators. In 1991, the Empire State Electric Energy Research Corporation (ESEERCO) sponsored a continuation and expansion of a monitoring program initiated in 1990 to follow the continued spread of the mussel through New York State. Monthly sampling commenced in March 1991 at eight locations on the Barge Canal, four on the Cayuga/Seneca Canal/Finger Lakes System, seven along the Hudson River and three in the Susquehanna River drainage. A total of six other locations were sampled on the Genesee, Oswego, Schoharie and Delaware Rivers.

In 1991, zebra mussel veligers were found for the first time in May. Veligers were present at the Palmyra and Baldwinsville locations only. The Baldwinsville sighting increased the zebra mussel's known range by 65 canal miles. In May 1991, adult mussels were independently reported to be in Oneida Lake, 25 miles further inland from Baldwinsville. In June, zebra mussels had extended their range into the Oswego River at Fulton. Zebra mussel veligers had infiltrated all of the Barge Canal and associated river systems where water flows downstream from the Niagara River source waters. To further extend its range, they would need to be lifted to a higher water elevation through the locks. Whether this would impede the mussel's progress was not known.

In July, veligers were found on the Cayuga Lake side of Lock C–1 on the Cayuga/Seneca Canal. Zebra mussel veligers were also identified in samples collected on the Susquehanna River near Binghamton, New York. Additional sampling in early August verified their presence. This was the first report of zebra mussels in a drainage system not connected to the Great Lakes system by a canal. Adult zebra mussels were also reported in discrete areas along the Mohawk and Hudson Rivers, but through July no veligers were collected during this program. Results indicate that two methods of transport are occurring in the inland waters: veliger drift and active transport of mussels by boats or other means.

Through July, the density of veligers ranged to 58,000/m^3 at Palmyra (June collections). The maximum density of settled mussels during the same period was 8,400/m^2 also at Palmyra. Sampling continued through November.

Kraft, Clifford[1], Mary Balcer[2], Art Brooks[3], Jory Jonas[1], Allen H. Miller[1], and Hans Pearson[4]
[1]University of Wisconsin Sea Grant Institute, [2]University of Wisconsin—Superior: Center for Lake Superior Studies,
[3]University of Wisconsin—Milwaukee: Center for Great Lakes Studies, [4]Silver Lake College

FROM THE FRONT LINE OF THE INVASION: EARLY-WARNING DETECTION OF ZEBRA MUSSELS

Since late 1989 it has been obvious that zebra mussels would eventually colonize Wisconsin waters of Lakes Michigan and Superior. Key questions were when this invasion would materialize, and whether a coordinated sampling effort could provide more useful information about the arrival of zebra mussels than unplanned observations. For two summers (1990 and 1991) we mounted a substrate and plankton sampling program in harbors and water intakes. In concert with this sampling effort, we conducted an intensive educational effort for utility personnel, divers and the general public concerning the impending arrival of zebra mussels.

At most sample sites the presence of zebra mussels was first reported from unplanned observations that were not part of our coordinated sampling effort. However, in most instances such reports were soon followed by quantified abundance estimates from our sampling program, providing information on the rate of colonization. These results suggest that: (1) at their earliest stage of infestation, zebra mussels are not likely to be detected by standard sampling protocols; (2) educated observers can provide useful clues regarding potential infestation by zebra mussels; and (3) a standard sampling program can provide useful information once a local reproductive population of zebra mussels has become established.

SESSION SIX:

BIOLOGICAL CONTROL/ MITIGATION, EXPLOITATION/BENEFICIAL USES

KEYNOTE PRESENTATION: Abraham Bijde Vaate

Institute for Inland Water Management and Waste Water Treatment, Rijkswater-staat, The Netherlands

ZEBRA MUSSELS: ENEMIES OR FRIENDS?

The zebra mussel has been a commonly occurring inhabitant in The Netherlands since 1827, when the first record was made. From the view of industrial activity it should be noted that the extension of the zebra mussel into Western Europe started before the period of industrial development in the 19th century. When the use of freshwater became more important for different purposes, the designers of intake systems already had to take the presence of zebra mussels into account, and antifouling measures were developed. Therefore the presence of zebra mussels in Western Europe did not have the same impact on industrial activity as they have nowadays in North America. Recently, studies have been started to use zebra mussels in water quality management: to reduce the amount of phytoplankton in eutrophic shallow lakes (a measure to increase the density of submerged waterplants), and to reduce the amount of polluted silt in the water supply of a manmade lake. Filtration rate and pseudofaeces production have been investigated for both employments respectively. They have been related to some important abiotic parameters. In addition, possibilities for obtaining sufficient densities of zebra mussels in these types of water management have been investigated as well. Removal of polluted silt calls for the whole water column to be filtered by the zebra mussels. Therefore an application of zebra mussels in hanging cultures (biological filter) was studied. A summary of the results of all mentioned investigations is presented, and the role of zebra mussels in river and lake ecosystems is discussed.

Molloy, Daniel P., and Barbara Griffin
New York State Museum Biological Survey, State Education Department

BIOLOGICAL CONTROL OF ZEBRA MUSSELS: SCREENING FOR LETHAL MICROORGANISMS

Initiated in April 1991, this research project focuses on the development of a biological method for controlling zebra mussels. Microorganisms are being tested in the laboratory to identify those which are lethal to attached zebra mussel life stages. Over 260 different microorganisms are being screened over a two year period. These candidate control microorganisms will not be "natural" parasites of zebra mussels, but rather naturally occurring soil and water microbes, which just by chance happen to be lethal to zebra mussels when the mussels are exposed to artificially high densities of the microbe. A microorganism which at artificially high densities is poisonous to zebra mussels undoubtedly exists in nature, and the proposed research is designed to identify it. This type of research approach has a track record of success, since it has already produced a commercially available, environmentally safe, microbial control agent for another aquatic, filter-feeding, invertebrate pest—the black fly. Preliminary results of those microorganisms screened to date will be presented.

SESSION SEVEN:

PHYSICAL CONTROL/MITIGATION

KEYNOTE PRESENTATION: Ludyanskiy, Michael, John F. Garey, and Derek M. McDonald

Marine Biocontrol Corp.

SOVIET EXPERIENCE ON ZEBRA MUSSEL RESEARCH AND CONTROL

Recently, in the Great Lakes region in general, and portions of Lake Ontario and Lake Erie in particular, populations of the freshwater zebra mussel, *Dreissena polymorpha*, have increased dramatically. The economic impact of this rapid change, and the resistance of *D. polymorpha* to established control methods, have had a profound effect on the power utilities.

D. polymorpha originated in the North Kaspiy region of the European USSR, and for over 2 decades has been considered the main macrofouling organism throughout the Soviet Union. A considerable body of untranslated Russian information concerning the biology, economic effect(s), control and regulation of the zebra mussel remains unavailable for study in North America—more than 600 scientific papers on these subjects have been published in the Soviet Union. In an effort to mesh this information with current studies in this country, the authors present a comprehensive review of this literature, focusing briefly on *D. polymorpha* biology, and primarily on Soviet methods for the (1) prevention of settlement, (2) inhibition of growth, and (3) methods of removal from already infested areas.

Active investigation of *D. polymorpha* biology in the Soviet Union began during the 1950's. Initial studies focused on structural and functional descriptions of *D. polymorpha* populations in different habitats—abundance, mass and size structure, and degree of settlement. Since that time, numerous reports investigating the peculiarities of fertilization, ontogenesis, phenology and growth of larval stages have been published. Of significance are investigations on the developmental patterns of *D. polymorpha* which are influenced by water quality, temperature and velocity.

A sizeable amount of study has been devoted to the prevention and/or control of zebra mussel populations. Studies in collaboration with Soviet utilities report abundances of *D. polymorpha* in sections of industrial water piping up to 0.5 million individuals/meter^2, fouling layers from 1–15 cm in thickness, and biomass levels up to 30 kg/meter^2. Buildup in some reservoirs of the Ukraine have reached 2000 tons, and annual estimates of zebra mussel soft tissue in the Volgograd Reservoir exceed 1 million tons. In these industries, and currently in power generation utilities in the northern United States, this fouling causes reduction in process water, leading to plant shutdowns, equipment failures, and reduced operating efficiency. The Soviet experience with methods for control and regulation of *D. polymorpha* demonstrates the need for *site-specific* evaluation of fouling potential and underscores the need for preventative measures, rather than

SESSION EIGHT:

PHYSICAL CONTROL/MITIGATION

(CONTINUED)

Martin, Benjamin, and Samuel E. Landsberger
Cornell University Department of Mechanical and Aerospace Engineering

DESIGN OF PIPE-CRAWLING VEHICLES FOR ZEBRA MUSSEL CONTROL

We are designing vehicles for operation in water pipes to control the growth of zebra mussel colonies. We address the problems involved in operating in the hostile environment present in water intake pipes; (1) operation in a confined space at a great distance from the control center, and (2) navigation and propulsion in high currents with varying geometry and obstacles. We then examine our designs for a pipe travelling vehicle in the light of the past history of autonomous and remotely controlled vehicles. These systems have had a varied record of success in the industrial world. There are examples of commercial success, such as the underwater use of Remotely Operated Vehicles (ROV's). On the other hand there are many cases of systems which worked wonders in the laboratory but whose field performance fell short of expectation. We examine these past robotic systems to determine what characterized the successful and the unsuccessful systems, and examine our proposed design solutions in this light.

Smythe, A. Gary [1], Cameron L. Lange[1], T.M. Short[1], and L. Ray Tuttle[2]
[1]Acres International Corporation, [2]New York State Electric and Gas Corporation

APPLICATION OF CENTRIFUGAL SEPARATORS FOR CONTROL OF ZEBRA MUSSELS IN RAW WATER SYSTEMS

Two centrifugal separators are being tested to determine their effectiveness in the control of zebra mussel (*Dreissena polymorpha*). The objective of the study is to assess the feasibility of using these separators to remove presettling and settling stage larvae from raw water supplies (Study Phase I), and to determine the effectiveness of such devices in filtering these larvae from the water (Phase II). An experimental set-up, including a Krebs desander and a Lakos Super-Separator, was installed at the New York State Electric and Gas Kintigh Station, Somerset, New York, adjacent to Lake Ontario. Testing utilizes Lake Ontario raw water from NYSEG's fire protection system. The Krebs desander (separator) is a hydrocyclone with a closed apex, used primarily in high pressure applications. The Lakos Super-Separator relies upon the same basic operating principle with some modifications to hydrocyclone design. The Lakos design offers some operational advantages relative to wear potential and equipment maintenance.

Both separators utilized centrifugal force to remove particles. The desander, due to its inlet design, will accelerate particles to a higher angular velocity in comparison with Lakos separator. The desander, therefore, may have a slight "edge" in separation efficiency.

Phase I sample collections began in July, 1991. The source water was water obtained through connection to the fire protection service water system in the circulating water pump house bay at the power station. Flows through the separators varied from approximately 0.4 to 0.8 M^3/min (100 to 220 gpm), system pressures varied from 2.8 to 9.8 kg/cm^2 (40 to 140 lbs/in^2) depending on valve settings for a given test.

Although the test apparatus and procedures are somewhat complex, the analytical approach is quite simple. The total number of larvae (differentiating veliger from post-veliger) was determined for the supernatant samples. The number obtained from each of these samples was added together and then divided into the number in the filtrate. This provided a separation efficiency factor for the veliger (D-forms) and post-veliger (umbonal forms).

Volumetric measurements have also been made using flow meters and pressure gauges. Accurate volume measurement, however, is quite difficult considering the high flows/volumes encountered for this study. As a result the direct measure and comparison of the numbers of larvae in the supernatant/filtrate are therefore appropriate.

The mean size of the umbonal forms was determined for a subsample of most of the supernatant/filtrate samples. Through the last lab analysis, the mean size of the umbonal forms in the filtrate was always greater than that in the supernatant sample for any sample pair (Krebs or Lakos). This would indicate that centrifugal force is selectively separating umbonal form larvae by size and/or specific gravity as was anticipated.

The separator efficiency for umbonal forms has ranged from 4.8 percent in early samples to 78.4 percent in later samples. It would appear that as the umbonal population ages, and the population mean size increases, the separator efficiency would increase as was anticipated. It is possible, however, that the maximum separation efficiencies obtained to date are being underestimated relative to settling stage larvae, since we are not differentiating the smaller umbonal forms. Larger umbonal forms are more susceptible to separation and are of more concern since they are at or close to settlement stage. It is anticipated that separation efficiencies will increase later in the season. Details of Phase I data, as well as any data analyzed from the Phase II study effort, will be presented.

Smythe, A. Gary[1], Cameron L. Lange[1], J.F. Doyle[1], and Paul M. Sawyko[2]
[1]Acres International Corporation, [2]Rochester Gas and Electric Corporation

APPLICATION OF LOW VOLTAGE ELECTRIC FIELDS TO DETER ATTACHMENT OF ZEBRA MUSSEL TO STRUCTURES

The objective of this study is to determine if electric fields could be useful in reducing the attachment rate of zebra mussels (*Dreissena polymorpha*) to submerged structures located within these fields. Conceptually we are assuming that if an electric field is of sufficient intensity the settling stage veligers will not attach while under the influence of, and for a short time after, exposure to a field. Any suitable flow of water will then carry the settler away from the "protected" structure.

The study site is at the Rochester Gas and Electric Russell Station in Rochester, New York, adjacent to Lake Ontario. A series of test flumes were set up and a continuous flow of power plant forebay water channeled through the flumes to provide a source of larvae. Bar rack arrays were placed in each of the test flumes. Flows in each flume were adjusted to about 0.5 fps (0.15 m/sec), a flow which could be expected to exist at some intakes. The bar rack arrays were constructed of steel plates 4 inch (or 6 inch) by 7 inch (5 plate/array) spaced to approximate that of a typical trashrack.

Low voltage electric fields of various intensities are being tested for 60Hz Alternating Current (AC), continuous Direct Current (DC) and pulsed DC. Analytically we are comparing the densities of attached mussels on control arrays to attached densities on arrays subjected to test electric fields. Spacial distribution of attached mussels for each plate is also being noted.

Laboratory analysis for several arrays has been completed. To date the data analysis has not been completed. However, in general, we can state that there has been zebra mussel attachment at some level on all arrays tested to August 28, indicating we are not attaining 100 percent success for the configurations tested so far.

Data analysis for tests already completed, for tests under way, and tests to be conducted over the next two weeks, will be finalized prior to presentation at the November conference.

Chalker-Scott, Linda, J.D. Scott, C. Dunning, and K. Smith
Buffalo State College

EFFECT OF ULTRAVIOLET-B RADIATION (280–320 NM) ON SURVIVORSHIP OF ZEBRA MUSSEL LARVAE (*DREISSENA POLYMORPHA*): A POTENTIAL CONTROL STRATEGY

Concern over depletion of the earth's ozone layer has resulted in a great deal of information being gathered on the effects of ultraviolet-B (UV-B, 280–320 nm) upon planktonic organisms. There is increasing evidence that naturally occurring UV-B is an important limiting ecological factor in zooplankton communities. In a natural habitat, *Dreissena polymorpha* larvae and other planktonic organisms could escape harmful radiation by changing their position in the water column. In a water intake pipe, however, the area is much restricted and escape from artificially-supplied ultraviolet radiation would be unlikely.

The critical point in controlling zebra mussel infestation is the settling of the planktonic larvae. When postveliger larvae settle, they secrete strong byssal threads which firmly attach the mussels to the substrate. Once settled, mussels are difficult and expensive to remove from intake pipes and other structures. Prevention of settling would be the easiest and most cost-effective mechanism to remediate zebra mussel fouling problems.

One possible control method, which apparently has not been tested, is exposure of the larvae to ultraviolet-B radiation. UV-B is a naturally occurring, water-transmissable radiation that can have profound effects on aquatic organisms. The use of ultraviolet-B radiation as a control for zebra mussel settlement would have several advantages over other methods. It is not a potential water pollutant as are chemical treatments such as chlorine, it is not labor intensive as are most mechanical methods, and it does not require costly cooling systems as does heat treatment. Additionally, this method retools existing technology and should therefore be much cheaper to implement than would a method developed "from scratch."

Veliger larvae of the zebra mussel, *Dreissena polymorpha*, were collected from Lake Erie and maintained in lake water under natural temperature (20°C) and day length (14 hr light/10 hr dark) conditions. Following acclimation, larvae were transferred to the experimental chamber and subjected to enhanced UV-B radiation. To control the wavelengths of exposure, Mylar and cellulose acetate filters were employed for experimental and control organisms, respectively. Larvae were maintained in lab and analyzed 24 hours post-exposure for mortality. Surviving larvae were defined as those whose velum was still functioning (i.e., are capable of swimming).

Recent experiments indicate that zebra mussel larvae are negatively affected by enhanced UV-B radiation. There is an increase in mortality above control levels after only 1 hour of exposure, which suggests that mid-range ultraviolet radiation may be effective in reducing larval populations.

Menezes, John
Sonalysts, Inc.

ZEBRA MUSSEL CONTROL USING ACOUSTIC ENERGY

The spread of the zebra mussel *Dreissena polymorpha* (Pallas) into the Great Lakes and adjoining waters is a great concern to utility, municipal, industrial, and environmental interests because of the propensity of the species to rapidly cover the area it colonizes. A practical and economical device or method that reduces zebra mussel colonization without detrimental side effects is highly desirable.

The research and technical programs in which Sonalysts has participated focused on affecting veliger and immediate post-veliger developmental stages using acoustic energy. In 1990, small-scale studies were performed under contract to Empire State Electric Energy Research Corporation (ESEERCO) by Sonalysts to survey the effect of underwater sound on the viability of larval, post-veliger, juvenile, and adult zebra mussels.

The acoustic energy was generated by several devices designed for underwater and laboratory applications using narrow frequency bands between 155 Hz and 1 MHz. The initial screening was conducted by evaluating gross morphological and behavioral effects in very small-scale (<1 liter) systems using short-term exposures at or near the maximum operating amplitude of each device. When an initial survey test showed promising results (e.g., veligers destroyed, mussels gaping, shells fractured or detached) the test was conducted on a larger scale with replicate and reference samples at different amplitudes, ranges, or durations.

Based on the 1990 results, ESEERCO sponsored Sonalysts to conduct additional research during the summer of 1991 (currently ongoing) which provided an opportunity to extend this work towards the optimization of acoustic parameters and an increase in scale (range, volume). A pilot-scale system will be developed and deployed in 1992 based on the information and results collected during the summer of '91 testing. The pilot-scale system is being designed to prevent the attachment of viable juveniles to intake walls and induce mortality as veligers pass through moving volumes of water.

From the surveys, we learned that high intensity acoustic sources can lethally disintegrate veligers and shatter the shells of juvenile zebra mussels. The effect on juveniles is size and time dependent. *In situ* tests also indicated that juveniles and adults longer than 10 mm could also be killed, even at lower amplitudes, with less than 18 hours of treatment. Sonalysts will discuss this acoustic research on zebra mussel control and their plan to demonstrate a full-scale installation of acoustic control devices at an operating intake.

Smithee, R.D., and William P. Kovalak
Technical and Engineering Services, Detroit Edison Company

CONTROL OF ZEBRA MUSSEL FOULING BY COATINGS

The effectiveness of 14 different coatings, most of which were applied to steel plates, in controlling zebra mussel fouling was tested in the intake canal at Detroit Edison's Monroe Power Plant (western Lake Erie) between June–October 1991. Preliminary results based on visual inspections indicated most of the coatings affected some reduction in fouling. The most effective products were those that were silicone based and those that contained copper or other toxic metals. Also promising were thermal plastic coatings, although these were not exposed to colonization for the entire study period. Plates will be quantitatively sampled in mid-October. This will allow a better evaluation of the cost-effectiveness of the various products.

SESSION NINE: CHEMICAL CONTROL/MITIGATION

Fisher, Susan W., and H. Dabrowska
Department of Entomology, The Ohio State University

TESTING OF CANDIDATE MOLLUSCICIDES ON THE ZEBRA MUSSEL

Methods were developed for measuring the toxicity of molluscicides to the zebra mussel, *Dreissena polymorpha* (PALLAS) in conjunction with studies conducted at the U.S. National Fisheries Research Center, La Crosse, WI. Adult zebra mussels (20–25 mm in length) were randomly selected from a stock culture 24 hours prior to initiation of toxicity tests. Groups of 13 mussels were placed on the bottom half of 9 mm glass petri dishes and were allowed to secrete new byssal threads over a 24–hour period. Those mussels which did not reattach were discarded. An average of 10 mussels per dish did secrete new byssal threads and were considered suitable for use in toxicity tests.

Toxicity tests were run in triplicate in hard standard reference water. Mortality was assessed at 24 and 48 hours after which the test animals were placed in clean water for 96 hours to screen for recovery and survival. Toxicity data were analyzed by probit analysis to give LC_{50} values and 95% confidence limits.

Using this protocol, the toxicity of a series of 12 molluscicides was determined in adult zebra mussels. These toxicity data were then compared to the results of tests performed with the same chemicals on two bivalves related to the zebra mussel; the latter tests were performed at the National Fisheries Research Center at La Crosse. From these data, the reliability of the standard method was assessed. In addition, a body of toxicity data was developed for molluscicides proposed for use on zebra mussels from which it will be possible to assess the efficacy of these chemicals in zebra mussel control and the likelihood of hazard to closely related freshwater bivalves.

Matisoff, Gerald[1], Alan Greenberg[2], Gerald Gubanich[2], and Julius Ciaccia[2]
[1]Department of Geological Sciences, Case Western Reserve University, [2]Cleveland Division of Water

EFFECTS OF POTASSIUM, CLORAMINE, AND CHLORINE DIOXIDE ON CONTROL OF ADULT ZEBRA MUSSELS

Chemical dose/response studies of zebra mussel adults in flow-through aquaria were conducted to evaluate the effectiveness of potassium, chloramine, and chlorine dioxide on adult mortality for exposure periods of up to several days. Potassium permanganate was effective at concentrations greater than about 2 ppm. Potassium hydroxide concentrations less than 1 ppm did not induce mortality in the mussels, but complete mortality was observed at concentrations greater than 10 ppm. Chlorine dioxide treatment resulted in mortalities of about 10%–20% at the 0.2–0.3 ppm level with 100% mortality reached in 24 hours at concentrations greater than 0.5 ppm. This yields an LC_{50} of about 0.4 ppm. Chloramine treatment resulted in 100% mortality in 24 hours at total chlorine concentrations as low as 1.2 ppm. However, the chloramine concentrations in those experiments were as low as 0.1 ppm, indicating a chloramine production yield of only about 10%. Thus, it is unclear if the mortality-inducing agent is chloramine at 0.1 ppm or free chlorine at 1.1 ppm. The high effectiveness of chlorine dioxide at inducing zebra mussel mortality, coupled with the fact that the addition of chlorine dioxide forms less THM's than chlorine and chloramine, indicates that it may be preferred as an oxidizing agent for zebra mussel control at water treatment plant intakes even if slightly higher concentrations are needed.

Fisher, Susan W.[1], K.R. Polizotto[2], and Beth Schneider[3]
[1]Department of Entomology, The Ohio State University, [2]PCS Sales,
[3]Environmental Sciences Program, The Ohio State University

THE TOXICITY OF POTASSIUM CHLORIDE TO ZEBRA MUSSEL VELIGERS AND SELECT NONTARGET ORGANISMS

The toxicity of potassium chloride was measured in static tests to zebra mussel veligers. In addition, the toxicity of continuous, low-level (25–50 ppm) exposure to KCl was measured in flow-through tests. The latter was accomplished using a customized testing apparatus consisting of a series of 9 pipes which were 4 inches in diameter and 1M in length. The pipes were suspended above the water at Stone Laboratory, Put-in-Bay, Ohio and Lake Erie water was pumped continuously through each pipe at a rate of 0.5 M/sec. Inside each pipe, a second pipe with a slightly smaller diameter was placed. Each of the inner pipes were transected by a series of 6 glass slides to serve as settling plates. The inner pipe and glass slides were removed daily for examination of veliger settling and survival. Three of the pipes received a continuous application of 50 ppm KCl and three pipes received 25 ppm KCl. The remaining three pipes served as untreated controls. The experimental application of KCl took place for a period of two weeks from August 1, 1991 to August 15, 1991.

In addition to assessing veliger settling and survival in each pipe, the number and condition of the veligers being pumped into the pipes were analyzed daily. The concentration of potassium in the effluent of each pipe was assessed daily using an ion specific potassium electrode and verified weekly with atomic absorption spectrophotometry. Veliger abundance in the lake water was also monitored on a daily basis.

The toxicity of KCl was tested in several benthic invertebrates. These included juvenile *Anodonta imbecillus* with and without sediment, adult *Corbicula fluminea* and fourth instar larvae of the midge, *Chironomus riparius*.

SESSION TEN:

MECHANISMS AND RATE OF SPREAD (CONTINUED)

Carlton, James T.
Maritime Studies Program, Williams College

DISPERSAL MECHANISMS OF THE ZEBRA MUSSEL

More than 20 dispersal mechanisms can transport zebra mussels overland, upstream, and downstream. Dispersal mechanisms may be natural (planktonic dispersal on currents; adult dispersal on other animals or on driftwood) and human-mediated (ranging from boats and bait buckets to amphibious planes and pet turtles). No quantitative data are available in Europe or North America for any dispersal mechanism. Control programs are thus based entirely upon certain assumptions and empirical understandings. The existence of these diverse mechanisms further renders difficult the estimation of the rate of dispersal based only upon current speeds. Significant jumps are predictable. Our two-year research program seeks to quantify selected dispersal mechanisms both through direct observation and through experimental studies specifically designed to test putative vectors.

Blodgett, K. Douglas[1], Pamella A. Thiel[2], Andrew C. Miller[3], and Richard E. Sparks[1]
[1]Illinois Natural History Survey and Long Term Resource Monitoring Program, [2]U.S. Fish and Wildlife Service, Environmental Management Technical Center, [3]U.S. Army Corps of Engineers, Waterways Experiment Station

ZEBRA MUSSEL INVASION OF THE UPPER MISSISSIPPI RIVER SYSTEM

The rapid expansion of the recently introduced zebra mussel (*Dreissena polymorpha*) forewarns of significant negative impacts on both the biology and economy of the Upper Mississippi River System (UMRS)—a resource the United States Congress has declared to be nationally significant both as an ecosystem and a commercial navigation corridor.

Zebra mussel populations developing in southern Lake Michigan provide a probable source for recent expansion of the species into the UMRS. Natural dispersal of larvae may occur with water diverted from Lake Michigan down the Illinois River (via the Chicago River, the Chicago Sanitary and Ship Canal, and the Des Plaines River) and into the Mississippi River. Both settled larvae and adults may be transported by recreational craft and commercial navigation vessels (barges) emanating from infested areas of southern Lake Michigan and traversing both the UMRS and the lower Mississippi River. Another possible means of dispersal is trailered recreational boats that transport larvae and adults overland to both lotic and lentic habitats in the Mississippi River Basin.

The first confirmed collection of a zebra mussel from the UMRS occurred on 18 June 1991 in a side channel of the Illinois River near Bath, IL, approximately 217 river miles (350 km) downstream from Lake Michigan and 110 river miles (117 km) upstream from the confluence of the Illinois and Mississippi rivers. The adult specimen was attached to a native threeridge mussel (*Amblema plicata*) and was taken by a commercial sheller. Additional adult specimens have been collected from the Illinois River by shellers and others, and settled larvae are reported as far as 118 river miles (190 km) downstream from Lake Michigan. In September, adults were reported from the Mississippi as far upstream as Pool 8 near La Crosse, WI, and as far downstream as the Melvin Price Locks and Dam at Alton, IL.

Negative biological impacts may result from the zebra mussel's competition for resources, especially food and space. These biological impacts may also manifest themselves economically by affecting commercial and recreational fishing and the harvest of native mussel shells for use in the cultured pearl industry. Other negative economic impacts may include mechanical interference at locks and dams, clogging of municipal and industrial water intakes and systems, and damage to engine cooling systems of recreational and commercial vessels as well as decreased fuel efficiencies due to increased drag.

In conjunction with six Long Term Resource Monitoring Program field stations on the UMRS, we have initiated a baseline monitoring effort for zebra mussels. Our major monitoring and research objectives are to 1) document the temporal and spatial distributions of zebra mussels in the UMRS; 2) understand their life history in midwestern, floodplain rivers; and 3) ascertain and interpret any shifts in community structure of native biota (plankton, macroinvertebrates, and fishes) resulting from the physical and biological alterations the invader may cause. A thorough understanding of zebra mussels and their impacts will provide information to facilitate the development of environmentally sound control strategies.

SESSION ELEVEN:

PHYSICAL CONTROL/MITIGATION
(CONTINUED)

McMahon, Robert F.[1], and Barry S. Payne[2]
[1]Center for Biological Macrofouling Research, The University Texas at Arlington,
[2]U.S. Army Corps of Engineers, Waterways Experiment Station

EFFECTS OF TEMPERATURE AND RELATIVE HUMIDITY ON DESICCATION RESISTANCE IN ZEBRA MUSSELS (*DREISSENA POLYMORPHA*): IS AERIAL EXPOSURE A VIABLE CONTROL OPTION?

Wet weighed adult zebra mussels (*Dreissena polymorpha*) were emersed at 5°, 15° and 25°C in relative humidities (RH) of <5%, 33%, 53%, 75% and >95% (RH maintained in desiccators with silica gel, super-saturated solutions of $MgCl_2.6H_20$, $Mg(NO_3)_2.6H_2O$, NaCl and water, respectively). Subsamples (n=6) were removed periodically (frequency dependent on desiccation rate), wet weighed, tested for viability by 12 h reimmersion and dried at 90°C. Cumulative total water (TW = corporal + extracorporal water) loss was assumed to be the decrease in wet weight during emersion (initial wet weight - final wet weight) and was expressed as a percentage of TW weight (initial wet weight - dry weight). Increasing temperature and decreasing RH decreased emersion tolerance. At 25°C, LT_{50} ranged from 42.2 h (<5% RH) to 70.2 h (>95% RH). Corresponding LT_{100} range was 69.7–96.7 h. At 15°C, LT_{50} ranged from 67.7 h (<5% RH) to 266.2 h (>95% RH). Corresponding LT_{100} range was 153.1–537.1 h. At 5°C, LT_{50} ranged from 169.8 h (<5% RH) to 346.1 h (75% RH) (data for >95% RH was incomplete at abstract due date). Corresponding LT_{100} range was 362.5–482.7 h. At all temperatures, individuals continually shut valves at <5% RH, but periodically gaped and displayed open inhalant siphons at higher RH. Water loss rates generally increased with increased temperature and decreased RH. At 15° and 25°C over <5–75% RH, mean per cent TW loss for living individuals in samples just preceding those with 100% mortality was 59–71%, suggesting that mortality was due to desiccation. In contrast, mean TW loss prior to death at >95% RH was 25% at 15°C and 43% at 25°C, suggesting that death was due to other causes (i.e., acidosis, anaerobic end-product or ammonia toxicity, or energy store depletion). A similar pattern occurred at 5°C. These data suggest that dewatering to kill zebra mussels would require 3–4 days at ≥25°C. At 15°C, it would require 7–9 days below 75% RH, but 23 days above 95% RH. At 5°C, minimal time for 100% kill would be >11 days and is likely to exceed 30 days above 95% RH. Thus, the most appropriate time for application of dewatering to control zebra mussels is mid-summer when elevated ambient temperatures would induce rapid kills. At lower ambient temperatures, application of dry and/or heated air to dewatered components may be required to produce acceptable kill rates.

SESSION TWELVE:

CHEMICAL CONTROL/MITIGATION
(CONTINUED)

Waller, D.L., L.L. Marking, and J.J. Rach
National Fisheries Research Center, U.S. Fish and Wildlife Service

EVALUATION OF THE EFFECTS OF CANDIDATE MOLLUSCICIDES ON TWO NONTARGET BIVALVES.

A variety of molluscicides have been proposed for use in control of zebra mussels, but their effect on nontarget aquatic organisms has not been evaluated. Standard methods were adapted for assessing the toxicity of candidate molluscicides to two nontarget bivalves. Fingernail clams, *Musculium transversum*, and the fawnfoot mussel, *Truncilla donaciformis*, were selected to represent the two families of native bivalves. Both are similar in size to the zebra mussel and are commonly found in the Upper Mississippi River. Test organisms were collected from pools 6 to 9 of the Upper Mississippi River near La Crosse, WI. Handling, holding, and acclimation procedures were adapted to minimize the stress to both species of bivalves. Tests were run in triplicate with groups of 10 organisms in each test vessel. Static acute toxicity tests were conducted for 48 hours followed by a 96-hour monitoring period in untreated water to more fully assess survival and mortality. Toxicity data were analyzed by probit analysis to give LC_{50} values and 95% confidence limits. We evaluated the same chemicals as those tested at Ohio State University against zebra mussels. Results from our studies and those conducted at Ohio State University will be used to evaluate the effectiveness of chemicals in zebra mussel control and their potential hazard to nontarget organisms.

Lee, Harold H.[1], and Aklilu Lemma[2]
[1]Department of Biology, The University of Toledo, [2]International Child Development Centre

TOWARDS MITIGATION OF ZEBRA MUSSELS AND ASIATIC CLAMS: THE USE OF ENDOD, *PHYTOLACCA DODECANDRA*

Experiments using a static bioassay system as a basis to develop a focal control method for *Dreissena* and *Corbicula* illustrate the potential usefulness of plant molluscicides, Lemmatoxins, from *Phytolacca dodecandra* or Endod. Endod at a dose higher than 15 mg/L is lethal to adult zebra mussels and Asiatic clams, while at lower doses prevent adhesion and aggregation of the mussels. In addition to being noncarcinogenic and nonmutagenic, Endod is biodegradable. Since Endod plants have been successfully grown as monoculture, demands on large quantities of Endod usage in water intakes should stimulate further agricultivation. Since infestations of zebra mussels and Asiatic clams are long-term problems and waterworks vary in design and environment, a conceptual methodology for mitigation is suggested using Endod as the primary agent in combination with mechanical and chemical means to remove adult mussels and Asiatic clams from and to prevent aggregation in water intake pipes. (Funded by a DeArce Research Award of the University of Toledo and an Ohio Sea Grant).

Van Benschoten, John E., James N. Jensen, and Daniel DeGirolamo
Department of Civil Engineering, State University of New York at Buffalo

CONTROL OF ADULT ZEBRA MUSSELS BY CHLORINE: COMPARISON OF LABORATORY AND FIELD STUDIES

Chlorine has been shown effective for the control of adult zebra mussels. In previous laboratory studies, zebra mussel mortality has been shown to be a function of chlorine dose, contact time, and water temperature. For example, in continuous flow laboratory studies (DeGirolamo *et al.*, presentation at the 1991 American Water Works Association Annual Meeting), 100% mortality was observed at 23, 27, and >36 days at chlorine doses of 3.0 mg/L (0–5°C), 1.0 mg/L (9–15°C), and 1.0 mg/L (0–5°C). Chlorination conditions on the field scale may differ from laboratory conditions. For example, field scale chlorinations may not be continuous for several weeks without interruptions in chlorine dosing due to equipment failure or a change in treatment goals.

The objectives of the present study are threefold. First, zebra mussel mortality was determined during full scale prechlorination at an operating drinking water treatment facility. Second, mussel mortality during full scale and laboratory scale chlorination was compared. Third, the results from intermittent chlorination studies will be used to determine if noncontinuous chlorination can explain differences in mussel mortality between the laboratory and full scale.

A full scale chlorination study was conducted at the Erie County Water Authority's Van de Water Water Treatment Plant (Tonawanda, NY) between April 8 and May 28, 1991. The plant treats water from the Niagara River. The nominal chlorine dose was 1.0 mg/L and water temperatures during the study period ranged from 6 to 12°C. A portion of the chlorinated raw water was diverted to flow through reactors where zebra mussel mortality was determined. Mussels were considered dead if they did not show any activity or respond to gentle probing after a 24 hour recovery period in unchlorinated water. Intermittent studies were conducted by pumping a chlorine stock solution into unchlorinated raw water prior to introduction into the reactors.

Mussel mortality during full scale chlorination exhibited an "S" shape observed in previous laboratory studies. Fifty percent mortality was observed after 30 days and 100% mortality after 50 days. Laboratory experiments under similar conditions (1.0 mg/L chlorine residual, 9–15°C) showed 50% and 100% mortality at about 13 and 27 days, respectively.

Hourly chlorine readings during full scale chlorination revealed that chlorine addition was not continuous. To investigate the effects of intermittent treatment, laboratory studies were conducted with three chlorine addition regimes: 1.0 mg/L chlorine dosed continuously, 1.0 mg/L chlorine dose with no chlorine added for four hours every 24 hours, and 1.0 mg/L chlorine does with no chlorine added for eight hours every 24 hours. The time to 50% mortality was 4.5, 8 and 18 days for continuous, 20 hour/24 hour and 16 hour/24 hour chlorinations.

Mortality was slower during intermittent chlorination even when the data were corrected for exposure time. This suggests that mussels recover and can withstand chlorination longer during intermittent treatment. Even intermittent treatment showed much faster mortality than the full scale chlorination. Thus, maintenance of a continual chlorine does appears to be critical for minimization of the time necessary for zebra mussel death.

Bidwell, Joseph R.[1], L.A. Lyons[2], D.S. Cherry[1], J.C. Petrille[2], and M.W. Werner[2]
[1]Department of Biology, Virginia Tech, [2]Betz Laboratories, Inc.

EFFECT OF INTERMITTENT CHLORINE AND BROMINE TREATMENTS ON SETTLING, SURVIVAL, AND GROWTH OF THE ZEBRA MUSSEL, *DREISSENA POLYMORPHA*

The effect of daily 2-hr treatments with chlorine (0.5 mg/L and 1.0 mg/L TRO) or bromine (0.5 mg/L TRO) upon growth and survival of two size classes (6–8 mm and 12–14 mm in length) of zebra mussels was assessed in a 30-day study which ran from early July to August 1991. The study was conducted in a field laboratory which had been fitted with 12 side stream loops, each receiving a continuous flow of Lake Erie water. Each loop contained a rack of glass slides and included a fouling chamber fitted with a cement panel to examine the impact of these treatments on larval settling and accumulation. Survival of both size classes of mussels was greater than 85% in all treatments. Mussels in all treatments also exhibited positive growth over the 30 days. Larger mussels increased in length by an average of 4.4 mm, while smaller mussels increased by 6.8 mm in length. Treatments of 0.5 mg/L chlorine and bromine did not have a significant effect upon weekly larval settling rates as compared to controls, with all groups ranging between 50 and 70 larvae/slide/week. Daily 2-hr treatments with 1.0 mg/L chlorine significantly reduced larval settling to 10 to 25 mussels/slide/week. Accumulations of larger possibly transient mussels were also observed in all treatment loops. A second study which repeats the daily 2-hr 0.5 mg/L and 1.0 mg/L TRO chlorine treatments, and also includes a 2-hr 0.5 mg/L and 1.0 mg/L bromine and 4-hr 0.5 mg/L chlorine was initiated in August to further examine the efficacy of these treatments in controlling zebra mussel fouling.

Harlan, Fred L., and Robert E. McCarthy
Nalco Chemical Company

USE OF AN OXIDIZING CHEMICAL PROGRAM FOR ERADICATION/PREVENTION OF ZEBRA MUSSELS

Chemical control for zebra mussel eradication has centered on oxidizing and nonoxidizing biocides. The purpose of this paper will be to highlight the differences between these two approaches, and to show the efficacy of the former in actual operating conditions.

The program of an oxidizing biocide and biodispersant to control zebra mussels under operating conditions will be discussed. The use of both continuous and intermittent applications will be covered, as well as their effect on the plant operations.

The use at a customer location indicates that the continuous application can be used as a kill (remediative) mode while the intermittent method can be used in the preventative mode.

Levels of free bromine at 0.3–0.5 ppm FRO are necessary to obtain complete kill. Time, temperature, and system parameters are important variables to be considered when the type of treatment is to be chosen.

Snyder, Fred L.[1], Susan W. Fisher[2], and Beth Schneider[3]
[1]Ohio Sea Grant College Program, [2]Department of Entomology, The Ohio State University,
[3]Environmental Sciences Program, The Ohio State University.

EVALUATION OF POTASSIUM CHLORIDE FOR REMOVAL OF ZEBRA MUSSEL VELIGERS FROM COMMERCIAL FISH SHIPMENTS

Shipments of live fish are potential vectors for the spread of zebra mussels (*Dreissena polymorpha*) into watersheds outside of the Great Lakes region. Currently, species such as emerald shiner (*Notropis atherinoides*), white bass (*Morone chrysops*) and carp (*Cyprinus carpio*) are being shipped in water from the Lake Erie region to other watersheds, allowing the possibility that zebra mussel veligers might also be transported. As the range of the mussel expands, shipments of species such as channel catfish (*Ictalurus punctatus*), golden shiner (*Notemigonus crysoleucas*) and fathead minnow (*Pimephales promelas*) could represent additional pathways for invasion.

A potential chemical treatment for selectively removing zebra mussel veligers from the water in fish shipments is under evaluation. Potassium chloride solutions of 0 ppm (control), 500 ppm and 1000 ppm are being used to determine 24 hr. mortality rates for emerald shiner, fathead minnow, golden shiner, white bass and carp. Zebra mussel veligers are scheduled for testing in potassium chloride solutions of 0 ppm (control), 25 ppm and 50 ppm to determine 24 hour mortality rates.

Initial results from testing on these five commercial fish species suggest that 24 hr exposure to potassium chloride concentrations as high as 1,000 ppm did not cause mortality in excess of that experienced by fish held in the 0 ppm control tanks.

Extremely low densities of zebra mussel veligers in western Lake Erie during the study period precluded testing of the lethality of potassium chloride to veligers. This portion of the investigation will be continued in 1992. Previous research has produced LC_{50} values for potassium chloride to adult zebra mussels as low as 138 ppm. Veligers are frequently seen to be more sensitive to toxicants than are adult mussels.

Identification of potassium chloride levels lethal to veligers but harmless to commercially shipped fish species could lead to recommendations for commercial fish haulers on the prophylactic use of this chemical in retarding the spread of zebra mussels by their activities.

Evans, David W., and Lisa M. Coughlin
Chemical Research Department, Ontario Hydro Research Division

EFFECT OF LITHIUM/HYDRAZINE WATER CHEMISTRY ON SHORT-TERM SURVIVAL OF ZEBRA MUSSEL

The emergency coolant injection (ECI) systems at Ontario Hydro's nuclear generating stations are part of the special safety systems used for cooling of the nuclear fuel in the event of a loss-of-coolant accident. The water reservoirs for the ECI systems basically consist of large volumes of demineralized water or lakewater, dosed with lithium hydroxide (pH 9 to 11) and hydrazine (50 to 200 mg/L) to control the corrosion rates of carbon steel components. Macrofouling by zebra mussels could potentially impair the availability of this safety system. A laboratory testing program was therefore undertaken to determine the effect of typical lithium/hydrazine chemistry on the survival of young (ca. 5 mm) zebra mussels, in the short term.

Batch tests were run for 96 hours in well-sealed, 1L glass vessels. Tests were conducted in both demineralized water and dechlorinated tap water. Initial hydrazine concentrations were 0, 20, 50, 100 and 200 mg/L. Lithium hydroxide was added to raise the initial pH to 10. All lithium/hydrazine dosed tests were maintained at 20°C, without aeration. Controls (no lithium or hydrazine) were run at 10°C and 20°C, both with and without aeration. About 20 young mussels, naturally attached to PVC substrates, were used in each treatment. All tests were duplicated. The mussels were not fed during the course of the testing. Dissolved oxygen, pH, conductivity and lithium and hydrazine concentrations were measured at the beginning and end of the test. Although an electro-shock method was available, the live/dead determinations were done readily by behaviourial observation.

After 96 hours complete mortality was achieved in all hydrazine-dosed treatments. No mortality was observed in any of the treatments in dechlorinated tap water where hydrazine was absent (i.e. no mortality in controls or in pH 10 Li-dosed, 0 mg/L hydrazine treatment). Elevated control mortality was found in demineralized water at 20°C, but no mortality was seen in corresponding 10°C controls. Observations made during the course of the experiment indicate that, at ≥20 mg/L hydrazine, 100% mortality could be achieved within 1 hour in demineralized water and within 24 hours in dechlorinated tap water.

The results indicate that hydrazine levels of 20 mg/L or greater should be rapidly toxic to zebra mussels in either dechlorinated tap water (which is similar to the lakewater used in the station ECI systems) or demineralized water. The precise mode of hydrazine toxicity is unknown, but the rapid mortality suggests that death is not caused by deoxygenation of the bulk water. Toxicity may result from some localized reductive mechanism affecting oxygen uptake at the respiratory surfaces. Not surprisingly, demineralized water alone also increased mussel mortality. Under the test conditions, pH, in the range 7.3 to 10, did not influence survival rates. The present ECI system chemistry regime, established to minimize materials corrosion, should prevent macrofouling by zebra mussels.

POSTER SESSION

Ackerman, J.D., C.R. Ethier, D.G. Allen, and J.K. Spelt

RECRUITMENT AND ADHESION OF ZEBRA MUSSELS ON A VARIETY OF MATERIALS

The recruitment of zebra mussels was monitored in Lake Erie (Nanticoke, Ontario) during the summer of 1991. Weekly photographic and visual surveys were conducted of 8 X 16 cm coupons made from copper, copper-nickel alloys, stainless steel, mild steel, aluminum, teflon, plexiglass, polyvinylchloride, marine plywood or concrete. Measurements of adhesion strength of the zebra mussels adhering to these coupons were undertaken using a wall jet device.

The first mussel recruitment occurred at the end of June and by the middle of July there was up to one mussel per square cm on some of the materials. At that time, three classes of materials (based on levels of recruitment) were identified: (I) materials with little or no mussel recruitment (copper and copper nickel alloys), (II) materials with some recruitment (<0.5 mussels per square cm; aluminum and concrete), and (III) materials with moderate levels of recruitment (>0.5 mussels per square cm; polyvinylchloride, stainless steel, plexiglass, and plywood). An increase in mussel densities was noted on most materials with time, including those from Category (I). For some materials, large increases were observed (e.g., concrete, mild steel, plexiglass). Generally, there were more mussels on roughened surfaces than smooth ones, although there were exceptions to this generalization.

Initially, the mussels were dispersed over the entire coupon. However, with time the mussels clumped and tended toward the edge of the coupons. In late July, the coupons were overgrown by an algal mat. Although the alga was several mm thick, it did not appear to affect the mussels.

The wall jet device produces a jet of water with well-defined fluid dynamic characteristics. The jet is used to detach mussels such that the adhesion force is related to the shear stress generated by the jet. Preliminary results indicate that it requires between 60 and 70 Pa of nominal wall shear stress to remove mussels from stainless steel and polyvinylchloride coupons. These results confirm our previous adhesion strength observations made with a rotating disk. Additional measurements are currently under way.

Barber, Bruce J.
Virginia Institute of Marine Science, College of William and Mary

PRELIMINARY INVESTIGATION OF THE SALINITY TOLERANCE OF ZEBRA MUSSELS, *DREISSENA POLYMORPHA*: IMPLICATIONS FOR CHESAPEAKE BAY

The potential for zebra mussels, *Dreissena polymorpha*, invading subestuaries of Chesapeake Bay was examined by exposing individuals to gradually increasing salinity and recording growth rate and cumulative mortality. Both experimental (in which salinity was gradually increased from 0 to 2.7 ppt) and control (in which salinity was maintained at 0 ppt) aquaria were constantly aerated at 15°C. One third of the water volume of each aquarium was changed every other day. Mussels were fed a daily ration of algal paste resuspended in deionized water. Cumulative mortality of both medium (7–16 mm) and large (19–22 mm) mussels in the experimental aquarium was 100% within 52 days while cumulative mortality of both medium and large mussels in the control aquarium was about 30%. Growth of medium mussels in both experimental and control aquaria was not observed in the first 38 days of the experiment. Cumulative mortality of *D. polymorpha* increased dramatically in the experimental aquarium after day 30 when salinity exceeded 1.5 ppt. Although many questions remain to be answered, *D. polymorpha* could potentially become resident in the upper reaches of Chesapeake Bay.

Bidwell, Joseph R.[1], L.A. Lyons[2], D.S. Cherry[1], and J.C. Petrille[2]
[1]Department of Biology, Virginia Tech, [2]Betz Laboratories, Inc.

SURVEILLANCE OF ZEBRA MUSSEL (*DREISSENA POLYMORPHA*), LARVAL DENSITIES, SETTLING, AND GROWTH AT A POWER PLANT ON WESTERN LAKE ERIE

Monitoring of zebra mussel densities, settling, and growth was initiated in June 1991 in the forebay of a power plant located on western Lake Erie. Densities of veligers were determined each week in water samples collected from depths of 2 and 4 m, while settled larvae were counted weekly on glass microscope slides which were suspended near the plant intake. Cement panels (10 cm x 20 cm) were also suspended in the forebay to further assess mussel accumulation and growth. Maximal veliger densities were observed in July, reaching as high as 530/L (530,000/m³) on one sampling date. Veliger densities appeared to oscillate with temperature through July, with significant drops noted on two occasions when water temperatures approached 30°C. Larval settling reached 277 mussels/slide/week (74,000/m²). When slides which were suspended on 6 July were examined after 30 days, the majority of those mussels greater than 1 mm in length fell into a 2 to 5 mm size range, with densities of 188/slide (50,000/m²). Larger (>10 mm), transient mussels were also occasionally found on these slides. Cement panels from the forebay were completely covered with a layer of mussels by day 40. By day 60, the majority of these mussels ranged between 5 and 11 mm in length. A 24 cm² subsample from these panels contained 8.79 mussels/cm² (87,900/m²) with a wet weight biomass of 1 gm/cm² (10 kg/m²). Based on the data collected to date, July appears to have been the peak period in terms of veliger densities and rate of mussel accumulation on monitoring substrates at this field site.

Conn, David Bruce, Kimberly A. Shoen, and Soo-Jin Lee
Department of Biology, St. Lawrence University

THE SPREAD OF THE ZEBRA MUSSEL, *DREISSENA POLYMORPHA*, IN THE ST. LAWRENCE RIVER, AND ITS POTENTIAL INTERACTIONS WITH NATIVE BENTHIC BIOTA

Beginning in October, 1989, zebra mussels, *Dreissena polymorpha*, were discovered attached to various substrates in and around the Snell Lock of the St. Lawrence Seaway at Massena, New York. Subsequent studies revealed no mussels on substrates examined throughout the approximately 160-kilometer stretch of the St. Lawrence River upstream from the locks at Massena, while substrates downstream from that site harbored many mussels. These results suggested that the zebra mussel colony near the locks at Massena did not become established from natural dispersal downstream from Lake Ontario, but more likely from ballast being dumped into the river by a ship going through the locks. The present study was designed to monitor the movement of zebra mussels into the section of the St. Lawrence River upstream from Massena, and to gather baseline data on benthic macroinvertebrates that might be affected by this invasion.

Between September, 1990 and August, 1991, benthic macroinvertebrates were collected from 60 sites along the upper 180 km of the St. Lawrence River. Collections were made by hand from both hard and soft bottoms and from aquatic macrophytes, mostly in shallow nearshore waters. Other collections were made from navigational buoys and their anchors in the river's channel, and by SCUBA dives in deeper waters. Plankton samples were taken from most of the sites using a 63mm mesh plankton net.

A few newly settled zebra mussels were found attached to rocks at a site approximately 1 mile upstream from Massena. No newly settled or adult zebra mussels were found at any site farther upstream, despite the fact that other researchers reported isolated colonies at Cape Vincent, New York (at the river's outflow from Lake Ontario) and Prescott, Ontario (halfway between Lake Ontario and Massena). No veligers were found in plankton samples taken upstream from Massena.

Native molluscs collected included 26 snail species (Gastropoda), and numerous unionid and sphaeriid clams (Pelecypoda). Unionid clams near the Massena site were frequently covered on their posterior (siphonal) ends with zebra mussels; many heavily covered unionids were dead. Insects collected represented 9 orders and 27 families. The number of families of each order were: 7 Trichoptera (caddisflies), 5 Coleoptera (beetles), 4 Hemiptera (true bugs), 4 Ephemeroptera (mayflies), 3 Odonata (dragonflies & damselflies), 1 Megaloptera (dobsonflies), 1 Diptera (true flies), 1 Hymenoptera (wasps), and 1 Lepidoptera (moths). Amphipod crustaceans were abundant, but isopods, crayfishes, sponges, bryozoans, *Hydra* and flatworms generally occurred in smaller numbers. The most abundant animals were caddisflies of the families Brachycentridae and Hydropsychidae. These insects require clean flowing water for feeding, and hard substrates for attachment. Because these requirements closely parallel those of *D. polymorpha*, strong competition may result as the latter spreads through the river. The results of such competition might have a negative impact on sport fishes that feed heavily on the insects.

This study was supported by grants from the Pew Charitable Trusts and St. Lawrence University.

Crawford, Gary W., Jon J. Mojares, James U. Walker, and Jeffrey L. Ram
Department of Physiology, Wayne State University

ZEBRA MUSSEL SPAWNING INDUCED BY SEROTONIN: VIDEO RECORDING OF SPERM AND EGG EJECTION AND SUBSEQUENT FERTILIZATION AND DEVELOPMENT

As reported elsewhere (Ram et al., this volume of abstracts) spawning of both male and female zebra mussels can be induced by external application of 10^{-3} M serotonin (5-HT). Video recording illustrates several features of the induced behavior and resultant gametes. Within 15 min of 5-HT application to males, sperm began to appear in a narrow "jet" from the excurrent siphon. This well-defined stream extended at least 15 mm from the spawning animal (the limit of the small vials used). Animals continued to expel sperm for an hour or more, in some cases producing enough sperm to obscure the spawning animal in the 10 ml total volume in which experiments were done. Similarly, eggs appeared in the excurrent stream of females within one and a half hr of 5-HT application. In some females, eggs were expelled with larger particulates, resembling gonadal fragments of ovarian tissue. Although valve closures and openings were repeatedly observed in spawning animals, this behavior does not appear to be directly involved in expulsion of gametes, since gametes were continuously ejected while valves were apart and siphons open. In the small vials in which experiments were done, a portion of the discharged eggs and sperm were drawn into the incurrent siphon, a phenomenon which may account for con-specific offspring suppression by zebra mussels, as described by MacIsaac & Sprules (1st Int. Zeb. Mus. Res. Conf., 1990). Projection of gametes to a distance from spawning animals in the observed jet streams may be a way of countering this tendency to offspring ingestion.

Eggs and sperm spawned in response to 5-HT were examined with videomicroscopy. Sperm swam actively. Within 2 hr of adding sperm to released eggs, many of the eggs began to show signs of fertilization: double nuclei, cleavage, and, in some instances, four divisions containing separate nuclei, etc. These observations indicate that viable gametes can be produced by 5-HT-induced spawning.

French, John R.P., and Michael T. Bur
U.S. Fish and Wildlife Service, National Fisheries Research Center—Great Lakes

FRESHWATER DRUM (*APLODINOTUS GRUNNIENS*), A PREDATOR OF THE ZEBRA MUSSEL IN LAKE ERIE

Freshwater drum (*Aplodinotus grunniens*) are considered major mollusk predators because they possess molariform pharyngeal teeth used to crush shells. However, mollusks were not found to be an important food of Lake Erie freshwater drum in the 1960-1980 period when they comprised less than 7% of the benthic communities in the western part of the lake. The European zebra mussel (*Dreissena polymorpha*) established a population in the late 1980s and became one of most abundant macroinvertebrates in western Lake Erie. We conducted a study to determine if these mollusks had become a major food of freshwater drum. We collected drum from 22 stations in the western basin of the lake and examined their gut contents in May, July, and September 1990. Freshwater drum did not feed significantly on zebra mussels until they were at least 250 mm long. Predation on zebra mussels increased as drum size increased. Medium-sized drum (250 to 374 mm long) fed mainly on dipterans in May and shifted their diets to zebra mussels in July and small fish in September. Large drum (over 375 mm long) fed almost exclusively on zebra mussels throughout the collection season. Since freshwater drum over 375 mm long feed heavily on zebra mussels, they should be considered as one component of a zebra mussel control strategy. We recommend that management agencies consider regulatory and public education options for increasing the population of large freshwater drum in Lake Erie to improve the likelihood of greater predation pressure on zebra mussels.

Nichols, Susan J.
U.S. Fish and Wildlife Service, National Fisheries Research Center—Great Lakes

DETERMINING THE SEX AND REPRODUCTIVE STATUS OF ZEBRA MUSSELS

Determining sex ratio and reproductive status of zebra mussels can provide useful information on when veliger production will begin and a general estimate of overall numbers. The reproductive status of a mussel is determined by removing a portion of the combined digestive-reproductive tract, and examining this material under a microscope. Zebra mussels fall into four categories—male, female, hermaphrodite, or immature (unidentifiable). The ratio of male-to-female, as well as the degree of hermaphrodism, varies considerably from colony to colony. Immature is a term used to describe mussels whose gametes are not differentiated at this time, regardless of shell size or previous spawning record. The general appearance and size of the gametes found during dissection indicates when spawning will occur. Mature females contain eggs showing both nuclei and germinal vesicles. However, although eggs can show both nuclei and germinal vesicles at a size of 0.030 mm, these eggs must reach over 0.060 mm before spawning occurs. Mature males contain sperm that are triangular in shape, less than 0.01 mm in size, with multiple tails. Sperm are not released until they are triangular in shape as well as tailed. In general, it takes about 8 to 10 weeks at 20°C for an immature mussel, with no distinguishable gametes, to develop fully ripe gametes.

Thorp, James H., and Kim H. Haag
University of Louisville, Water Resources Laboratory

USE OF A RIVERINE MESOCOSM TO STUDY THE ENVIRONMENTAL TOLERANCES OF ZEBRA MUSSELS IN LOTIC ECOSYSTEMS

There is a paucity of information on the biology and impact of zebra mussels in rivers. In Europe, where *Dreissena* is well established, the polluted condition of many lotic habitats has presumably limited riverine populations. In the United States, the zebra mussel has only recently spread from lacustrine ecosystems to rivers draining into the Gulf of Mexico and Atlantic Ocean. Significant differences in environmental conditions existing in rivers versus lakes make it inadvisable to rely solely on available data from lakes when predicting impacts of zebra mussels in rivers.

To overcome this lack of applicable data we have designed an outdoor, flow-through riverine mesocosm to study the environmental tolerances of zebra mussels in lotic ecosystems. The initial phase consists of forty PVC troughs with a maximum depth of 4 inches and a length of 10 feet. After entering a head tank, untreated water from the nearby Ohio River is pumped through the individual troughs at an "average" current velocity of 0.1 m/sec. From 50 to 75% of the water is recirculated, to reduce the required pump capacity. Waste water from the system is pumped through a mixed-media filter, treated with high concentrations of chlorine, and then sent to a holding lagoon. Channels are colonized with adult zebra mussels attached to removable, unglazed ceramic tiles at various densities (4000/m^2 in an initial study).

We are conducting studies to determine effects of temperature on the biology of *Dreissena* and the effects of zebra mussels on native mussels. For the thermal experiments, ten replicates of 3 different temperature regimes are being run: ambient (corresponding to the average weekly temperature at the intake pipe on the Ohio River); 25% lower than ambient; and 25% higher than ambient. Dependent variables in this 18-month temperature experiment are percent survival, growth rate, and patterns of reproduction.

We are also building an indoor, 100% recirculating mesocosm which will use untreated water from the Ohio River. Initial studies will examine the effect of current velocity on settling of postveligers. A headtank will be colonized by adults and temperatures will be maintained at 18–20°C. Veligers will be circulated through the channels at current velocities of 1.0–2.0 m/sec. Glass slides and other substrates will be placed in the channels and examined semiweekly to determine settling frequency.

Yankcovich, Tamara Lynn and G.D. Haffner.
Department of Biological Sciences, Great Lakes Institute, University of Windsor

INFLUENCE OF POPULATION AGE STRUCTURE ON THE TOXICOKINETICS OF THE ZEBRA MUSSEL, *DREISSENA POLYMORPHA*

Field and laboratory observations indicate that *Dreissena polymorpha* colonization strategies, both on natural substrates and artificially-placed substrates, such as cement blocks, are dependent on population densities and age structure. Size frequency distributions of populations illustrate that habitat selectivity declines with increasing population density. It is likely that selective preferences are related to *Dreissena*'s filtering mechanism, where a "better" position equates to more food. Filtration represents a critical mechanism by which chemicals are bioaccumulated in organisms such as zebra mussels. Additional investigations are currently underway in order to determine the filtering rate and calibrate the chemical dynamics of *Dreissena polymorpha* in the laboratory and in the field. Once calibrated, this information will be used to index the toxicokinetics of *Dreissena polymorpha* with reference to population age structure and mussel orientation on substrate.

ADDENDUM

THERMAL BACKFLUSHING TO CONTROL ZEBRA MUSSELS AT STEAM STATION

E.F. Neuhauser[1]
M.A. Rhode[1]
J.J. Knowlton[2]
R.J. Wahanik[2]
M. Borden[2]
D.P. Lewis[3]
G. Mackie[4]

ABSTRACT

Other than thermal treatment, the use of various chemical treatments to control zebra mussels (Dreissena polymorpha) in both the U.S. and Canada is well documented and appears to be effective under a number of different protocols. However, concerns over the potential impact of these treatments to receiving water bodies has motivated industry to investigate alternative or complementary control approaches. The control of zebra mussels by thermal treatment is an alternative approach to chemical treatment which may be effective while producing minimal harm to the environment.

To remove the zebra mussel infestation in the circulating water system at Niagara Mohawk Power Corporation Dunkirk Steam Station, it is proposed to increase the temperature of the intake water used for steam condenser cooling from 55-65°F (13-18°C) to at least 95°F (35°C). The construction of the circulating water system at the Dunkirk Station is such, that by adjusting some of the gates in the system, it is possible to redirect the main condenser heated discharge water back to the intake structure and to the screenhouses instead of discharging into the harbor. This redirecting of the condenser discharge water to the intake structure/screenhouse has resulted, during previous treatments, in an increase in circulating water intake temperatures to at least the anticipated temperatures required to kill zebra mussels. To prevent equipment damage, the maximum intake temperature will be limited to approximately 100°F (38°C).

Biological and temperature monitors were placed throughout the circulating water system. These monitors were used to first establish a control base of mussels present at Dunkirk Station prior to thermal treatment implementation and then to monitor mussel activity associated with temperature changes.

This Research and Development project to control zebra mussels by thermal treatment at Niagara Mohawk Power Corporation's Dunkirk Steam Station yields results which can be used in several ways. The main goal of this project is to follow up on the experience gained during previous thermal treatments and to establish a controlled study base using sound experimental technologies. The main benefits from the project are the applicability of the results to similarly designed power generating stations and the potential use for the design of new generating facilities.

1. Niagara Mohawk Power Corporation, Syracuse, New York
2. Gilbert/Commonwealth, Inc., Reading, Pennsylvania
3. Aquatic Sciences Inc., St. Catharines, Ontario
4. Mackie and Associates Water Systems Analyst, Guelph, Ontario