US Army Corps
of Engineers
Waterways Experiment
Station

Zebra Mussel Research Technical Notes

Section 2 — Control Methods

Technical Note ZMR-2-14

May 1994

Review of Zebra Mussel Control Methods

Background and purpose

There is a large and varied body of literature, from Europe and more recently from North America, describing the relative merits of chemical and nonchemical macrofouling control technologies for zebra mussels. (Reviews of this literature are given in Shtegman 1986, McMahon 1990, and Jenner and Janssen-Mommen 1993.)

The purpose of this technical note is to examine the technologies and application methods presently used to control zebra mussel macrofouling in raw water systems, as well as the potentially efficacious emerging technologies not yet fully tested or implemented. Information on control technologies discussed in this technical note was developed principally from reviews by McMahon (1990), Jenner and Janssen-Mommen (1993), and Miller and others (1992) and from the personal experience of the authors in the control of zebra mussel macrofouling.

Additional information

This technical note was written by Dr. Robert McMahon, Mr. Thomas A. Ussery, and Mr. Michael Clarke, Center for Biological Macrofouling Research, University of Texas at Arlington. For more information, contact Dr. McMahon, (817) 273-2412. Dr. Ed Theriot, U.S. Army Engineer Waterways Experiment Station, (601) 634-2678, is Manager of the Zebra Mussel Research Program.

Systems susceptible to zebra mussel infestations

Systems that are susceptible to zebra mussel infestation include those associated with management and control of inland waterways (including navigation structures, water level control structures, vessel locks, stream level gauging stations, pumping stations, and drainage structures) and those raw water systems used in potable water treatment, agricultural systems, industry, and power generation (including intake structures and cooling water, irrigation, and fire protection systems) (Table 1). Efficacious technologies for control of zebra mussel fouling must be developed for each of these systems.

Mitigation and control technologies for zebra mussel macrofouling in facilities that use raw water can be divided into several major categories, including off-line intermittent strategies and on-line intermittent or continuous strategies.

Prepared and published by the Zebra Mussel Research Program, U.S. Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

PRINTED ON RECYCLED PAPER

Table 1. Raw Water System Components Possibly Fouled by Zebra Mussels

Lock Structures

- Air vents
- Lock walls
- Level gauges
- Miter gates
- Bubbler systems
- Bulkhead slots
- Grating and screening
- Water culverts
- Fire protection systems
- Intake trash screens
- Gauging systems with small-diameter piping and openings
- Valves
- Smaller diameter piping
- Auxiliary locks
  - Low water flow when unused
  - May allow rapid accumulation of mussel encrustations

Problems: Blockage of water flow; corrosion of metallic surfaces; prevention of operation; poor sealing; increased weight; erosion and abrasion; increased maintenance; unbalanced forces; disposal of mussels

Navigation Dams

- Dam gates
- Rubber side seals on dams
- Dam gate interiors
- Drains
- Roller gate tracks, chains, cables
- Pier nose
- Wickets

Problems: Abrasion of seals; increased gate weight; corrosion of metallic surfaces; poor flow distribution; flow blockage; prevention of operation; prevention of wicket lifting

Stream Level Gauging Systems

- Blockage of intake pipe openings
- Fouling of gauge mechanisms

Problems: Improper gauging; blockage; corrosion of metallic surfaces; increased maintenance

Reservoir Level Control Structures

- Trash booms
- Trash racks
- Bulkheads
- Gates
- Water quality wet wells
- Conduits and piping
- Culverts
- Valves

Problems: Abrasion of seals; increased gate weight; corrosion of metallic surfaces; poor flow distribution; flow blockage; prevention of operation; sinking of floating structures

Pumping Stations

- Flap gates
- Suction bells
- Sump walls
- Impellers
- Discharge and intake piping

Problems: Inoperable flap gates; increased loads on pumps, causing bent shafts; abrasion of bearing surfaces and impellers by shell fragments; vibration of impeller causing wear on bearings; flow reduction in piping

(Continued)

Table 1 (Continued)
Drainage Structures ● Piping and conduits ● Stop logs ● Inflatable dams ● Trash booms ● Culverts (continuous flow) ● Trash racks and grating **Problems:** Corrosion of metallic surfaces; flow restriction; flow blockage; prevention of operation; sinking of floating structures
Intakes for Municipal and Agricultural Water Facilities and Fossil-Fueled, Hydropowered, and Nuclear Electric Power Stations ● Traveling screens ● Intake tunnels and discharge tunnels ● Valve seats and plates ● Embayment walls ● Stationary trash racks ● Trash booms ● Pump intake housings and pump impellers ● Cement and rock surfaces in irrigation canals ● Bulkhead slots ● All exposed hard surfaces **Problems:** Blockage of flow; corrosion of metallic surfaces; prevention of operation; poor sealing; increased structural weight; erosion and abrasion of seals; increased maintenance; unbalanced forces; disposal of mussels; poor flow distribution; sinking of floating structures; increased loads on pumps, causing bent shafts; abrasion of bearing surfaces and impellers by shell fragments; vibration of impeller causing wear on bearings

Raw Water Systems in Municipal and Agricultural Water Facilities and Fossil-Fueled, Hydropowered, and Nuclear Electric Power Stations
● Large-diameter piping (reduction in pipe diameter)
● Dead-end piping
● Low-flow piping <2 m/sec
● Small-diameter piping (flow reduced or prevented)
  • By single shells
  • By clusters of shells
● Heat exchangers
● Pipe bends
● Water boxes and tube sheets
● Exchanger tubing
  • By single shells
  • By shell clusters
● Valve plates and seats
● Joints of unequal pipe diameter
● Pipe bends
● Reservoir tanks
● Fire protection systems
● Underground distribution piping
● Sprinkler nozzles
● All small-diameter piping systems
Problems: Blockage of flow; corrosion of metallic surfaces; prevention of operation; poor sealing; increased weight; erosion and abrasion; increased maintenance; unbalanced forces; disposal of mussels

(Continued)

Table 1 (Concluded)

Navigable Waterways

- Navigation buoys
- Boat hulls
- Vessel engine cooling systems
- Port structures

Problems: Blockage of flow; corrosion of metallic surfaces; prevention of operation; increased structural weight; erosion and abrasion of seals and bearings; increased maintenance; disposal of mussels; sinking of floating structures (buoys)

When implementing the off-line, intermittent strategies (outlined in Table 2), systems or structures are periodically taken out of service and treatment applied to remove mussel infestations before they reach levels severely impacting operation. For the on-line, intermittent or continuous strategies (outlined in Table 3), mussel mitigation or control treatments are applied without disrupting system operation.

Treatment technologies can be further divided into "chemical" and "nonchemical" technologies, and chemical technologies can be further subdivided into those involving application of "oxidizing" as opposed to "nonoxidizing" molluscicides (Table 4).

Table 2. Candidate Technologies for Intermittent, Off-line Mitigation of Zebra Mussel Fouling in Intakes and Raw Water Systems

Candidate Off-line Technologies:

- Manual removal*
- Robotics*
- Pigging*
- High-pressure water jetting*
- Penetrants and surfactants
- Chemical cleaning (limited applicability)*
- Abrasive blast cleaning
- Exposure to hypoxia/anoxia*
- Dewatering and desiccation*
  - Below 30°C kill time is temperature and relative humidity dependent
  - Heated air treatment (rapid kill above 35°C)
- Thermal treatment
  - > 32°C is lethal, 36°C is instantaneous
  - Steam injection
  - Localized heating systems
  - Thermal backwash or recirculation
- Molluscicides (oxidizing and nonoxidizing)*

Advantages of Off-Line Mitigation Technologies:

- Cost-effective
- Minimal environmental impact

Disadvantages of Off-Line Mitigation Technologies:

- Allows mussels to build up in system
- Removal and disposal of shells
- Downtime can be extensive
- Can be labor intensive

*Most applicable to Corps facilities.

Table 3. Candidate Technologies for On-line Mitigation and Control of Zebra Mussel Fouling of Intakes and Raw Water Systems

Candidate On-line Technologies:

- Robotics*
  - Robotic surface cleaners*
  - Robotic pipe cleaners*
  - Robotic pigging systems*
- Electrifying of metal surfaces
- Toxic coatings*
  - Hot metallic sprays*
  - Copper or zinc*
  - Paints or coatings*
    - Copper or zinc*
    - Molluscicide impregnated*
- Toxic construction materials*
  - Copper, brass, galvanized piping*
  - Toxic metal pipe inserts*
- Nontoxic (silicone-based) foul-release coatings*
  - Prevent strong byssal attachment
  - Must be replaced every 2 to 5 years
  - Application can be expensive ($15 to $50 per square yard)
- Penetrants and surfactants
- Sand filtration systems*
  - Submerged infiltration beds*
  - Onshore backwash systems*
- Disposable substrates*
  - Netting*
  - Coverings*
  - Inserts*
- High-voltage electric fields
  - 600 V/cm^2, 36 MW/5,000 gal
- Hypoxia/anoxia*
- Strainer systems*
  - Fixed*
  - Centrifugal*
  - Installation may be expensive
- Molluscicides (oxidizing & nonoxidizing)*
  - Intermittent application*
  - Continual application*
- Thermal treatment*
  - > 32°C is lethal, > 40°C is instantaneous
  - Localized heating*
  - Steam injection*
  - Thermal backwash or recirculation*
- Ultraviolet light
- Ultrasonics and high-intensity sound

Advantages of On-line Intermittent or Continuous Technologies:

- Continuous application prevents any fouling
- Not labor intensive
- Reduces downtime

Disadvantages of On-line Intermittent or Continuous Technologies:

- Increased environmental impact
- May be less cost-effective
- May involve extensive downtime

*Most applicable to Corps facilities.

Table 4. Molluscicide Applications for Mitigation and Control of Zebra Mussel Macrofouling

Treatment	Application	Effect
Oxidizing Molluscicides		
Chlorination (adults)	0.5 ppm for 7 days 0.3 ppm for 14-21 days	75% kill > 95% kill
Chlorination (adults)	2-ppm continuous flow-through	90% kill
Chlorine dioxide	0.5 ppm for 24 hr	100% veliger kill
Chloramine	1.2 ppm for 24 hr	100% veliger kill
Ozone	1.5 ppm applied continuously	Prevents settlement
Cyanuric acid	2,000 ppm for 17 days	50% kill
Metallic Molluscicides		
Potassium ions (KH_2PO_4) (KOH) (KCL)	 160-640 ppm continuous > 10 ppm 50 ppm for 48 hr	 100% kill 100% veliger kill 100% kill
Tri-butyl tinoxide	Surface coatings reapplied every 1-2 years	High success
Copper ions	5 ppm for 24 hr	100% kill
Silver ions	5 ppm for 24 hr	72% kill
Mercury ions	5 ppm for 24 hr	57% kill
Zinc ions	5 ppm for 24 hr	5% kill
Lead ions	5 ppm for 24 hr	0% kill
Copper sulphate	100 ppm for 5 hr at 22.5°C 300 ppm for 5 hr at 22.5°C	40% kill 55% kill
Nonoxidizing Molluscicides		
Dichloro-2' nitro-4' salicylanilide	0.05 ppm for 24 hr 0.1 ppm for 24 hr	70% kill 100% kill
N-triphenyl-methylmorpholine	0.5 ppm for 24 hr 0.9 ppm for 24 hr	70% kill 100% kill
Poly[oxyethylene-(dimethyliminio)-ethylene(dimethyl-iminio) ethylene dichloride]	0.3 ppm for 826 hr 1.2 ppm for 313 hr 4.8 ppm for 197 hr	100% kill 100% kill 100% kill
2-(thiocyanomethylthio)-benzothiazole	0.15 ppm for 758 hr 0.6 ppm for 313 hr 1.2 ppm for 260 hr	100% kill 100% kill 100% kill
Dimethylbenzyl ammonium chloride & Dodecylguanidine hydrochloride	1.95 ppm for 12 hr at 11°C 1.95 ppm for 14 hr at 14°C 1.95 ppm for 6 hr at 20°C 1.95 ppm for 14 hr at 20°C	100% kill after 48 hr 100% kill after 48 hr 100% kill after 24 hr 100% kill after 48 hr
Didecyl dimethyl ammonium chloride	1.0 ppm for 24 hr	100% kill

(Continued)

Table 4 (Concluded)		
Treatment	**Application**	**Effect**
Nonoxidizing Molluscicides (Continued)		
Akyldimethylbenzyl ammonium chloride & akyldimethylethylbenzyl ammonium chloride	10.0 ppm for 48 hr 20.0 ppm for 48 hr	100% kill after 144 hr 100% kill after 72 hr
Endod (plant extract)	15 ppm continuous	100% kill
1,1',-(methyliminio)bis (3-chloro-2-propanol), polymer with N,N,N',N'-tetramethyl-1, 2-ethanediamine and potassium ion	0.75 ppm for 1295 hr at 20°C 2.25 ppm for 346 hr at 20°C 0.75 ppm for 1295 hr 2.25 ppm for 633 hr	100% kill SL* < 11 mm 100% kill SL* < 11 mm 100% kill SL* > 14 mm 100% kill SL* > 14 mm
*Shell length.		

In all cases, when developing zebra mussel mitigation or control strategies for public facilities on inland waterways, Federal and state environmental regulatory agencies are likely to require evidence that they will cause minimal impact to the biotic and/or abiotic environment. Thus, when developing and implementing zebra mussel control strategies, potential environmental impacts could require equal or greater consideration than efficacy and cost-effectiveness (McMahon 1990).

Off-line technol ogies

Off-line, intermittent zebra mussel mitigation and control strategies are based on periodic application of treatments designed to eradicate existing mussel infestations when a fouled system is out of service. The success of these strategies is based on periodic mitigation of existing zebra mussel infestations at a frequency that prevents their development to levels that could negatively impact operations.

Off-line, intermittent strategies are particularly appropriate for structures such as navigation locks or raw water intakes, where infestations do not seriously affect operations until a minimal threshold level of fouling is surpassed. Such treatments are most cost-effective when they can be matched with regularly scheduled maintenance outages or mussel settlement patterns.

Available off-line, nonchemical technologies presently used to mitigate zebra mussel fouling include manual removal by scraping, removal with high-pressure water jets (hydrolazing), and thermal shock treatment and line pigging.

For thermal shock treatments, 32°C is lethal within 5 hr, while 36°C is instantaneously lethal (Jenner 1983a, Jenner and Janssen-Mommen 1993). Thermal treatment can be affected by recirculating heated effluents into intakes (by reverse-flow of heated discharge water through raw water systems) (Jenner and Janssen-Mommen 1993) or by specialized heating of specific components (for example, steam injection, hot water injection, or use of heating elements) (Miller and others 1992).

Pigging systems involve forcing plugs (pigs) through mussel-infested lines to scrape mussels from pipe walls, forcing them out an opening in front of the advancing pig. Pigs may be forced through lines by pressure or by hauling on cable systems (McMahon 1990).

Emerging nonchemical technologies not yet fully developed or implemented for off-line intermittent zebra mussel control include automated robotic cleaners for removing mussel infestations on intake surfaces and within large- and small-diameter piping systems (Mussalli and Tsou 1988), dewatering of structures, exposing mussels to air, causing death by desiccation or freezing, and exposure to anoxia or hypoxia, which has been used effectively against Asian clams (*Corbicula fluminea*) (Smithson 1986).

The number of presently available off-line intermittent chemical control technologies for zebra mussels is limited. All oxidizing and nonoxidizing chemical control agents potentially useful against zebra mussels are listed in Table 4. The most commonly used molluscicide against zebra mussels is chlorine. Recommended levels are 0.3 to 0.5 ppm total residual chlorine (TRC) for 7 to 21 days to mitigate adult populations (Greenshields and Ridley 1957; Jenner 1983a,b) (Table 4).

Application of chlorine at higher concentrations can reduce the duration of treatment required for 100-percent mussel mitigation (Lewis 1990). A second chemical successfully used in mitigation of zebra mussel infestations is a combination of dimethylbenzyl ammonium chloride and dodecylguanidine hydrochloride, which at 1.95 ppm can produce 100-percent kills within 48 hr (Lyons and others 1990).

Other molluscicides for which preliminary testing indicates potential efficacy in mitigating zebra mussel infestations include the **oxidizing molluscicides** chlorine dioxide, chloramine, bromine, and ozone and the **nonoxidizing molluscicides** poly[oxyethylene-(dimethyliminio)ethylene(dimethyliminio) ethylene dichloride]; 2-(thiocyanomethylthio) benzothiazole; didecyl dimethyl ammonium chloride; a mixture of akyldimethylbenzyl ammonium chloride and akyldimethylethylbenzyl ammonium chloride; *Endod saponins* (soapberry plant extract); and 1,1’,-(methyliminio)bis(3-chloro-2-propanol), polymer with N,N,N’,N’-tetramethyl-1, 2-ethanediamine; and potassium ion (K^+) (Table 4).

The advantages of off-line, intermittent mitigation of zebra mussel infestations are that it can be cost-effective through minimization of manpower and chemical requirements and that release of biocidal chemicals to the environment in once-through systems is periodic, reducing environmental impact.

The disadvantages are associated with the periodic buildup of mussel infestations between treatments and include system performance losses and degradation, mussel removal and disposal problems after treatment, economic loss due to downtime associated with treatment, and where manual scraping or other manual forms of mussel removal are used, extensive labor costs (McMahon 1990, Miller and others 1992).

On-line technologies

On-line technologies for zebra mussel control are those which mitigate or control zebra mussel fouling in raw water systems while they remain operational (McMahon 1990). These technologies can be subdivided into intermittent treatments (which are directed toward periodic mitigation of existing infestations before they reach threshold levels that impact system operation) and continuous treatments (which prevent zebra mussels from becoming established within a system). As with off-line technologies, on-line technologies can be either chemical or nonchemical.

Among the available on-line nonchemical zebra mussel macrofouling control technologies, those most commonly used in Europe and the United States involve thermal treatments. Among large-scale systems, thermal treatment is particularly applicable to electric power generating facilities, which produce large volumes of heated effluent. On-line, intermittent recirculation or backwash of heated discharge waters through the raw water systems of these facilities has been used to eradicate mussel infestations before they affect system operation (>32°C is lethal) (Jenner 1983a, Jenner and Janssen-Mommen 1993). On a smaller scale, heating of specific components with hot water, steam injection, or installed heating devices could be used to protect specific fouling-sensitive systems from mussel infestation without impacting operation (Miller and others 1992).

Filtration systems have also been used to remove veligers from raw water intakes, eliminating downstream mussel fouling. Presently, onshore, backwashable sand filtration systems or submerged infiltration beds (that is, intake piping buried under a submerged infiltration field made up of successive layers of fine sand, coarse sand, and gravel) can eliminate veligers and juvenile mussels from intake waters. While these systems can be used to prevent zebra mussels from entering relatively low flow volume raw water facilities, they have not yet been adapted for use with high flow volumes, such as those characteristic of power station raw water systems. Instead, they may be most useful for control of mussel fouling in municipal potable water treatment, industrial, fire protection, and agricultural applications.

Strainer systems have not yet been developed to the point they can reliably remove settlement-competent zebra mussel post-veligers from raw water. However, the advent of zebra mussels in North America has spurred the development of this technology, making it likely that both fixed and centrifugal strainers capable of retaining settlement-competent veligers (>150 μm in shell diameter) will be marketed in the near future. Such strainers could be used to protect specific mussel fouling-sensitive components in raw water systems. Presently, strainer technology allows reliable removal of entrained juvenile and adult zebra mussels and mussel shell debris greater than 300 μm in diameter.

Another emerging nonchemical, on-line zebra mussel control technology involves silicon-based nontoxic foul-release surface coatings that protect systems from mussel fouling by covering them with a slick, unstable surface to which mussels cannot form firm byssal attachment (Mussalli and Tsou 1988). However, the present technology requires replacement of these coatings every 2 to 5 years, and application is relatively expensive (Mussalli and Tsou 1988).

Another technique likely to be used in the future for control of mussel fouling is disposable substrates. These are removable, dispensable structures that attract mussel settlement and thus protect the permanent structures into which they are installed from mussel fouling. Nets are placed in front of intake structures to attract settlement of post-veligers before they are entrained on raw water system flows (Szlauer 1974). Removable inserts could be used to protect bulkhead slots and similar submerged structures from mussel fouling (Miller and others 1992), and removable coverings could be placed over intake surfaces that require protection from mussel fouling.

Other on-line nonchemical zebra mussel control technologies that require further research and development include robotic cleaners, exposure to anoxia or hypoxia, and use of ultraviolet light or ultrasonic and high-intensity sound (Table 3).

Chemical on-line control technologies for zebra mussel macrofouling involve use of the same molluscicides described above for off-line chemical control (Table 4); however, chemical application occurs while the system is operational.

Chlorine is the molluscicide most commonly used for on-line control of mussel infestations. To periodically eradicate adult mussel infestations, continual application of chlorine at 0.3 to 0.5 ppm TRC for 7 to 21 days is recommended (Greenshields and Ridley 1957; Jenner 1983a,b).

The veliger and post-veliger larval stages are much more sensitive to chlorine than juvenile or adult mussels and can be inhibited from settlement by exposure to 2 ppm TRC for 30 min twice daily. Juvenile and adult mussels are not affected by intermittent chlorination at these levels because they close the valves for short periods to isolate their tissues from the lethal effects of chlorine (Claudi and Ackerman 1992, Evans and Simms 1992). Power stations on Lake Erie using twice-daily 30-min applications of 2-ppm TRC to control zebra mussel post-veliger settlement have recently reported development of mussel fouling problems due to settlement of translocating juvenile mussels entrained with intake water. To control fouling by translocating juveniles, these power stations have had to switch to continuous chlorination at >0.3 ppm TRC (Claudi and Ackerman 1992, Evans and Simms 1992).

Other oxidizing molluscicides potentially efficacious for on-line control of zebra mussel macrofouling include chlorine dioxide, chloramine, ozone, and hydrogen peroxide (Table 4).

The nonoxidizing molluscicide most commonly used for on-line mitigation of zebra mussel macrofouling is a combination of dimethylbenzyl ammonium chloride and dodecylguanidine hydrochloride. This molluscicide is used for periodic on-line mitigation of mussel infestations by application for periods of usually less than 48 hr at concentrations of less than 1.95 ppm. It is inactivated in discharge waters by the addition of bentonite clays, to which it becomes absorbed (Lyons and others 1990).

Also approved for use as a molluscicide in once-through cooling water systems is 2-(thiocyanomethylthio)benzothiazole. Recommended treatment strategy with this biocide is continuous application at a low concentration (<0.15 ppm) (Long, Erck, and Valenkamph 1990). There is little field trial information on the efficacy of the remaining nonoxidizing molluscicides listed in Table 4 against zebra mussels.

A number of metallic salts have been tested for toxicity to zebra mussels (Table 4). Of these, potassium (K^+) may have the greatest potential for use in on-line control of zebra mussel macrofouling (Fisher, Polizotto, and Schneider 1991). Potassium ion at 50 ppm will induce 100-percent kills of adult zebra mussels within 48 hr. Unfortunately, many native unionacean freshwater mussels are even more sensitive to potassium salts than are zebra mussels, making their use for control of mussel fouling in once-through raw water systems problematic.

Toxic substances may also be incorporated into paints and coatings to prevent zebra mussel fouling of exposed surfaces. Paints and coatings impregnated with copper and zinc have been shown to prevent post-veliger settlement (Table 4). These metals may be directly applied to metal surfaces as hot metallic sprays. However, they are more commonly applied to a variety of surfaces (metal, concrete, wood) as paints or other types of coatings (McMahon 1990, Miller and others 1992).

Piping systems constructed of copper, copper alloys, or galvanized piping are toxic to zebra mussels and therefore reduce the likelihood of fouling. Copper, zinc, or galvanized inserts may also be used to protect the openings of small-diameter piping from occlusion by zebra mussels (Miller and others 1992). However, piping constructed of toxic metals can still be fouled by mussels or groups of mussels translocated on water currents from upstream populations into pipe openings (McMahon 1990).

Another emerging on-line chemical control technology involves the development of surface coatings that are impregnated with molluscicides, such that the slow release of the molluscicide from the coating surface prevents post-veliger settlement.

A number of advantages are associated with on-line zebra mussel control technologies. These methods do not impact system operation. In cases were application is continuous, system degradation and corrosion associated with mussel fouling is prevented. Many on-line systems operate automatically with little requirement for manual manipulation, saving labor costs.

Disadvantages of on-line control technologies include the possibility of increased environmental impact resulting from continuous release of biocides into source waters; possible extensive costs associated with retrofitting of systems with on-line control equipment, reducing cost-effectiveness; and possible extended downtime, initially, to retrofit the systems for on-line controls (molluscicide application hardware, coatings, etc.).

References

Claudi, R., and Ackerman, J. D. 1992. "Post-Settlement Movements of Juvenile Zebra Mussels and Their Potential Impact on Plant Systems," Annual Meeting (26 April-1 May 1992, Nashville, TN), Reprint 341, National Association of Corrosion Engineers, Houston, TX.

Evans, D., and Simms, B. 1992. "Chlorine Minimization -Nanticoke Field Trials" (abstract)," *Second International Zebra Mussel Conference*, Toronto, Canada.

Fisher, S. W., Polizotto, K. R., and Schneider, B. 1991. "The Toxicity of Potassium Chloride to Zebra Mussel Veligers and Select Nontarget Organisms" (abstract), *Second International Zebra Mussel Research Conference*, Rochester, NY.

Greenshields, F., and Ridley, J. E. 1957. "Some Research on the Control of Mussels in Water Pipes," *Journal of the Institute of Water Engineers*, Vol 11, pp 300-306.

Jenner, H. A. 1983a. "Control of Mussel Fouling in the Netherlands: Experimental and Existing Methods," *Symposium on Condenser Macrofouling Control Technologies: The State of the Art*, I. A. Diaz-Tous, M. J. Miller, and Y. G. Mussalli, eds., CS-3343, Electric Power Research Institute, Palo Alto, CA, pp 18-1 - 18-13.

Jenner, H. A. 1983b. "Chlorine Minimization in Macrofouling Control in the Netherlands," *Water Chlorination: Environmental Impact and Health Effects*, Ann Arbor Science Publishers, Ann Arbor, MI, pp 1425-1432.

Jenner, H. A., and Janssen-Mommen, J. P. M. 1993. "Monitoring and Control of *Dreissena polymorpha* and Other Macrofouling Bivalves in the Netherlands," *Zebra Mussels: Biology, Impacts and Controls*, T. F. Nalepa and D. W. Schloesser, eds., Lewis Publishers, Ann Arbor, MI, pp 537-554.

Lewis, D. 1990. "Zebra Mussel Monitoring Strategies for Early Detection of Larvae and Effectiveness of Control Programs in Industrial Complexes," *International Macrofouling Symposium*, Electric Power Research Institute, Palo Alto, CA, pp 387-400.

Long, D. P., Erck, D., and Valenkamph, B. 1990. "Application of an Aromatic Hydrocarbon Molluscicide for the Mitigation of the Asian Clam, *Corbicula fluminea*, and a Polyquaternary Ammonium Compound as a Biological Control Agent for the Zebra Mussel, *Dreissena polymorpha*, for Potable Water," *International Macrofouling Symposium*, Electric Power Research Institute, Palo Alto, CA, pp 167-185.

Lyons, L. A., Petrille, J. C., Donner, S. P., Fobes, R. L., Lehmann, F., Althouse, P. W., Wall, L. T., Post, R. M., and Buerger, W. F. 1990. "New Treatment Employing a Molluscicide for Macrofouling Control of Zebra Mussels in Cooling Systems," *Proceedings, American Power Conference,* Vol 52, pp 1012-1021.

McMahon, R. F. 1990. "The Zebra Mussel: U.S. Utility Implications," EPRI GS-6995, Electric Power Research Institute, Palo Alto, CA.

Miller, A. C., Neilson, F., Payne, B. S., and McMahon, R. F. 1992. "Control Strategies Suitable for Zebra Mussel Infestations at Public Facilities," *Proceedings: Electric Utility Zebra Mussel Control Technology Conference,* TR-100434, prepared by Stone and Webster Environmental Services, Boston, MA, for Electric Power Research Institute, Palo Alto, CA.

Mussalli, Y. G., and Tsou, J. 1988. "Nontoxic Fouling Control Technologies: U.S and Japanese Perspectives," *Proceedings: Service Water Reliability Improvement Seminar,* Electric Power Research Institute, Palo Alto, CA, pp 103-128.

Shtegman, B. K., ed. 1986. *Biology and Control of Dreissena,* Israel Program for Scientific Translations, Ltd., IPST Cat. No. 1774, Jerusalem, Israel (available from National Technical Information Service, Springfield, VA, ISBN: 11-67-51396).

Smithson, J. A. 1986. "Development of a *Corbicula* Control Treatment at the Baldwin Power Station," *American Malacological Bulletin,* Special Edition No. 2, pp 63-67.

Szlauer, L. 1974. "Use of Steelon-net for Protection of the Hydro- engineering Works Against *Dreissena polymorpha* Pall.," *Pol. Arch. Hydrobiol.,* Vol 21, pp 391-400.