Cooling Water Intake Debris Management: Dreissenid Mussel Control Survey Results

Technical Brief — *Aquatic Resource Protection Program*

Introduction

An EPRI member survey was conducted to collect information on the impacts of and methodologies/technologies for controlling invasive Zebra and Quagga Mussels (*Dreissena polymorpha, Dreissena bugensis*, respectively) at various water-use facilities. The survey solicited information on:

- Facility type and design details
- Species of concern at each facility and risk of infestation
- Settlement and growth data
- Mussel-related impacts to facility operation
- Monitoring techniques
- Mitigation and control measures

In addition to a summary of the survey results, this Technical Brief provides an overview of the issues caused by Dreissenid biofouling at power plants, the current distribution within the U.S., and a summary which provides recommendations for choosing the most appropriate mitigation method for Dreissenids.

Issue

Zebra Mussels and Quagga Mussels are invasive freshwater mussel species that have infested lakes, reservoirs, and rivers in North America. Both species are prolific breeders and their early life stages can, under the right conditions, settle on submerged infrastructure (e.g., bar racks, gates, screens, pumps, instrumentation, pipelines, or other submerged surfaces). Once settled, they colonize and grow to adulthood, eventually developing into large communities. Depending on the location of settlement, they can disrupt water flow – impacting the operation and maintenance of hydropower, cooling water, drinking water, and other water intake systems or withdrawals.

Biofouling is a progression of growth which begins as microfouling (biofilms) that gives way to macrofouling (aggregations of larger organisms such as mussels and hydroids). Both must be mitigated to ensure the continuous reliable operation and integrity of industrial water intakes and distribution systems. Uncontrolled biofouling can impair operation and performance and can restrict intake water flow, bias monitoring equipment, block heat exchangers and cause a loss of heat transfer. This may lead to increased costs for control and corrective maintenance and lead to physical damage of equipment. If the biofouling results in blockage events, derates or forced outages of the facility may occur. Colonization of industrial water infrastructure by mussels and other macrofouling organisms is therefore a major concern and topic of considerable focus for industrial facilities and critical infrastructure all over the world, in any source water type.

Extent and Occurrence

Zebra and Quagga Mussel species originated from eastern Europe (Ukraine and Russia predominantly). The Quagga Mussel was, until the early twenty-first century, a slower invader than the Zebra mussel. The Quagga Mussel invaded the Great Lakes area of North America probably simultaneously with the Zebra Mussel around 1987, arriving most likely as larvae in ballast water. The Quagga Mussel was recognized for the first time in the Great Lakes in 1991.

Since their introduction into the United States, Dreissenid species have been documented in 131 river systems and 772 inland lakes, reservoirs, and impoundments (Benson et al., 2022, Benson, 2013, Karatayev et al., 2015) (Figure 1). For current distributions of Zebra Mussels throughout the United States and Canada, see the United States Geological Survey's (USGS) interactive point distribution map. The lack of natural ecological constraints (i.e., predators, parasites, and diseases) has rapidly expanded the Zebra Mussel's North American range (Ludyanskiy et al., 1993).

Modeling predicts that Dreissenids will spread much farther across North America but will ultimately be limited by extreme temperatures and lack of calcium. The most recent models disagree on how far the invasion will spread west of the Rockies, but it is predicted that Zebra Mussels will not spread to calcium-poor waters (such as those found in the Northeast and the Pacific Northwest, very cold waters, or very warm waters (Strayer, 2008)).

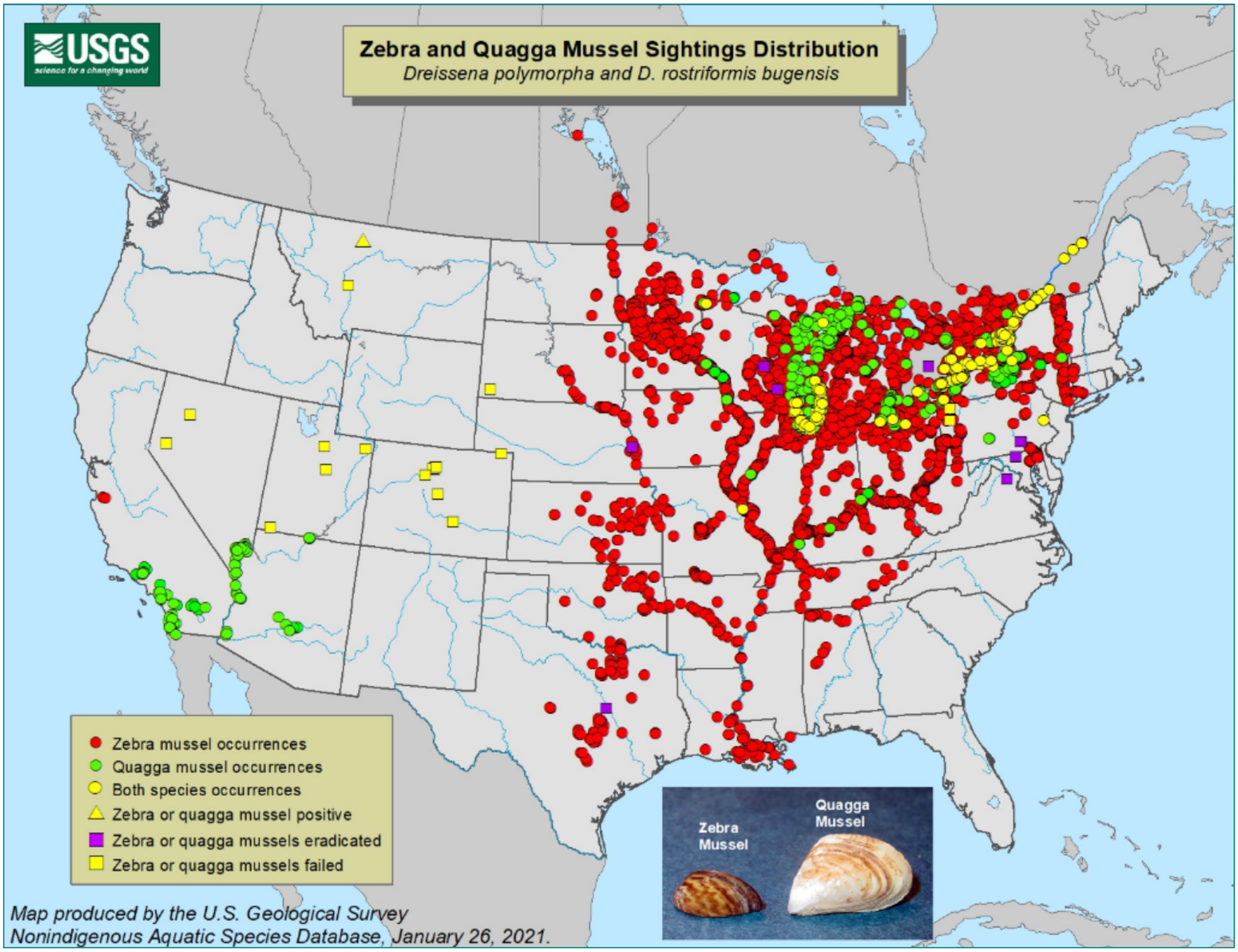

Figure 1. Current distributions (2021) of Zebra and Quagga Mussels in North America (Benson et al., 2022)

Survey Responses

The following sections summarize the survey responses received.

Species of Concern and Risk of Infestation

In total, there were 20 respondents to the survey, of which 19 represented steam electric power plants (fossil/nuclear, 18 in USA, one in Europe) and one hydropower facility (Table 1). For 17 of the respondents, Dreissenid biofouling is of concern due to their location on freshwater systems (cooling water intake flows varying between 11 – 3,170 million gallons per day (MGD)); this includes one retired power plant. The remaining two respondents are located on the coast and operate marine coastal power plants where Dreissenids do not occur.

The extent of the risk posed by the presence of Dreissenids in the cooling water source is related to the source water conditions (i.e., growth conditions), as well as the position of the intake and hydraulic conditions therein. As a result, Dreissenid biofouling can vary significantly among geographic locations; even between different facilities within the same source waterbody. These sorts of differences were reflected in the survey responses.

Regarding species of concern and their relative presence, 29% of respondents indicated Zebra Mussels (D. polymorpha) were present; 24% of respondents indicated both species (Zebra and Quagga Mussels [D. bugensis]) were present. The remaining 47% were unsure of the species or had no information available. Note that no respondents indicated only the presence of Quagga Mussels (Figure 2).

Table 1. Member responses ranked by risk of infestation

Location	Facility type	Risk of infestation	Species
Lake Erie (Michigan)	Fossil/Nuclear	High	*Dreissena polymorpha*
Mississippi River (Iowa)	Fossil/Nuclear	High	Both
Mississippi River (Wisconsin)	Fossil/Nuclear	High	Unsure
Missouri	Fossil/Nuclear	High	Unsure
Missouri River (Missouri)	Fossil/Nuclear	High	*Dreissena polymorpha*
Missouri River (Nebraska)	Fossil/Nuclear	High	Both
Missouri River (Nebraska)	Fossil/Nuclear	High	*Dreissena polymorpha*
Tennessee River (Tennessee)	Fossil/Nuclear	High	Unsure
Niagara River (New York)	Hydro	High	Both
n.a.	Fossil/Nuclear	High	n.a.
Europe (different rivers)	Fossil/Nuclear	High	Both
Lake Ontario (New York)	Fossil/Nuclear	Medium	Unsure
Lake Ontario (New York)	Fossil/Nuclear	Medium	Both
Mississippi River (Wisconsin)	Fossil/Nuclear	Medium	n.a.
Savannah River, Chattahoochee River, Altamaha River (Georgia)	Fossil/Nuclear	Medium	Unsure
Tennessee River (Alabama)	Fossil/Nuclear	Medium	*Dreissena polymorpha*
Lower Susquehanna River (Pennsylvania)	Fossil/Nuclear	Low	*Dreissena polymorpha*
NA	Fossil/Nuclear	NA	Unsure

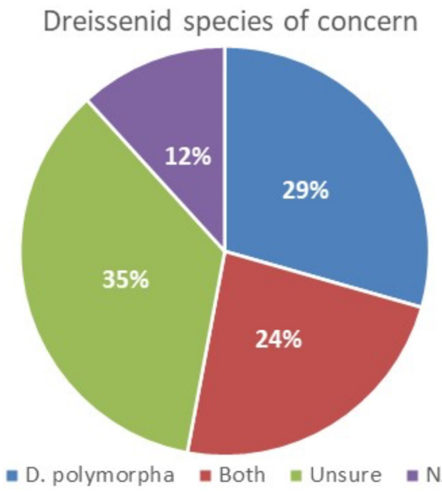

Figure 2. Responses from survey results indicating Dreissenid species of concern

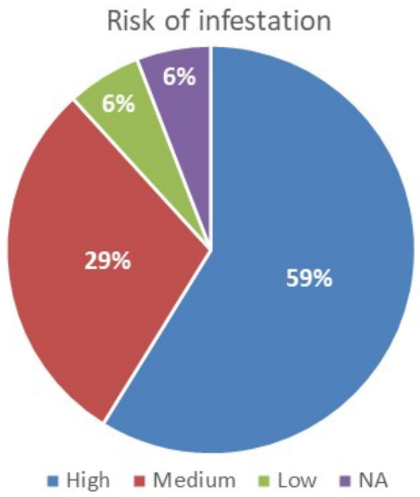

Figure 2. Responses from survey results indicating Dreissenid species of concern

The risk of infestation was assumed to mean the respondent's perceived risk of biofouling due to the presence of mussels in the source water. Approximately 59% regarded the risk as 'high' and 29% 'medium'. Only 12% of respondents perceived a 'low' risk of infestation (Figure 3).

Settlement and Growth

Dreissenid mussels have a distinct spawning season with differences between Zebra and Quagga Mussels. After spawning, both species have a planktonic development stage, which is followed by settlement by veligers ('spat') on submerged surfaces. Once settled, the specimens start to grow and develop a community. Understanding when peak settlement and/or growth occurs is key to implementing the most effective mitigation strategy. Mitigation efforts can be tuned to the seasonality of spat settlement (preventive approaches) and/or growth (corrective approaches) and will allow operators to plan mitigation approaches (e.g., starting up the dedicated chemical dosing (prevent/suppress settlement) or monitor densities and growth for corrective approaches). Peak settlement and growth vary based on geographic location and fluctuating environmental variables such as water temperature regimes and available nutrition. Increased monitoring assists in acquiring the necessary insights to these events.

The responses indicated that the duration of the settlement and growth periods varied between locations/sites. It was not possible from the responses to distinguish differences between Zebra and Quagga Mussels. Figure 4 shows the predominant periods of concern for settlement and growth in the U.S. based on the total number of responses for each individual month. Figure 4 reflects responses where at least 50% of the cases involved only Zebra Mussels and the remaining involved either both species or data were unavailable (species unsure). For Europe, respondents indicated a predominant period for settlement of April – July, and for growth of May – August.

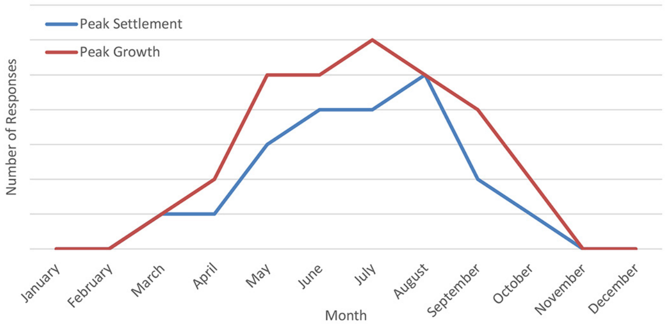

Figure 4. Responses from survey results indicating peak settlement and growth periods for Dreissenids experienced at participating US-based facilities.

Mussel Related Impacts

Dreissenid mussel fouling communities that develop on cooling water intake structures (CWIS) can have a direct impact on operation (e.g., impair flow) and can negatively affect the integrity of metal components (e.g., increase corrosion). Dreisennid mussels can settle on various intake components, including trash racks, traveling water screens, intake tunnels, forebays, and pumps. Mussels can also settle downstream of the intake system, i.e., in the circulating water system (e.g., service water systems, condenser waterboxes/tubesheets, heat exchanges, sponge ball strainers).

Approximately 36% of respondents recognized that mussels created an impact on operations (Figure 5). The main impact cited was plant derates due to suboptimal back pressure differential in condensers, as well the need for outages to remove large quantities of mussels. However, 50% of the respondents cited no direct impacts to operations.

Material integrity refers predominantly to corrosion of metal components (e.g., trash racks and other submerged CWIS structures like supports). Such corrosion is likely initiated by anaerobic conditions under the mussel community, especially when the layer of mussels is sufficiently thick to impair water circulation over long periods of time. Approximately 21% of respondents indicated that Dreissenid biofouling had an impact on corrosion at their facility. No impact was indicated in 50% of respondents, and 29% had no information available to share (Figure 6).

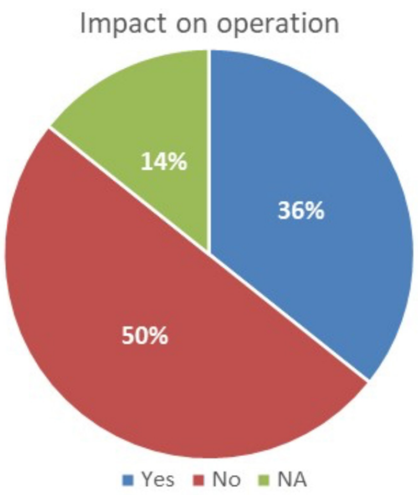

Figure 5. Responses from survey results indicating if Dreissenid biofouling communities had a direct impact on operation of infrastructure

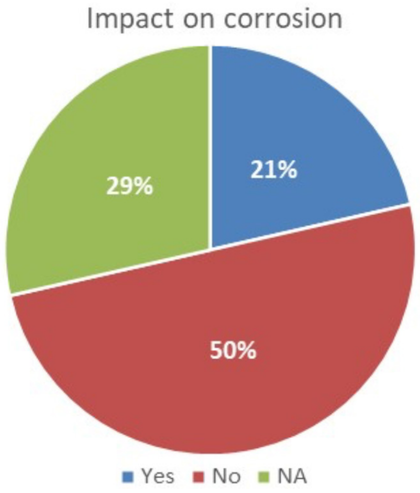

Figure 6. Responses from survey results indicating if Dreissenid biofouling communities caused corrosion of metal components

Monitoring

Dedicated, active monitoring is a critical component of a Dreissenid mussel mitigation strategy. Monitoring can be performed:

- In-field to detect presence in source waterbody and timing of veliger presence and settlement
- In-plant to directly observe settlement of larvae within the CWIS

Approximately 46% of respondents indicated they did not perform any kind of active monitoring and 15% had no available information to share on this topic (Figure 7). In 38% of cases, only field monitoring of source water was performed (as opposed to in-plant monitoring). Field monitoring is performed mainly through water sampling to either directly quantify veliger densities (e.g., plankton net tows) or indirectly to determine presence/absence of veligers via environmental DNA (eDNA). In one case, only water parameters were tested to determine if environmental parameters were conducive to veliger development. At locations where no dedicated Dreissenid mussel sampling is done, dedicated inspection of equipment during outages occurs (e.g., trash racks, pump bays). None of the respondents for the fossil/nuclear facilities indicated that in-plant monitoring was their method of choice for monitoring. The hydro facility does perform scheduled in-plant monitoring by means of a side-stream monitor implemented in the service water system. Although none of the respondents from thermal plants indicated that they do in-plant monitoring, we are aware of plants that do.

Note that the use of in-plant monitoring is a common approach in Europe to provide information on the timing of settlement, spat densities, and biofouling community development throughout the season. In addition, in-plant monitoring allows operators to assess mitigation efficacy. In-plant monitoring is applicable to all mitigation approaches.

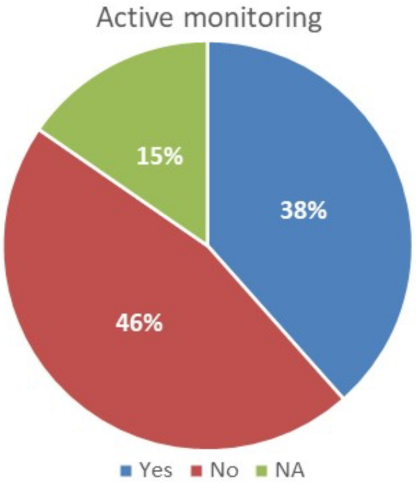

Figure 7. Responses from survey results indicating if active monitoring of Dreissenids was performed at their location. For those respondents that indicated yes, active monitoring consisted of field monitoring of source water only (no in-plant monitoring conducted).

Mitigation Strategies

Dreissenid mussel mitigation can be generally parsed into proactive strategies (prevent/reduce/control settlement of the veliger stage) and reactive strategies (mitigate/control the settled (juvenile/adult) fouling community). Approximately 44% of respondents use a combination of both proactive and reactive control methods, most often chemical treatment combined with manual removal (e.g., divers cleaning submerged parts or scraping mussels in dewatered onshore sections). In 19% of the cases, only a proactive (chemical) approach is applied and in 13% only a reactive (physical) approach (Figure 8). Four of the respondents (25%) did not provide any information on the mitigation strategy, where it is most likely some strategy is applied. Survey responses are further detailed in the following sections according to proactive versus reactive control methods.

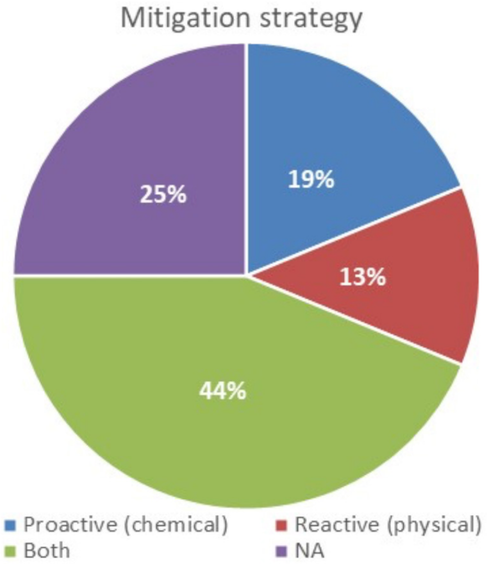

Figure 8. Responses from survey results indicating the mitigation strategy method used at participating facilities.

Chemical Control

The chemical approach is diverse, and in most cases an oxidant is used. A number of respondents identified only NaOCl (sodium hypochlorite) as their chemical of choice, while others apply a combination of chemicals (listed below). The dosing strategies were diverse, but predominantly periodic dosing is applied (referred to as periodic or intermittent), rather than continuous (note that even continuous dosing can be reactive when applied only for short periods [e.g., some days or weeks]). The periodicity of dosing varied from every 1 – 12 hrs on a daily or weekly basis to a few times per year for some chemicals.

The various chemistries noted in the survey results are listed below:

- NaOCl
- NaOCl + quaternary ammonium compounds (QACs)
- NaOCl + NALCO H150M (QACs) + Bromine
- NaOCl + NaOBr
- Bromine + NALCO H150M (QACs)
- Monochloramine + Clamicide

The use of chemicals, and the dosing strategy, are limited by the residual chemistry discharge limits imposed by the National Pollutant Discharge Elimination System (NPDES) permit in the U.S. Similar regulations in the EU regulate application of chemicals and biocides. However, tuning the chemical dose (e.g., by reducing the initial concentration, reducing number of scheduled doses, or providing longer intervals between dosing periods) to this permitted discharge limit may strongly affect the mitigation efficacy. This may explain why at most locations a combination of both chemical and manual removal strategies is used (i.e., despite chemical control, physical removal of settled biofouling communities is still required). Additionally, cost for bulk chemicals and dosing infrastructure seem to limit their use and affects the dosing strategy. Some strategies (e.g., dosing Clamicide and QACs) require a unit outage or rotation in to/out of service of individual systems which adds additional effort and costs to the mitigation strategy. For some chemicals, a post-treatment is required to reduce discharge impacts by residual chemistry (e.g., amines, QAC molluscicides).

Mechanical Control

The most common reactive strategy is manual removal of juvenile/adult fouling communities on submerged components by divers. Such efforts can only be performed during outages for diver safety reasons. At some locations, manual cleaning without the use of divers was indicated, requiring both plant outages and dewatering of the infested area and typically involves physical scraping as the method of removal. In some instances, manual cleaning was listed as the control method, though it was unclear whether it referred to manual cleaning done by divers, or by scraper (Table 2). At some locations, a thermal treatment is also used; however, the infrastructure must allow recirculation of heated effluent to the intake. In one case, thermal treatment was the sole control strategy as the NPDES permit did not allow chemical dosing. Figure 9 provides a summary of the various reactive mitigation strategies taken by participating facilities; approximately 25% rely on thermal treatment, 25% rely on manual removal techniques, which requires dewatering of the plant during outages (i.e., scraper cleaning), and 50% rely on divers as their mitigation method.

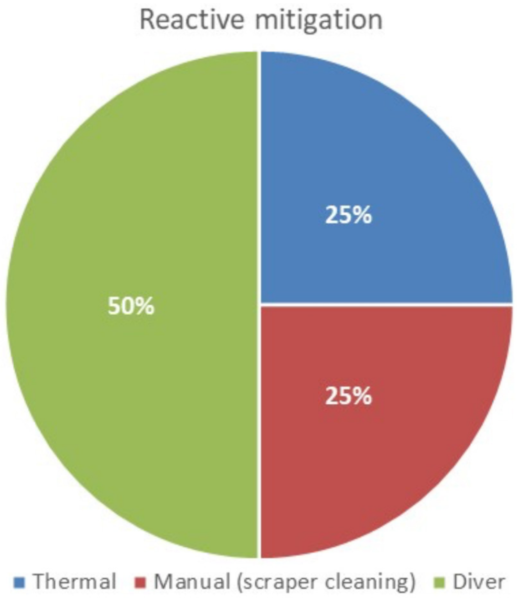

Figure 9. Responses from survey results indicating the reactive mitigation approach taken by participating facilities.

Table 2. Mitigation approaches used by survey respondents, including dosing strategies and chemical(s) used

Location	Mitigation by	Approach
Unknown	NaOCl	*Continuous dosing, no further specification provided*
	Manual (diver)	Periodic
Tennessee River, Alabama	NaOCl	2 x 21 days during winter months
	QAC	3x/yr during spring, summer and fall
Mississippi River, Iowa	Thermal	*8-hour treatment during baseload ops*
Missouri River, Nebraska	NaOCl	Periodic: throughout year, 2-3x/week in cold period, 4-5x/week in warm periods
	Nalco-H150M	*12-hour dosing 2x/year*
	Thermal	1x/6 months in intake bay
Missouri River, Nebraska	Bromine	Dosed every other day
	Nalco-H150M	Dosed annually, no further specification provided
	Manual (diver)	Diver, as well shovels (dewatering)
Lower Susquehanna River, PA	None	Very low numbers of zebra mussels are observed
Missouri River, Missouri	NaOCl	Dosing 3x/week
Lake Ontario (NY)	NaOCl	Dosed up to 2 hours/day
	NaOBr	Dosed up to 2 hours/day
	Manual	During scheduled outages every 18 months
Missouri	Monochloramine	No specification provided
	Clamicide	*During outage only*
	Manual	*Waterboxes to be cleaned when needed, derates required*
Niagara River (NY)	NaOCl	Periodic dosing 2x/year continuous dosing (24/7) during 14 days
	Manual	Bar racks and strainers when needed

Mitigation and Control Approaches – Proactive Versus Reactive

Proactive control mainly refers to chemical approaches, although this depends on the dosing strategy applied, where reactive (responsive) control mainly refers to physical removal methods (manual removal and/or thermal treatment but could also refer to chemical treatment depending on the dosing strategy applied). Respondents who indicated using a chemical approach to address Dreissenid biofouling were included in the proactive mitigation strategy for the purposes of this report. The working principle, however, is determined by how a chemical is dosed in terms of timing throughout the season of concern. Those chemicals dosed on a consistent, (semi)continuous basis to prevent or strongly reduce the initial settlement of veligers, as well suppress growth are considered proactive, while dosing strategies that are aimed at mitigating the fouling community (juvenile/adult) that has already settled (i.e., NaOCl shock dosing, seasonal dosing) are considered reactive control strategies. Due to the ambiguity of some responses, all chemical control strategies were considered a form of proactive mitigation. Table 2 summarizes the various mitigation approaches (both proactive and reactive), dosing strategies, and chemicals used by respondents.

Summary

The survey indicates that despite various chemical approaches being used as the primary treatment method (preventive and corrective), physical removal is still required. The principal reason may be ineffective application of the chemicals (e.g., treatment period, dosing schedules, chemical distribution). Increasing dosing effectiveness would require a different/optimized means of application.

For facilities considered at risk of Dreissenid infestation, the following steps are recommended:

- Risk assessment of source waterbody infestation by Dreissenids
- Completion of facility-specific vulnerability assessments
- Implementation of a monitoring program. Such a program can include monitoring in the source waterbody and within the plant
- Development of an action plan
- Assessment of best possible mitigation approaches or optimization of current mitigation is deemed ineffective

The selection of a method to control Dreissenid fouling depends on several factors. These factors include, but are not limited to, the following:

- ***Effectiveness:*** A method must be effective for the site under consideration (e.g., water flow, species, season). It is important to note that a method or approach (e.g., a biocidal treatment approach) that is effective in one system, may not be effective in another system, even if the systems appear to be identical.
- ***Regulatory requirements:*** In many cases, regulatory requirements limit the technology and approaches that can be chosen by industries to control Dreissenid fouling.
- ***Cooling system type:*** The system type determines the residence time of the water in the cooling distribution system (from intake to outfall), and thus the contact time between the chemical or other treatment and the water volume to be treated. In once-through cooled systems where residence times typically are short, fast reacting, oxidising biocides are generally selected. Slower reacting, non-oxidising biocides are predominantly only used in recirculating water systems.
- ***Water quality:*** Water quality conditions (e.g., chemical, biological, suspended solids) affect the choice of a control method. Presence of Dreissennid densities in the source water is also dependent on water quality. Improved surface water quality typically results in increased occurrence of macrofouling.
- ***Interactions with other water treatment chemicals:*** The choice of a suitable biocide can also be affected by other additives such as corrosion and scaling inhibitors. Interactions among cooling water additives are many and must be considered when selecting a chemical control method.
- ***Economic aspects:*** There is a wide range in costs associated with biofouling mitigation approaches: e.g., product, logistics, equipment, control and monitoring, operational penalties. Some chemicals are delivered as relative low-cost bulk product while others are custom designed and only economically feasible when the water flow to be treated is small and the product effectiveness is high. The configuration of the water intake and distribution system can also have an impact on the cost. As noted above, all control approaches are site-specific resulting in costs that can vary greatly between similar facilities.

Consideration of the above aspects results in a short-list of best possible control methods for a given facility. To the extent that implementation of a preferred control approach is not feasible (e.g., permit restrictions), R&D may be conducted to identify an alternative control approach that may be biologically effective, cost-effective, and permissible from a regulatory perspective.

Key Resources

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Zebra Mussel Guide
https://www.greatlakesnow.org/2020/02/\zebra-mussels-impact-good-bad/

Experts

Below is a list of invasive mussel experts:

Alexander Karatayev
Great Lakes Center
Expertise: Management of Freshwater Ecosystems
Email: karatayev@buffalostate.edu
Phone: 716.878.4329

Allen Skaja
U.S. Bureau of Reclamation
Expertise: Invasive species research
Email: askaja@usbr.gov
Phone: 303.445.2396

David Aldridge
Conservation Research Institute
Expertise: Aquatic Ecology
Email: da113@cam.ac.uk
Phone: 01223(3)34436

Diane Waller
U.S. Geological Survey
Expertise: Research fishery biologist
Email: dwaller@usgs.gov
Phone: 608.781.6282

Leonard Willett
RNT Consulting, INC.
Expertise: Water Treatment Specialist
Email: willettleonard@gmail.com
Phone: 702.274.2580

Maarten Bruijs
Pecten Aquatic
Expertise: Environmental Consulting
Email: info@pectenaquatic.com
Phone: 316.150.3325

Renata Claudi
RNT Consulting, INC.
Expertise: Invasive mussel research
Email: rntconsultinginc@outlook.com
Phone: 613.476.7994

Sherri Pucherelli
U.S. Bureau of Reclamation
Expertise: Invasive species research
Email: spucherelii@usbr.gov
Phone: 303.445.2015

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J. Black, *Technical Executive*
978.799.5494, jblack@epri.com

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EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 • USA
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