QUAGGA AND ZEBRA MUSSEL ERADICATION AND CONTROL TACTICS

4. CHEMICAL APPLICATION

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This series of information sheets is provided for educational purposes only. It is intended to provide a general overview of what is required for implementing tactics to eradicate and control aquatic invasive species (AIS). Although prevention is the best approach, it also is important to be prepared to respond quickly to new infestations and to reduce risks posed by existing infestations. No work should be conducted without first consulting the California Department of Fish and Wildlife (formerly California Department of Fish and Game) and the Regional Water Quality Control Board or, if in another state, the lead local resource management and water quality agencies for the AIS you are interested in managing. Consult the California Department of Pesticide Regulation or corresponding agency in another state before applying chemical tactics.

TACTIC

As with many household and garden pests, chemicals can be used to eradicate and control aquatic invasive species. Chemical control tactics are considered toxic, so they are placed high on the Integrated Pest Management (IPM) pyramid and used sparingly. For quagga and zebra mussels, infusing a water body with a pre-determined concentration of a chemical targets all life stages of the mussel: larvae, juveniles and adults. However, not all chemicals are equally effective at various concentrations and on the different life stages. Chemicals, including chlorine (Dichlor Max, active ingredient sodium hypochlorite), have been used successfully in *facilities* to control quagga and zebra mussels, yet potassium chloride (KCl) is the only chemical successfully used to eradicate mussels and not harm other species in a water body.[1,2] For this reason, only KCl will be discussed in this information sheet. It is unknown exactly how KCl kills the mussels, but evidence suggests that potassium interferes with the organism's ability to transfer oxygen across gill tissue, resulting in asphyxia, and eventually death. Although KCl is not currently approved for use as a pesticide in California, options for use can be reviewed with the Department of Pesticide Regulation.[3]

WHEN TO USE TACTIC

A system-wide application of KCl is typically only considered when the mussel infestation is dense and widespread and other more benign tactics, such as manual and mechanical removal and oxygen deprivation, are no longer options. Due to the costs and potential environmental impacts of the widespread application of chemicals, including KCl, such application is best used for eradication and not a long-term control measure.[4]

Broad application of KCl works best when lakes/reservoirs have no, or very little, flow-through that would increase dissipation of the chemical.[5] A target concentration of KCl must remain present in the water for a certain amount of time depending on water temperature and the life stage of the mussels in the system. The addition of KCl to a water body requires an in-depth, location-specific, permitting, and regulatory process that will impact the timeline for implementing the tactic and should be accounted for in the planning stages. KCl infusion has been used in Millbrook Quarry, VA to successfully eradicate zebra mussels (see "Success Stories").

In some cases chemical tactics may be used for site-specific control of aquatic pests, often integrated with other control tactics as part of an IPM approach. For example, chemicals can be used in conjunction with tarps or in small, contained areas to effectively control pest populations (see "Success Stories").

STEPS TO BE TAKEN

1. **Obtain Required Permits.** Seek guidance in obtaining the required permits for chemical applications in a lake/reservoir. Contact the Department of Pesticide Regulation for specific regulations regarding the use, transport and procurement of chemicals. See the Permitting and Regulatory Processes information sheet for agencies to contact and environmental consultants who may be able to provide assistance.

2. **Conduct Pre-Implementation Survey.** Consult with agency and/or university biologists to develop a pre- and post-application monitoring program that allows for a before-and-after comparison of the effects of the KCl on mussels and selected indicator species. Use trained divers and staff to carry out the monitoring program. For a list of potential divers, see Manual & Mechanical Removal information sheet. Note: This work also may occur prior to or concurrent with Step #1, depending on the situation and the permits required.

3. **Determine Quantity of Chemical.** Calculate the amount of KCl that will be needed to maintain an effective concentration of potassium for 2 to 4 weeks. The amount of chemical needed will vary based on the water temperature and volume of the lake/reservoir.[6] Consider lowering the water level (as occurs with a water draw-down) to reduce the volume of the water body and the amount of chemical needed. Additional storage infrastructure may be needed to store the chemical on land. The price of KCl has been known to fluctuate and in some cases may prove to be cost prohibitive.

4. **Apply Chemical.** Infuse the water body with the pre-determined amount of KCl to reach an effective potassium concentration. A small watercraft equipped with a diffuser system (Fig. 4-1) can be utilized to apply the required concentration of KCl to the water body. The watercraft should follow predetermined transects to ensure even distribution of the chemical throughout the water body. The goal is to infuse the lake with enough KCl to achieve the desired potassium concentration throughout the entire lake system. In Millbrook Quarry, KCl was dispensed at the surface and at a depth of 10 feet (3 meters) to achieve the target chemical concentration throughout the entire water body.[7] In water bodies with less efficient mixing, it may be necessary to add chemicals at additional depths to ensure the target concentration is achieved throughout the water body.

Figure 4-1. Watercraft equipped with diffuser system in Millbrook Quarry. *Photo Credit:* Virginia Department of Game and Fisheries

5. **Monitor Chemical Concentration.** Have trained staff or volunteers monitor the chemical levels throughout the infusion process by sampling water at various locations and depths to ensure target concentration levels are met and maintained. Re-apply KCl as needed to maintain target potassium concentration, monitoring the status after each application.

6. **Decontaminate Persons and Gear.** Be sure divers and boat operators decontaminate themselves and their gear in order to minimize the possibility of transferring live mussel larvae, juveniles or adults to other water bodies. Consider following the California Department of Fish and Wildlife (CDFW) decontamination protocol upon leaving the water body. Or, review the Hazard Analysis and Critical Control Point (HACCP) planning guidelines by the U.S. Fish and Wildlife Service, which aim to reduce or eliminate the spread of undesirable species through proper planning.[8]

7. **Evaluate Tactic Success.** Conduct post-application surveys (e.g., diver, remotely operated vehicle [ROV], substrate sampling) to evaluate the effectiveness of the KCl infusion (Fig. 4-2). During the first year of the project, these surveys should be conducted frequently (quarterly at a minimum) to measure the initial effectiveness of the effort. **When eradication is the goal,** frequent assessments are critical and will allow rapid follow-up measures to be implemented as needed. If the eradication effort appears to be successful after one year, surveys can then be conducted less frequently, but at least once a year. Annual surveys are critical for determining the long-term success of the effort, as it is typically difficult to detect low infestations of a pest. Be sure to budget for and conduct surveys for 5 to 10 years. Consider including a third-party agency or university biologist when designing and conducting surveys to validate the scientific design and findings. Due to the costs and potential environmental impacts, this tactic has not been applied system-wide over multiple years as a control tactic, but rather as an eradication measure.

Figure 4-2. Dead zebra mussels photographed by Aquatic Sciences L.P. using a robotic camera during extensive video surveys following chemical application in Millbrook Quarry. *Photo Credit:* Virginia Department of Game and Inland Fisheries

SAFETY

Proper safety precautions are essential when conducting any eradication or control tactic. We support these and other recommendations covered in the National Park Service Quagga/Zebra Mussel Infestation Prevention and Response Planning Guide:

1) No work should be started unless appropriate safety controls are in place;
2) Have a safety professional review your implementation plan; and
3) Make sure employees are properly trained, well-rested and alerted to hazards before starting.

Chemicals

Managers should consult with chemical suppliers about the risks associated with each chemical being used, and about the proper procedures regarding potential exposure to humans.

Dive Safety Plan

Anyone involved in the project (divers, volunteers, dive support staff, biologists, etc.) must know all natural and man-made hazards or potential hazards in the area where they will be working (e.g., intake structures, nearby energized equipment, boat traffic). They must also be trained in and follow all applicable Occupational Safety and Health Administration (OSHA) and industry safety requirements and guidelines, that can be found on the ADCI website. If volunteer divers are involved, the project manager and lead diver must brief them on potential risks and safety issues. Liability waivers also may be required in some situations.

COSTS TO CONSIDER

Many costs are associated with implementation of this tactic. The following list highlights some of the primary equipment and staffing needs, along with some additional expenses that may be incurred when using this tactic.

Equipment

- Land-based storage tanks and pump system
- Work boat outfitted with liquid diffuser system
- Floating pipeline
- Dive equipment (for pre- and post-monitoring)
- Water quality sampling kit

Staffing (Technical/Volunteer)

- Boat operator and assistant (for applying chemicals and assisting with monitoring)
- Professional and/or scientific divers (for pre- and post-monitoring surveys)
  - See list of qualified divers in Manual & Mechanical Removal information sheet
- Water quality monitoring personnel to evaluate chemical application (utilize local water quality lab or possibly students at a local university)
- Third party agency or university biologist to assist with survey design and to validate results

Additional Costs to Consider

- Pre- and post-application survey (e.g., water sample collection and analyses; substrate sampling and monitoring)
- Permits (see Permitting and Regulatory Processes information sheet)
- Price of desired chemical (this can fluctuate widely from year to year for KCl)
- Public outreach materials
- Signage (closure signs, information signs)
- Lost revenue due to closures (if implemented)

SUCCESS STORIES

System-Wide Application — **Millbrook Quarry, VA**

In January 2006, the Virginia Department of Game and Inland Fisheries eradicated the zebra mussel from Millbrook Quarry. In this system-wide application they infused the entire quarry with 174,000 gallons of potassium chloride (KCl) solution over a 3-week period. The target chemical concentration was 100 mg of potassium per liter of water, which was high enough to successfully eradicate the zebra mussel population but far below the level that would invoke environmental or human health concerns. (You would need to drink about 19 gallons (72 liters) of KCl-treated Millbrook Quarry water to consume your daily recommended dose of potassium.) [9,10] Post-application surveys indicate the eradication was successful with little impact to other aquatic species.

Enclosed Area Application — **Darwin Bay, Australia**

Chemicals also have been used successfully by closing off and treating certain sections of an infested water body. In late March 1999, black striped mussels were discovered in three marinas in Darwin Bay, Australia. A high-level management committee led by the Department of Primary Industry and Fisheries was created, and the marinas were immediately quarantined by closing a lock system and restricting access. In total 42,250 gallons (160,000 liters) of liquid sodium hypochlorite and around 6,600 tons (6,000 metric tonnes) of copper sulfate were added to the three marinas over two weeks, along with several tons of powdered calcium hypochlorite to create sterile "plugs" near the locks.[11] All the vessels that were either currently or recently in the marinas were also hauled out and chemically treated. By late April, after multiple dive surveys to confirm the eradication efforts were successful, the marinas were re-opened. It should be noted that other species in the locks experienced adverse effects due to the chemicals.

Site-Specific Application — **Carlsbad, CA**

Chemicals also can be applied to specific locations in a water body using tarps or similar barriers. In Carlsbad, CA, PVC tarps were used in conjunction with liquid sodium hypochlorite and chlorine tablets to contain, treat, and successfully eradicate the invasive alga *Caulerpa taxifolia* from a lagoon. Approximately 10,890 square feet (1,000 square meters) of lagoon floor was covered with overlapping large tarps anchored with sand bags.[12] It was estimated that 11,270 square feet (1,047 square meters) of *C. taxifolia* was present in the lagoon at the start of the eradication effort in summer 2000. This amount declined steadily throughout the eradication effort, with only 4.3 square feet (0.4 square meters) found in the lagoon in summer 2002. No *C. taxifolia* has been detected since that date.[13] This is considered a successful eradication effort.[14]

CITED WEB LINKS

ADCI - http://www.adc-int.org/
Decontamination protocol – http://www.dfg.ca.gov/invasives/quaggamussel/
Department of Pesticide Regulation - http://www.cdpr.ca.gov/
Hazard Analysis and Critical Control Point (HACCP) planning guidelines - http://training.fws.gov/EC/Resources/pdf/HACCP%20Manual.pdf
National Park Service Quagga/Zebra Mussel Infestation Prevention and Response Planning Guide - http://home.nps.gov/applications/digest/headline.cfm?type=Announcements&id=5488&urlarea=npsnews
OSHA - http://www.osha.gov/SLTC/commercialdiving/index.html
Quagga and Mussel Eradication and Control Workshop – http://ca-sgep.ucsd.edu/quaggazebra_mussel_control/new_workshop

[1] Note that other freshwater mussels and gill-breathing snails would be harmed by potassium. In the case of Millbrook Quarry, the only such species in the quarry was the Asian clam (*Corbicula fluminea*), another invasive exotic species (which also was killed as anticipated). Personal communication, Raymond Fernald, VDGIF, September 12, 2012.

[2] Various chemicals have been used in attempts to eradicate invasive mussels, but only KCl has been successful, albeit not in every case (see endnote 4). Unsuccessful eradication of zebra mussels was attempted with copper sulfate in Lake Ossawinnamakee in Minnesota and in Offutt Air Force Base lake in Nebraska. In both cases, the chemical application resulted in the killing of a large number of fish and harmful effects to other aquatic species.

[3] In Virginia, an emergency exemption to use KCl was granted to the VDGIF for the Millbrook Quarry eradication project. Details of the permitting process required for that eradication project are provided in the presenter abstracts (R. Fernald) from the Quagga and Zebra Mussel Eradication and Control Workshop.

[4] Note that potassium is potentially long-lived in the environment, in nonflowing waters. This persistence was a primary factor in the selection of KCl for use at Millbrook Quarry (i.e. as prophylaxis against reintroduction of zebra mussels or quagga mussels to the quarry, and as a "safety measure" in case isolated pockets of mussels somehow survived the initial treatment). Personal communication, Raymond Fernald, VDGIF, September 12, 2012.

[5] In 2010, KCl was applied continuously for 32 hours, every 15 minutes to Sister Grove Creek in Texas in an attempt to stop the spread of zebra mussels. This was the first attempt at using the chemical in a “flowing” system. While initial results showed mussels died, further investigation showed pockets of zebra mussels remained alive. Eradication was not achieved because the target concentration of KCl could not be maintained due to flow in the water body. No tarps or other barriers were deployed to contain the chemicals in the upstream area. https://fishgame.com/article.php?ArticleID=5166

[6] Based on laboratory studies, minimum concentration of KCl needed to kill zebra mussels is 30 mg/L at a temperature of 17°C (63°F). http://www.sciencedirect.com/science/article/pii/S0380133093712575
The successful field application at Millbrook quarry used a higher concentration of 100 mg/L (see “Success Story”).

[7] The target concentration was 100 milligrams of KCl per liter of water [mg/L, or parts per million (ppm)]. However, a lower concentration (50 ppm) of KCl was used as a minimum “acceptable” concentration. When a concentration of 50 ppm or higher was detected, surveys were then started to assess impacts on the mussels and other organisms. A lower concentration was used as a trigger for the surveys because it was unclear how much KCl was being taken up by vegetation or bound to sediments, thereby reducing the net concentration of KCl in the water column. Personal communication, Brian Watson, VDGIF, September 12, 2012.

[8] HACCP training is available from the U.S. Fish and Wildlife Service at the National Conservation Training Center.

[9] Final Environmental Assessment Millbrook Quarry Zebra Mussel and Quagga Mussel Eradication. Dec. 2005. Prepared by VDGIF, Wildlife Diversity Division.

[10] Fernald, R.T. and B.T. Watson. 2012. Eradication of zebra mussels from Millbrook Quarry, Virginia: Rapid response in the real world. Quagga and Zebra Mussel Eradication and Control Workshop. Presenter Abstracts.

[11] Ferguson, R. Dec. 2000. The effectiveness of Australia’s response to the black striped mussel incursion in Darwin, Australia. http://www.environment.gov.au/coasts/imps/publications/pubs/bsmfinalreport.pdf

[12] Anderson, L.W.J. 2005. California’s reaction to *Caulerpa taxifolia:* A model for invasive species rapid response. *Biological Invasions* 7: 1003-1016.

[13] Woodfield, R. and K. Merkel. 2006. Eradication and surveillance of *Caulerpa taxifolia* within Agua Hedionda Lagoon, Carlsbad, California. Fifth Year Status Report January to December 2005. Prepared for Steering Committee of the Southern California *Caulerpa* Action Team. 15 p.

[14] Anderson, Lars W.J. 2012. Rapid response and eradication of *Caulerpa taxifolia*: Lessons learned from a successful team effort. Quagga and Zebra Mussel Eradication and Control Workshop. Presenter Abstracts.

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Carolynn Culver, California Sea Grant Aquatic Resources Specialist, University of California
Heather Lahr, California Sea Grant Research Assistant, University of California
Leigh Johnson, Coastal Resources Advisor, University of California ANR, Cooperative Extension
Jodi Cassell, Natural Resources Advisor, University of California ANR, Cooperative Extension

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