Quagga and Zebra Mussel Eradication and Control Workshop

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Eradication of colonizing populations of zebra mussels (*Dreissena polymorpha*) by early detection and SCUBA removal: Lake George, NY*

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Eradication/Control Strategy:

Physical removal of mussels by the use of SCUBA was explored to eliminate zebra mussels from a site in Lake George, NY, USA. The proximity of the Lake (< 40 km) to several zebra mussel colonized water bodies (Lake Champlain, Hudson River, Glen Lake, Saratoga Lake) increased the risk of zebra mussel introduction. After initial removal of over 19,000 mussels, continued monitoring of the site for larvae, recruitment and growth was carried out to determine if there was successful reproduction of the remaining population. Bi-annual (2001-2007) and annual (2008-2011) visits to the site, to remove remaining mussels via SCUBA hand-harvesting was carried out, and continues.

Efficacy of Treatment (metrics):

Efficacy of the eradication strategy was assessed using the following results:

1. Reduced numbers of adult mussels at the site.
2. Subsequent to the initial removal of more than 19,000 mussels, neither larvae nor recruitment was observed, suggesting that the small number of remaining mussels had not successfully reproduced since the start of the project in April 2000.
3. In 2008, 2009, 2010, 2011 only 5, 14, 3 and 16 zebra mussels respectively, were found at the site. The greatest mussel shell lengths (up to 37mm) were found in 2011 and no mussels with shell lengths less than 27mm are now found at the site. This also suggests that the remaining mussels are not successfully reproducing.

We remain optimistic that SCUBA removal efforts combined with the life expectancy of zebra mussels will result in their eradication at this site.

Timeline of Events:

- *December 18, 1999*: Zebra mussels found in the Village of Lake George. Mussels were found by volunteer divers who were removing trash.
- *December 1999*: SCUBA surveys defined an affected area of approximately 3900m2. The site was divided into nine sections.
- *April 2000 - June 2000*: SCUBA divers worked within sections to locate and remove as many mussels as possible. Removal efforts during the first year concentrated on the area of approx. 140m2 that had the highest density of mussels. These efforts resulted in the elimination of approximately 90% (19,176) of mussels found at the site during the study period through 2007.
- *October 2000 to Sept. 2007*: Removal of mussels continued each spring and autumn from the total area and an additional 2,076 mussels were eliminated. Larvae were routinely monitored for (none found); spat traps also revealed no juveniles, and water chemistry was monitored and appeared to be non-permissive for larval survival.
- *2008-2011*: Removal of mussels continued once a year and an additional 38 mussels were eliminated.

Permits Required:

Prior to beginning the project, a collection permit for zebra mussels was obtained as required by the New York State Department of Environmental Conservation. No other permits were required using a SCUBA hand harvesting approach.

Equipment and Training Needed:

For zebra mussel removal efforts, essential equipment included steel rebar and nylon lines (for delineation of the treatment area), as well as SCUBA gear, collection bags, sample preservative and containers (for removal and collection). For assessment of settlement and recruitment of juvenile zebra mussels custom-designed collectors (spat traps) (24 x 11 x 14 cm) that contained eight removable stainless steel plates (8 x 13 cm) were used. For collection of plankton samples bilge pump and 44-µm mesh plankton net was used to concentrate samples. Laboratory analyses required: calipers (for zebra mussel size measurement); and cross-polarized light microscope (for plankton and spat trap sample analyses).

Training was carried out to ensure that all divers were using consistent techniques for identification and removal of zebra mussels. Additionally, all shore support was trained to safely support divers, collect samples, record data, and provide basic information to the general public interested in the activities.

Collaborators:

In addition to Darrin Fresh Water Institute scientists, staff and students, this eradication effort could not have been accomplished without local volunteers, businesses and organizations. Scientific divers from Bateaux Below, Inc., InnerSpace Scientific Diving, Scientific Diving International, and Skidaway Institute of Oceanography were essential in the eradication effort as was support from local dive shops (Capitaland SCUBA and Morin's Professional SCUBA Centers). Also crucial for the project was the cooperation of many commercial marinas around Lake George and the Town of Bolton Landing and the Village of Lake George.

Costs and Financing:

Costs: Removal effort costs included diving, shore support, data logging, water sample collection and analyses, and reporting. At the Lake George Village site the total number of dive hours was 860. Shore support included diver logistic assistance, equipment and sample handling, outreach to and education of interested observers. Diver support and diver out-of-water time was estimated to be 400% of underwater time. Sample analyses and record keeping was estimated to be 200% of underwater time. Overall, the largest cost associated with this eradication approach was labor. If funding had been required to cover all labor expenses, the total would have been prohibitive. However, the strategy to involve the community and the ability to mobilize qualified volunteers made the project possible. Actual labor costs included one full-time scientist and a small amount of support for several other professionals. The importance cannot be overemphasized of good public relations, proactive planning, and cultivation of a local sense of ownership, and optimism that the problem is manageable.

Funding: National Oceanic and Atmospheric Administration awards through the auspices of the Research Foundation of the State University of New York for New York Sea Grant initiated a zebra mussel monitoring program on Lake George. The zebra mussel removal and eradication effort was largely funded by the Helen V. Froehlich Foundation. Additionally in 2007 the Lake George Watershed Conference provided funding towards this effort.

Lessons Learned (Obstacles [Ob] and Solutions [Sl]):

Ob1: Logistics: Very labor intensive and initially required dry suit certified SCUBA (due to water temperature). Access to site on a routine basis.
Sl1: Enlisted additional scientific divers and established a pool of local volunteers to draw from. Formed partnerships with marinas, businesses, town and village for access to site. One staff member was supported with salary to coordinate the project.
Ob2: Funding: Sustained funding for an effort over a 12 year period of time
Sl2: Diversification of funding sources for project. Dissemination of results demonstrating significant progress in combating zebra mussels in Lake George
Ob3: Detection: Invasive species can be introduced in many locations all of which can't be regularly monitored.
Sl3: Establish as an effective monitoring program as soon as possible. Promote public awareness to help be the "eyes". Be prepared to act immediately, ideally with a rapid response plan.

Conclusion:

This study demonstrates that, if detected early and removed before extensive reproduction occurs; it is possible to prevent an irrevocable invasion of zebra mussels, even after establishment. The applicability of the methods presented here to other water bodies must be evaluated on a case by case basis, but the demonstrated success of this strategy in Lake George challenges the conventional wisdom that permanent zebra mussel colonization, once begun, is inevitable. Empowered by this knowledge, future stakeholders, researchers, and managers can consider zebra mussel eradication with confidence.

*Information included in this abstract is largely drawn from Wimbush et al. 2009 [Aquatic Convserv: Mar. Fresw. Ecosyst. 19: 703-713 (2009).

Lars Anderson

Dr. Anderson recently retired after a 36 year research career with the USDA- Agricultural Research Service that focused on the biology and management of invasive aquatic plants. He served on the Steering Committee and chaired the Science Advisory Committee of the Southern California Caulerpa Action Team (SCCAT) from 2000-2007, which successfully eradicated *C. taxifolia* from two California infestations that threatened the west coast.

Rapid Response and Eradication of *Caulerpa taxifolia*: Lessons Learned from a Successful Team Effort

Lars W.J. Anderson, USDA- Agricultural Research- (Retired)

Synopsis:

When the invasive marine alga *Caulerpa taxifolia* was discovered June 12, 2000, in California at Agua Hedionda Lagoon, there was already an awareness of the risks and potential impacts to the environment due to a 15-year history of spread in the Mediterranean Sea. It had already been placed on the Federal Noxious Weed list in 1999. This awareness greatly facilitated consensus building and setting clear eradication goals among a large number of state, federal and local agencies as well as private groups and NGOs (non governmental organizations) that became the "Southern California Caulerpa Action Team" (SCCAT). Field containment and treatments began 17 days after the discovery due to: (1) timely notification of the "find"; (2) the proactive staff of the San Diego Regional Water Quality Control Board who deemed this invasion tantamount to an "oil spill", thus freeing up emergency funding; and (3) the mobilization of diver crews already working at the site. Three essential components were brought to bear on the problem: (a) expertise and knowledge on the biology of *C. taxifolia*; (b) knowledge on the uses, "ownership" and characteristics of the infested site; and (c) knowledge and experience in the implementation of aquatic plant eradication. These, combined with the requisite resources (approximately $1.2 million per year) resulted in containment, treatment and total eradication over a 6 year period. Successful rapid response to other aquatic invasive species will require similar readiness to act and immediate access to adequate funding. Conducting fire alarm-type exercises ("Pest Alarms") with potential invasive species, the expertise, resources, regulatory issues and entry pathways can be identified before the arrival of the pest, thereby reduce the time needed for an effective and appropriate response. Since most aquatic sites are unique with regard to uses of the water/site, potential for off-site dispersal, human, fish and wildlife (non-target) risks, "ownership" and "authorities" to act, the composition of the response team must be tailored to provide accurate and timely input on these site-specific characteristics. Lastly, the organizational "team" structure must include mechanisms and agreements to arrive at consensus-driven decisions as well as clear mechanisms to deploy needed resources to execute containment, eradication and monitoring plans that are communicated to all stakeholders.

Specific Issues met and resolved:

a. Setting feasible goals: From the first meetings of multiagency representatives within a week after the discovery of *C. taxifolia*, the clear consensus was total eradication using best available tools and strategies. In spite of no prior successful eradications of a marine alga, and in spite of the unchecked spread of *C. taxifolia* in the Mediterranean, those who were experienced with other successful AIS eradications were convinced it could be done.

b. "Lead-Authority", "Lead Agency": No federal or state agency was clearly identified as having full authority and resources to serve as a typical "lead agency". The stakeholders (state, federal, local, private) therefore established an ad-hoc "team" approach whereby decisions were made after full discussions of options for all action taken. The Southern California Caulerpa Action Team (SCCAT) served as the unifying body through which and by which all actions were implemented and all outreach/education efforts were made. Within SCCAT, certain partners took on responsibilities for different components of the overall project based on their capacities and their statutory authorities. This included garnering funds, dispersing funds, implementing and enforcing existing and new regulatory authorities, research components (e.g. technical inputs), and budget and project tracking.

c. Methods development (containment, treatment and post-treatment monitoring). A technical advisory committee reviewed all options for eradication and arrived at a consensus on approaches most likely to work. Research gaps were identified and projects were conducted to answer specific questions regarding efficacy and optimal treatments. Monitoring was a major concern due to highly variable underwater visibility and small target size.

d. Establishment of criteria for evaluating progress toward eradication. This is a key component since it directly focuses on how success is measured and how to know when "eradication" is achieved. The Technical Advisory Committee spent considerable time developing scientifically sound and defensible metrics to track progress and to define an "end point". This effort included using QA/QC practices in monitoring that addressed the detection threshold variables.

e. Outside review of strategies, progress and goals. A year after SCCAT began implementing its project, a scientific review panel was convened to provide an independent view of the progress and to identify gaps, errors and to provide constructive input. Panel comments and suggestions were incorporated into the project as appropriate.

The final monitoring and eradication criteria model was reviewed by independent experts.
f. Communication of actions and plans. Monthly updates were provided by key team members who were executing components of the project. A website was established to make key events, actions and reports available to all stakeholders. Communications also included local governmental bodies such as city councils, water sports/diving groups, political representatives and the general media.

g. Developing on-going and sustainable support (cash and in-kind). To support what was clearly a multi-year effort, long-term funding sources were identified. This included granting agencies, regulatory and environmental advocacy NGO's.

An overall “Model” of the adaptive *C. taxifolia* eradication project is provided below.

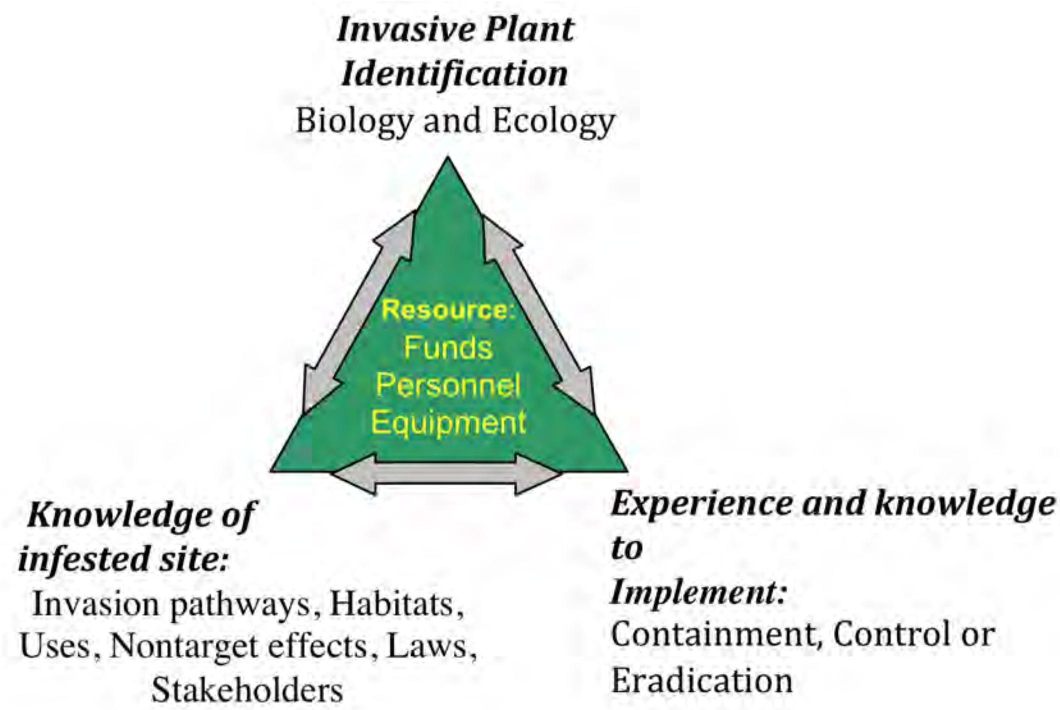

Figure 1. The schematic representation of the SCCAT knowledge, skill, experience and reources inputs that resulted in successful eradication of *C. taxifolia*

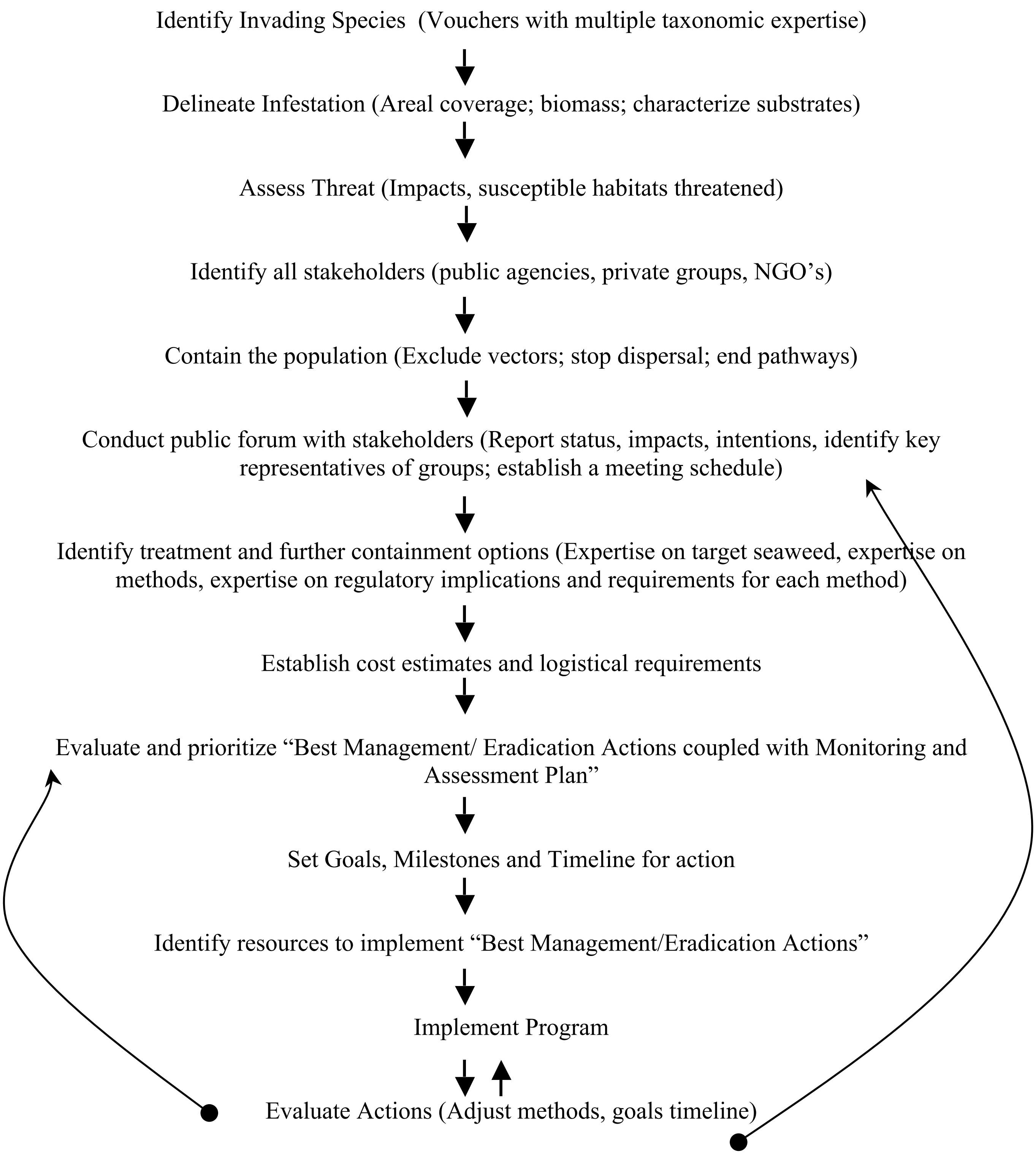

Figure 2. Generic Scheme for developing response to invasive species infestations. (From Anderson 2005)

Raymond T. Fernald

Ray manages the Environmental Programs of the Virginia Department of Game and Inland Fisheries, with primary emphasis on review of state or federal environmental assessments, permits, or projects that may impact the Commonwealth's fish and wildlife resources, and on coordination of VDGIF activities regarding invasive exotic species. After receiving his Bachelor's Degree at Florida Southern College, he earned his Master's Degree through the Cooperative Wildlife Research Laboratory at Southern Illinois University, studying the impacts of changing land use and habitat conditions on Northern Bobwhites. He then spent 13 years with the Florida Game and Fresh Water Fish Commission; first reviewing environmental permits and major developments to minimize impacts on fish and wildlife, and initiating establishment of native tropical hammock vegetation on estuarine spoil islands; and later researching the distribution, ecology, and potential management of coastal xeric scrub communities and species. In 1990, Ray was hired as VDGIF's Environmental Services Biologist; in 1991 he was promoted to manage the Environmental Services Section; and from 1995 through October 2010 he also managed the Department's Nongame and Endangered Wildlife Program. Ray is a Certified Wildlife Biologist, an Advanced Open Water Diver, an alumnus of the Virginia Commonwealth Management Institute, and a member of the Virginia Invasive Species Technical Committee and the Mid-Atlantic Panel on Aquatic Invasive Species.

Eradication of zebra mussels from Millbrook Quarry, Virginia: *Rapid response in the real world.*
R.T. Fernald and B.T. Watson

In early September 2002, zebra mussel infestation of Millbrook Quarry, a popular scuba diving site serving the Washington, D.C. metropolitan area, was confirmed by the Virginia Department of Game and Inland Fisheries (VDGIF), thus propelling the Department into the first attempt to eradicate a large open-water population of this invasive exotic species. This presentation explores the statutory, regulatory, procedural, and technical hurdles encountered by the Department and our partner agencies, and offers recommendations for enhancing the ability of government agencies to effectively deal with such infestations.

Millbrook Quarry was opened in 1947 to produce stone for construction of Virginia Highway 55, and was closed to excavation by 1963. Bathymetric analysis revealed a 2002 surface area of approximately 4.86 ha, maximum depth of 30 m, and volume of approximately 680 million liters. The Dive Shop in Fairfax, VA first began using the quarry for scuba diving in the early 1970's, and has leased the quarry as a training and recreational dive site since 1978. Diving occurs on weekends only, and primarily from April through mid-November. Millbrook Quarry has a single gated entrance, and no public non-diving use is permitted. It is separated from Broad Run, a perennial tributary of the Occoquan River, by a 60-90 meter-wide berm. Lake Manassas, about 9 km downstream of the quarry, serves as the primary water supply for the City of Manassas, and further downstream you encounter Occoquan Reservoir, a primary water supply for over 1 million people in northern Virginia. From there, the Occoquan River flows into the Potomac, and thence to Chesapeake Bay.

Given the proximity of Millbrook Quarry to Broad Run and its extensive use as a dive location, we considered it highly unlikely that the zebra mussel population in Millbrook Quarry could simply be forever isolated. Broad Run has historically flooded the bank separating it from Millbrook Quarry (1972, Hurricane Agnes), and unintentional transport of veligers or juvenile mussels by divers from the quarry to other state waters was considered likely. Conversely, while we suspected groundwater connections between Millbrook Quarry and Broad Run, there is no direct surface outflow or inflow, effectively eliminating most natural dispersal modes and rendering this population relatively isolated. Also, since this was the only known zebra mussel infestation in Virginia, its eradication would completely remove this invasive species from the Commonwealth; a significant sociopolitical, if not geographical, consideration.

Upon confirmation of the infestation, preliminary assessment of the threat to native wildlife communities posed by zebra mussels, and review of our legal jurisdiction to intervene, VDGIF organized a meeting of numerous federal, state, and local agencies and organizations, thereby establishing the Millbrook Quarry Zebra Mussel Workgroup. Membership in the Workgroup was open to all interests, and we especially sought participation of local governments and of agencies with pertinent technical expertise, or with responsibility for wildlife, environmental protection, public health, and potable water issues. At the Workgroup's first meeting in November 2002, all parties agreed that eradication of the population, if possible, should be the ultimate goal, despite recognition that eradication of a large open-water population of zebra mussels had never been attempted. The Workgroup further concluded that, before an eradication plan could be developed, substantial technical information needed to be collected regarding regional and site-specific hydrology, geochemistry, ecology, and physical parameters of the quarry and zebra mussel population.

VDGIF and our partner agencies sought to conduct the necessary onsite data collection in mid-November 2002, but were thwarted by access constraints imposed by the property and dive shop owners, stemming from the lack of statutory authority of government agencies to compel landowner assistance or cooperation in such matters. Partly in response to this dilemma, legislation was passed by the 2003 General Assembly establishing a list of Nonindigenous Aquatic Nuisance Species (including zebra and quagga mussels), authorizing VDGIF to respond to such invasive species, and establishing civil penalties for violating the Act or obstructing VDGIF from responding to such incidents. Immediately upon passage of the Act in March 2003, the landowner and dive shop owner granted VDGIF and cooperating agencies access to the property to pursue eradication of the infestation.

In April 2003, upon implementation of decontamination protocols for all fieldwork at Millbrook Quarry, staff from key agencies conducted the prescribed fieldwork, and the analyses of these initial data were completed in June 2003. We confirmed widespread occurrence of zebra mussels of several year classes throughout the quarry, from near the surface to depths exceeding 21 m, and established a baseline hydrologic and geochemical characterization of the quarry, groundwater, and Broad Run. In essence, the Workgroup agencies established that the water chemistry of Millbrook Quarry largely reflects the regional groundwater, that groundwater flow proceeds through the quarry from north to south, and that leakage from the quarry to groundwater occurs at a rate of about 3-4 percent volume per year.

In late July 2003, VDGIF initiated formal efforts to obtain funding for eradication of the infestation, and sought eradication proposals from potential vendors via the Commonwealth's Emergency Procurement Solicitation process. Unfortunately, confirmed offers of funding were not forthcoming and, on 30 October 2003, the emergency solicitation was cancelled due to lack of funding to proceed. Based on preliminary review of the emergency procurement responses, the eradication effort was anticipated to cost between $150,000 and $800,000, so we established $800,000 as our funding target. A wide variety of funding options were explored including numerous federal agencies; state, regional, and local governments likely to be adversely impacted by presence of zebra mussels in Virginia's waters; and prominent Virginia industries that would be similarly impacted. Our goal of securing $800,000 in funding commitments was reached in September 2004, including $300,000 from the U.S. Department of Agriculture as a Wildlife Habitat Incentive Program grant, $100,000 from the U.S. Fish and Wildlife Service as a State and Tribal Wildlife Grant, a $200,000 contribution and an additional pledge of up to $163,000 from Fairfax Water, and $37,000 in contributions from Virginia industries and local governments.

In Virginia, Competitive Negotiation is a preferred procurement method used for goods and nonprofessional services when it is not practicable or fiscally advantageous to use competitive sealed bidding. This process requires issuance of a Request for Proposals and formal documentation of the criteria to be used in evaluating proposals, but it allows the purchasing agency to generally describe what is being sought, and to change both the content and price of offers submitted through formal negotiation and modification of the proposals. In anticipation of the breadth of expertise required to properly evaluate proposals, and recognizing the wide range of technical, public health, environmental, and socioeconomic issues to be considered, we assembled an interagency Evaluation Panel of eight members representing seven agencies, including primary stakeholders, academic researchers, and Virginia regulatory agencies.

Three proposals were submitted in response to our solicitation, including treatment with Spectrus CT-1300 (a commercial molluscicide), lowering of dissolved oxygen via injection of liquid carbon dioxide into the quarry water, and treatment with potassium via injection of a KCl (muriate of potash) solution into the water column. Upon review of the proposals and completion of negotiations with the prospective vendors, the Panel unanimously selected the muriate of potash treatment proposal as the preferred alternative, expressing confidence that use of potassium offered the greatest likelihood of successfully eradicating the zebra mussel population with virtually no significant adverse environmental impacts, and furthermore would provide long-term protection against reinfestation of the quarry with zebra mussels: a contract for the eradication ($365,069) was awarded to Aquatic Sciences L.P. of Orchard Park, NY on August 24, 2005. Besides the three formal proposals, other alternatives considered and rejected included no treatment, desiccation and freezing via dewatering the quarry, increasing salinity, lowering of pH, and treatment with copper sulfate, chlorine, and/or other commercial molluscicides.

Early in our consideration of alternatives, we recognized that any eradication proposal would be subject to extensive environmental review by federal, state, and local agencies, and by various non-government interests. The most significant environmental requirements included compliance with the federal (and state counterparts thereof) National Environmental Policy Act (NEPA), Endangered Species Act, Coastal Zone Management Act, and Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). Because we could not anticipate what treatment alternatives would be submitted as formal proposals, and because the state procurement process mandates confidentiality throughout the evaluation and selection process, we could not develop an Environmental Assessment for this effort until the proposals were formally submitted and reviewed, and the procurement process concluded. After consultation with the U.S. Fish and Wildlife Service, which served as the lead federal agency for NEPA compliance, we included a statement in the RFP to specifically require compliance with all federal environmental review requirements under NEPA and other applicable laws and regulations.

Through review of the Department's GIS data and project specific field surveys, we determined that no federal or state *threatened* or *endangered* species would be impacted by the proposed eradication. Similarly, through field surveys, literature review, analysis of data from the onsite investigations, and interagency consultation, we determined that no significant impacts would accrue to aquatic wildlife, streams or other surface waters, groundwater or potable wells, terrestrial wildlife, wetlands, natural areas and unique or important vegetation, cultural or historic resources, or recreational or socioeconomic resources.

In addition to compliance with state and federal environmental review requirements, because our selected treatment was not a registered pesticide use, we had to secure an Emergency Exemption (quarantine) under Section 18 of FIFRA. Approval of this exemption, though not as complex or lengthy a process as compliance with NEPA, nonetheless required nearly three months to achieve.

We also were required to ensure compliance with state and local regulations regarding pollutant discharge, submerged lands and wetlands protection, water quality, hazardous and solid waste management, sediment and erosion control, emergency preparedness, potable water quality protection, and public review of all environmental documentation. Thus, after nearly 3 ½ years of site evaluation, fundraising, alternative review, and pre-eradication environmental compliance, we received final approval to proceed with the eradication.

To kill the zebra mussels through exposure to potassium, the entire quarry was injected with 658,662 liters of a 12% potassium solution (131,000 kg of muriate of potash – MOP 98%) over a 3-week period from 31 January to 17 February 2006. The solution was delivered each Monday through Friday to the site by tanker truck, and then pumped from land-based storage tanks through a floating supply line to a 6.7 m workboat outfitted with a specially designed diffuser manifold on its bow. After each five days of treatment, the contractor measured potassium concentrations at 59-67 points along transects throughout the quarry, ranging from the surface to 29.0 m depths, and also in Broad Run. Our target concentration for the quarry was 100 ppm; far below the level that would invoke environmental or human health concerns, but more than twice the minimum concentration needed to kill zebra mussels. After three weeks of treatment, our sampling revealed potassium concentrations ranging from 98 to 115 ppm throughout the water column, with no apparent potassium leakage from the quarry into adjacent waters.

Several weeks after treatment was completed, four separate methods of confirming eradication of the infestation were implemented. First, over a thousand zebra mussels were scraped from shallow (<1 m) subsurface rocks at numerous sites around the quarry during informal assessments, revealing no live mussels. Second, VDGIF divers who had documented the extent of the infestation during pre-eradication studies conducted another scuba inspection of the quarry, searching for live zebra mussels but finding none. Third, our contractor conducted extensive video survey and documentation of the dead zebra mussels through use of a robotic camera. Finally, eighty bioassays of 100 live zebra mussels each (imported for this purpose) were placed at various locations and depths throughout the quarry and thus exposed to the treated quarry water. After 31 days of in-situ exposure, 100% of the test mussels had died. None of the 100 "control" zebra mussels held in untreated water drawn from Broad Run died during the bioassay period. In dramatic contrast, other aquatic wildlife including turtles, fishes, aquatic insects, and pulmonate snails continued to thrive in the quarry.

Follow-up sampling of Millbrook Quarry through January 2008 confirmed lethal potassium concentrations throughout the quarry, though potassium levels declined during the 24 months post-treatment to approximately 70 ppm, possibly due to changes in water chemistry and increased biological uptake. Insignificant seasonal low-flow increased potassium concentration was noted in Broad Run, but neither of the two concurrent post-treatment studies indicated any infiltration of potassium into potable wells downstream of the quarry.

In many respects, our success at Millbrook Quarry reflected the nature of the infestation and setting; *i.e.,* the quarry was essentially isolated from other surface waters; groundwater connections were inadequate to dilute the potassium below the desired concentration or to result in downstream contamination; there was no uncontrolled public use or access to the site; all fieldwork, including treatment and bioassays, could occur on weekdays when there was no public use, or during the winter when no diving was scheduled; and, there were no sensitive or imperiled native species that precluded our use of potassium for the eradication. Even so, our effort revealed strengths and weaknesses of our approach, and indeed of many invasive species control efforts.

Our first decision proved critical to our success: rather than accept the presence of zebra mussels in Virginia as inevitable and insurmountable, we decided to evaluate all potentially reasonable measures to eradicate the infestation. The second decision proved equally important: we recognized our lack of expertise to pursue the eradication ourselves, and formed a workgroup comprised of experts from various state and federal agencies, and local interests. The Workgroup served three major objectives: (1) we enlisted technical expertise in public health, water chemistry, and geochemical hydrology; (2) we garnered project support from landowners, non-governmental conservation interests, potentially affected corporations, and from local, state, and federal agencies, many of whom would ultimately provide critical public support for the eradication; and (3) non-government Workgroup members and other activists recognized the need for legislation to authorize our undertaking, and successfully gained passage of the Virginia Nonindigenous Aquatic Nuisance Species Act. The third major factor in our success also emphasized our external partners: the RFP Evaluation Panel served to: (1) ensure that all technical, public health, and environmental issues were fully considered by experts in their respective fields; (2) maintain focus and engagement of essential project partners through a sometimes arduous and frustrating path to project selection and approval; and (3) integrate the primary political and regulatory agencies that ultimately would review our project proposal into the decision process, thereby ensuring (to the extent possible) that our proposal would be acceptable to those agencies during their regulatory review. Finally, the Competitive Negotiation process itself was instrumental to development of a final project that maximized our chances of success, rather than simply attainment of the most convenient or lowest-cost contract for the eradication attempt.

Nonetheless, through our own naiveté and circumstances beyond our control, we encountered significant obstacles during the 3 ½ year project, a few of which may be instructional for dealing with similar situations in the future. First and foremost, and as recognized in many existing invasive species management or rapid response plans, it is imperative that responsibility and legal authority to address invasive species issues be clearly established in appropriate legislation and in agency strategic/operational plans. Second, to the extent possible, interagency Rapid Response plans could establish guidelines and protocols for decision-making and agency actions to address such environmental issues, thereby avoiding the "design as you build" approach we faced. Third, efficient and streamlined procurement and environmental review procedures (state and federal) for responding to invasive species emergencies could greatly reduce the time required for responding to future invasions or discoveries. Finally, availability of staff and funds to address invasive species issues is critical to program or project implementation, and ultimately will determine success or failure.

In summary, our eradication of zebra mussels from Millbrook Quarry reflected a fortuitous and nearly ideal site and circumstances for success, a firm decision to attempt what many considered unlikely or impossible, and inclusion of as much technical and political expertise and public support as we could generate and maintain. "Rapid Response" in our real world involved nearly 3 ½ years of planning, investigation, negotiation, and project design, followed by a mere 3 weeks of project implementation. Preparation of interagency Rapid Response plans that address agency responsibilities and authority; guidelines, protocols, and decision-matrices for project design and implementation; streamlined procurement and environmental review; and enhanced funding for invasive species management could dramatically shorten the time required to respond to future invasions.

Carolyn Link

Carolyn Link joined Marrone Bio Innovations in April 2010, and since then has contributed to the field team by developing commercial methodologies for demonstrating how the company's microbial-based molluscicide, Zequanox, can be used to control mussels at all life stages. Ms. Link decided on a career path in aquatic conservation while working towards her B.S. in environmental chemistry from Northern Arizona University. Later, she obtained a M.S. from the University of Nevada, Las Vegas in water resources management, focusing her studies on quagga mussel ecology with a graduate assistantship from the Desert Research Institute. Ms. Link's past experience includes work in aquatic animal husbandry and life support engineering, where she has swam with sharks and worked with komodo dragons.

Zequanox: Invasive Mussel Control for Watershed Management

Carolyn Link and Sarahann Rackl Ph.D, Marrone Bio Innovations

Throughout the world, invasive mussels are becoming a devastating problem. Because of their significant impacts on infrastructure and the environment, solutions—environmentally sound solutions—to this spreading problem are important. Development of a naturally derived molluscicide, ZequanoxTM, which offers environmental safety and application flexibility for controlling invasive mussels during all their life stages, has been successful for industrial use. This presentation will describe the rapidly progressing development of an additional eradication/control strategy with enormous potential: open water application of Zequanox.

Extensive laboratory screening trials by New York State Museum (NYSM) of more than 700 bacterial strains identified a North American isolate, strain CL145A of *Pseudomonas fluorescens*, to be lethal to invasive *Dreissena* mussels. *P. fluorescens* is worldwide in distribution and is present in all North American water bodies. In nature, it is a harmless bacterial species that is found protecting the roots of plants from plant diseases. Following a nation-wide search, NYSM chose to partner with Marrone Bio Innovations (MBI), because its teams of scientists and management have been involved in the biopesticide industry since its inception. MBI is responsible for developing Zequanox into a commercially viable product and is the commercial license holder on the Pf-CL145A patent.

MBI, with the assistance of contracted labs and collaborators including NYSM, the United States Bureau of Reclamation (Reclamation), and Institute of Technology Sligo, have completed a wide breadth of mammalian and non-target studies beyond the requirements to register pesticides in the United States, Canada and Europe. These studies have included sensitive, threatened, and endangered species of concern to support the use of Zequanox in environmentally sensitive areas. In tests, Pf-CL145A is not lethal to other aquatic organisms. At treatment concentrations that produce high zebra mussel mortality (76–100%), no product-induced mortality was recorded among any of the non-targets, including algae, fish, mollusks and crustaceans.

In January 2009, MBI began conducting trials at Reclamation's Davis Dam in Bullhead City, Arizona. Davis Dam is an important hydroelectric facility on the lower Colorado River that is operated with Hoover and Parker Dams to provide water and power. In August 2010 the EPA approved a Section 18 emergency use permit for application of Zequanox within the Lower Colorado River system. Per National Environmental Policy Act requirements, Reclamation and MBI completed an Environmental Assessment for treatments at Davis Dam with a finding of no significant impact, which was released in June 2011. Subsequent to the finding, MBI and Reclamation conducted successful treatments at Davis Dam throughout 2011.

On July 29, 2011, the EPA registered Zequanox in accordance with the Federal Insecticide, Fungicide and Rodenticide Act Section 3 regulations to control dreissenid mussels in defined discharges. Registrations of newer formulations of Zequanox are expected in March 2012. Expanded label uses, including open water application, are expected in 2012 with no anticipated restrictions. Zequanox offers many advantages over chlorine and other chemical pesticides, including safety and ease of use. Zequanox is safe to store, handle, and apply in the environment. Zequanox label requirements do not require specialized personal protective equipment and only specify that applicators wear long sleeves and pants, and standard latex gloves and the lowest level dusk masks only when mixing and directly handling the material. Injection of Zequanox into treated systems is accomplished with standard pumps and diffusers. In some cases, MBI has been able to use facility equipment already in place for alternative treatments.

Zequanox is likely to have major advantages for open water application as well. It is a highly flexible mussel control tool that can achieve a variety of open water treatment objectives:

- <u>Control of source populations</u>. A large mussel population in one area of a flowing water body may not cause problems at its own location, but can act as a source of reproducing mussels, affecting downstream locations heavily if the veliger source is uncontrolled.
- <u>Habitat restoration support</u>. Invasive mussels can have a widespread impact on habitats for sensitive native species, including species with limited mobility, such as unionids. Control of invasive mussel populations can support programs to reestablish native populations. Reduction or removal of a mussel population may help endangered benthic species from being out-competed by the mussels for habitat, and can support overall ecosystem restoration, by allowing a return of the natural balance for nutrient stoichiometry, benefitting native mussels, algae, and fish.
- <u>Shoreline restoration.</u> Shorelines support many recreational and educational uses, and many waterways heavily infested with mussels have lost their usable shorelines due to invasive mussel accumulation and debris. Reducing mussels to controllable levels can, in time, lead to restoration of these water resources.
- <u>Protection of infrastructure.</u> Applying Zequanox to open water sources can help to protect the intake, transmission, and transport equipment and infrastructure that draw water from them.

Experience with the development and use of Zequanox for confined systems has provided a significant start for the development of open water Zequanox use. Development of top formulations and production of commercial quantities of material have already been achieved. The technical-grade active ingredient and early formulations have regulatory approval, and the necessary non-target studies have been completed. Researchers have developed the methods for accurate efficacy determination, for both adult mussels and juvenile mussel settlement. For facility treatments, efficacy is determined by monitoring mussels contained within the treated systems in bioboxes. The bioboxes, which have mesh cages containing adult mussels and settlement plates for juveniles to grow on, have provided product efficacy data demonstrating greater than 90% control. Upcoming Zequanox field research will identify the best related method for efficacy determination in open water.

Through cooperative efforts across the industry, researchers at MBI are developing methods for the evaluation of absolute veliger mortality from specific treatments, as well as application methods for Zequanox in open water systems. Current studies are addressing application methods, inclusive of physical application techniques, and optimal application strategies (how much and how often). These studies, scheduled to begin in 2012 both in the United States and abroad, will address open water application challenges such as how best to treat only the waters in close proximity to mussels (as opposed to whole bodies of water) and how to maintain target treatment concentrations for specific durations.

These studies include field trials at locations such as Deep Quarry Lake. Deep Quarry Lake, which is within the West Branch Forest Preserve near Bartlett, Illinois (approximately 33 miles west of Chicago), has been infested with zebra mussels for at least five years. Zequanox trials at Deep Quarry Lake will be an opportunity to study the application of Zequanox in a natural, open water setting. As a complement and extension of laboratory-based experiments, the tests at Deep Quarry Lake will help to better understand how to apply Zequanox in a less controlled, natural setting and how to conduct field trials in open water environments.

The Illinois trials will utilize barriers to section off multiple small sections of the lake for treatments. The trials will be conducted in coordination with Dr. Greg Whitledge's lab at Southern Illinois University with grant funding and personnel support by Illinois Department of Natural Resources. Personnel from Dr. Whitledge's lab will collect pre-treatment sampling to determine the characteristics of the zebra mussel population in Deep Quarry Lake, as well as the chemical and physical water properties. Dr. Whitledge's lab will use artificial substrate and plankton samples to study veliger and adult mussel densities and size structure prior to and after treatment. An additional partner on this project is the Forest Preserve District of DuPage County.

Additional studies are in the planning phases; these studies will treat a zebra mussel-infested fish pass of the hydro power station in Ballyshannon, County Donegal in September 2012. Researchers at MBI will perform these studies in collaboration with Dr. Frances Lucy, Institute of Technology Sligo, and the Electricity Supply Board of Ireland. The power station blocks the mouth of the River Erne and native salmon must use the salmon pass to move upstream. The current method of mussel control at the power station is mechanical removal and subsequent disposal, which results in the shutdown of the fish pass for weeks at a time. Before trials at the fish pass, treatment simulation style non-target studies will be conducted on two life stages of Atlantic salmon (*Salmo salar*), eggs and parr. These studies will be conducted at the on-site Atlantic salmon conservation hatchery (non-commercial). Results from this effort will further document and support ongoing, non-target work on sensitive fish species and will help evaluate the potential to use Zequanox to protect expensive infrastructure without negatively affecting facility function or the environment.

Supported by a grant from the Great Lakes Restoration Initiative, the NYSM, the U.S. Geological Survey, and the U.S. Fish and Wildlife Service will be completing additional non-target studies with Zequanox in 2012 on multiple life stages of seven freshwater mussel species and seven fish species. These studies will provide the foundation for subsequent field trials that are intended to aid native freshwater mussel (unionid) restoration efforts.

Additional governmental and environmental entities in the Great Lakes region, in both the United States and Canada, are interested in conducting open water development treatments in 2012. MBI is in discussion and preliminary planning phases with these organizations. Zequanox, a studied, environmentally safe treatment for mussel infestations, is reaching initial commercial market use with a long history of studies and testing, and is now expanding into open water use with research and development underway in 2012.

Cathy Karp

Cathy Karp is a fish biologist with the Bureau of Reclamation‘s Technical Service Center in Denver. Prior to that, she was also a fish biologist with the US Fish and Wildlife Service in Utah. Cathy has worked on a variety of fishery projects including movements, distribution and abundance studies of threatened and endangered species, tank studies, and hydraulic flume and fish screening studies. She has a MS in Fishery Biology.

Summary of Laboratory Experiments to Evaluate Consumption of Juvenile/Adult Quagga Mussel by Redear Sunfish and Bluegill

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Abstract

Quagga mussels, *Dreissena bugensis*, from Eurasia are becoming widespread in the Colorado River drainage and associated waterworks, and are impacting state and federal water delivery operations. One potential mussel suppression agent is predation by redear sunfish, *Lepomis micropholus*. Redear sunfish, a molluscivore native to the southeastern United States, occurs in portions of the lower Colorado River. In aquaria experiments, 85.7% of juvenile and adult redear sunfish and bluegill, *L. macrochirus*, were found to consume quagga mussels. Predated mussels were crushed and shell material was regurgitated. Mean mussel size consumed was positively correlated with fish size (r=0.7, P=0.000). These experiments suggest that redear sunfish, and possibly other fish species, may help to suppress quagga mussel colonies in areas where the two c-occur.

Introduction

Quagga mussels (*Dreissena bugensis*) are exotic freshwater bivalves (Mollusca, Dreissenidae) that were introduced to the United States in the mid-1980’s through ballast water discharge (Claudi and Mackie 1994; Mills et al. 1993, 1996; Ram and McMahon 1996). They are native to the southern Bug/Dnieper River delta (north Black Sea, Ukraine; Rosenberg and Ludyanskiy 1994; Son 2007) and were identified in Lake Ontario/Erie Canal in 1989 (May and Marsden 1992; Mills et al. 1993, 1996; Spidle et al. 1994). Quagga mussels have spread through much of the Great Lakes and were discovered in the western United States in Lake Mead in early 2007. Since then, quagga mussels have spread downstream through the lower Colorado River and associated canal, pumping, and power generation facilities. Zebra mussels (Dreissena polymorpha), another exotic freshwater bivalve (Mollusca, Dreissenidae) from Eastern Europe, has spread more quickly through the eastern United States but remains uncommon in the west (Benson 2011).

Zebra and quagga mussels have both benthic and planktonic aspects to their life history. Larvae (veligers) are free-swimming and may disperse through the water body. Juveniles and adults (post-veligers) settle and attach to most hard and soft surfaces using byssal threads, forming thick dense mats. These mussels can also detach and move using their foot like other freshwater bivalves (Toomey et al. 2002). Zebra mussels attain adult size quickly (>8mm) and both species may become reproductive their first year (Mackie 1993; Mackie and Schlosser 1996). Quagga and zebra mussels have somewhat different environmental tolerances (Mackie and Schloesser 1996; Spidle et al. 1994; Stoeckmann 2003) and historical distributions (Orlova et al. 2005; Son 2007), but both species are undergoing rapid range expansion through Europe and the United States (Orlova et al. 2005; Son 2007; Molloy et al. 2007).

Establishment of zebra and quagga mussel in the United States has and will continue to have far-reaching negative economic and ecologic impacts (MacIssac 1996; Kennedy 2007; Strayer 2009; Western Regional Panel on Aquatic Nuisance Species 2009). Mussel infestations clog water intake and conveyance structures thereby reducing water delivery, pumping, and hydropower capabilities (Claudi and Mackie 1994; MacIssac 1996). Additionally, quagga and zebra mussels filter substantial amounts of water (Miller et al. 1992; Strayer 1999) which negatively alters the food web of infested waters, in part by increasing water clarity (MacIssac 1996; Snyder et al. 1997). They also generate and potentially concentrate toxic waste that may pass up the food chain. Possible dreissenid mussel control measures include chlorination (and other chemicals), oxygen deprivation, thermal, electrical, sonic and pressure shock, desiccation, antifouling coatings, toxic bacteria, and predation. The objective of this study was to determine if fish predation on quagga mussels could help suppress mussel colonization in the lower Colorado River. Redear sunfish, *Lepomis micropholus*, were selected for study because they are known molluscivores in southeastern United States (Lee et al. 1980), co-occur with quagga mussels in some areas (e.g., Lake Havasu, introduced to the Colorado River in mid-late 1940's (Minckley 1973)), and have been found with quagga mussels in their stomachs ((Bureau of Reclamation, Zebra and Quagga Mussel Research Program, ZQMRP-2010-RN-06; Figure 1). Bluegills, L. macrochirus, were included because they co-occur with redear sunfish and quagga mussel in Lake Havasu.

Methods

Redear sunfish and bluegill were collected from the upper Lake Havasu, Colorado River in June 2009 and 2010 and transported to Reclamation's Boulder City, Nevada Fish Lab. Fish were held in dechlorinated flowthrough water (19.4-25.6 oC (67-78 oF)) and fed earthworms once daily at least for one month prior to use in experiments. Water temperature was not controlled in first set of experiments and influenced by ambient air temperature. Unused fish were maintained on earthworms for use in later experiments. Fish were kept off feed for 24 h prior to an experiment. Quagga mussels (from the Colorado River and the Willow Beach National Fish Hatchery, US Fish and Wildlife Service) were brought into the lab 24 h prior to use in each set of experiments.

For each experiment, a group of 12-19 mussels were measured and counted into a 10 or 20 gallon aquaria so that each tank contained a similar size range and number of available mussels (small and large sized mussels were uncommon in late fall). After 24h during which the mussels had time to attach to the aquarium sides/bottom (dead mussels were removed and replaced with a similarly sized live individual before the start of each experiment), a single fish was added. Each tank was surrounded in black plastic so that there was no interference from neighboring tanks, or people. Additionally, artificial lighting was reduced during the day. Tanks were maintained on aerated flow-through water for 48 h. At the end of each experiment, the fish was removed from the tank, anesthetized (50-ppm Tricaine Methanesulfonate) and measured (fork length, FL, and total length, TL). Stomachs of some fish were examined for presence of whole or crushed mussels. Remaining mussels were counted and measured (length and height to the nearest mm) and mussel consumption was determined.

Stomachs of all potential molluscivore fish species occurring in lakes Havasu and Mohave were examined for presence of juvenile/adult quagga mussels.

Results

A total of 35 redear sunfish (N=28, 116-310 mm FL) and bluegill (N=7, 117-207 mm FL) predation experiments with quagga mussels were conducted in summer/fall 2009 and 2010. Most fish (85.7%) consumed quagga mussels (89.3% of redear sunfish and 71.4% of bluegill). Consumed quagga mussels averaged 12.4 mm length (3.0-26.8 mm) and 7.4 mm height (2.2-16.2 mm). The largest mussel offered was 28.3 mm in length and 16.1 mm height. Mean mussel size selected was highly correlated with fish size (r=0.7, P=0.0000; Figure 2). Ingested mussels were mostly crushed and shell pieces regurgitated by the redear sunfish. Conversely, ingested mussels were not crushed by bluegill.

A total of 110 fish stomachs comprising 10 species were examined (Table 1). Of these, four species, redear sunfish, bluegill, channel catfish, *Ictalurus punctatus*, and common carp, *Cyprinus carpio*, had consumed quagga mussels.

Discussion

Four fish species were found with quagga mussels in their digestive tract. Of these, redear sunfish is the only true molluscivore currently present in the lower Colorado River system. Redear sunfish have rounded molariform crushing teeth on both upper and lower pharyngeal arches that enables molluscivory when fish reach 25-75 mm in length (Huckins 1997; Huckins et al. 2000; Ledford and Kelly 2006; Collar and Wainwright 2009). Our study found that redear sunfish can consume quagga mussels up to 26.8 mm in length, and that size of predated mussel was correlated with predator size. Redear sunfish are also known to consume zebra mussels up to 20mm in length (French and Morgan 1995; Magoulick and Lewis 2002; Towns 2003).

Predation by crabs, crayfish, turtles, diving ducks, and over 20 fish species on zebra and to a much lesser degree quagga mussels has been documented (French 1993; Boles and Lipcius 1994; French and Morgan 1995; Tucker et al. 1996; Marsden 1997; Molloy et al. 1997; Thorp et al. 1998; Magoulick and Lewis 2002; Andraso 2005; Bartsch et al. 2005; Bowers and Szalay 2007; Watzin et al. 2008). Redear sunfish are not widespread in the lower Colorado River system as other mussel predators because they prefer vegetated littoral areas with submerged stumps and brush with very little or no flowing water (Pflieger 1975; Trautman 1981; Moyle 2002). However, redear sunfish may help to suppress quagga mussel colonization in areas where the two species co-occur.

Renata Claudi

Renata is an Environmental Scientist with over 30 years of diverse business and technical experience. With undergraduate and graduate degrees from McGill University, she is currently the Chief Scientist of RNT Consulting Inc. This Environmental Consulting Company focuses on the various aspects of alien species invasions, including their economic impact, selection of appropriate control options and installation of these control options. The company also undertakes custom research, experimental design and engineering assessment tasks.

Adjustment of background pH as a control strategy for dreissenid mussels in raw water conveyance systems

Renata Claudi MSc., RNT Consulting Inc.

Dreissenid mussels (*Dreissena polymorpha* – zebra mussel and *Dreissena bugensis* – quagga mussel) are an environmental and economic nuisance across North America. When present in the source of raw water, they become a serious problem for all water conveyance systems which carry this water unless their settlement and growth is controlled.

The control treatments of choice tend to be ones which utilize chemicals. Chemical treatments have often proven to be convenient and effective. The major advantage offered by chemical treatments is that they can be engineered to protect raw water in most once through facilities from intake to discharge. A wide variety of chemical treatment strategies is available for controlling mussel populations; however, minimizing local environmental impact is frequently difficult. Chlorine, widely used for dreissenid control, creates undesirable by-products. Proprietary compounds used for mussel control may have to be detoxified by bentonite clay and very few are approved for drinking water applications. Both oxidizing and proprietary products are non-selective and therefore toxic to most forms of aquatic life.

Dreissenid mussels have a relatively narrow range of pH tolerance, with the optimum range being pH 7.5 to 9.3. It was hypothesized that by manipulating this environmental variable it may be possible to control the growth, settlement, and survival of dreissenids in raw water systems by increasing or decreasing the pH outside of the normal range. This adjustment would simulate a chemical treatment but the adjustment would persist much longer than any oxidizing chemical. This would make pH adjustment an appropriate treatment for water conveyance and irrigation systems which retain water for many hours, sometimes days.

A proof of principle experiment was required to verify the hypothesis that pH adjustment could be utilized for dreissenid control. The first experiment carried out in 2009 involved downward adjustment of pH in a flow-through system using a mobile laboratory situated on the shore of Lake Ontario. Phosphoric acid was used to continuously depress the pH in the incoming raw water which contained live dreissenid veligers. The dreissenid mussels present in the study area were primarily quagga mussels. Captive adult mussels were kept in the flow through settlement chambers throughout the experiment. The experiment demonstrated that modest downward adjustment of pH can both inhibit the settlement of quagga mussel and over time, cause significant mortality of adults. In addition, at the pH level which prevented mussel settlement, the length to dry shell to weight relationship, used as an index of mussel fitness, changed. At the lowest pH tested, the mussels were significantly lighter (*i.e.* less fit) for any given length than those in control groups.

The experiment was repeated in a flow-through laboratory at San Justo Reservoir which has a sizable population of zebra mussels. At San Justo, the water quality, particularly the Total Dissolved Solids (TDS), was significantly different from the original site on Lake Ontario. Although low pH inhibited new settlement, there was virtually no mortality observed in captive adults. However, at the lowest pH level tested, once again, the mussels were significantly lighter for any given length than in controls.

Therefore, depending on water quality, a fairly modest downward adjustment of pH may protect a raw water conveyance system from settlement of dreissenid mussels and over time this adjustment may also eliminate any adults which may be present.

Applying the same experimental design to the test of elevated pH, two field experiments were carried out using the flow-through laboratory. The first experiment was carried out on quagga mussels in the Lower Colorado River; the second was performed on zebra mussels using water from San Justo Reservoir in San Benito County, California. In both experiments the pH of the raw water was elevated using sodium hydroxide. Both experiments tested the ability of the dreissenid pediveligers to settle under conditions of elevated pH and the long-term survival of the adult dreissenids under the same conditions.

In both experiments the settlement of dreissenid pediveligers was inhibited with increasing pH. Small, but significant mortality of adults was also observed with increasing pH. The length to dry shell weight relationship did not vary between treatments and control.

In the Lower Colorado River, which has high calcium content (80mg/L), high levels of conductivity (1,000 µSiemens) and high alkalinity 130mg/L, the increase in pH caused unacceptable level of precipitation of calcium carbonate in the raw water. This did not occur at San Justo until very high pH levels were reached. This difference is due to San Justo having lower calcium content (20mg/L), conductivity level of 600 µSiemens and alkalinity of 80mg/L. The difference in chemistry affects the scaling potential of the two bodies of water. Other areas, such as Lake Ontario, have even lower scaling potential due to conductivity, which rarely passes 300 µSiemens. The research site on Lake Ontario had calcium of 40mg/L, conductivity of 300 µSiemens and alkalinity between 90 and 100mg/L.

At San Justo, we also tested the response of adult zebra mussels to very high and very low pH levels to determine if this strategy could be used as an end of season treatment to eliminate settled adults. At the highest pH level tested adults experienced complete mortality in 120 hours. At the bottom of the high pH range tested, complete adult mortality was achieved in 96 hours.

From this project, we conclude that pH adjustment could be used both as a preventative treatment to eliminate settlement by dreissenid mussels and as an end of season treatment to eliminate adults, provided the source water chemistry is appropriate and the materials of construction can tolerate the required changes in pH.

Jackson Gross

Dr. Gross has expertise in ecotoxicology, amphibians, and reproductive and developmental toxicology. His research Interests include invasive species eradication and suppression. Jackson received his PhD in Animal Sciences (Endocrine & Reproductive Phys.) from the University of Wisconsin, Madison. He received his M.S. in Public Health/Toxicology and his B.S. in Biology (Zoology) from San Diego State University.

UV light and seismic technology as potential control strategies for dreissenid mussel invasion

Jackson Gross MSPH PhD

Across the southwest United States, the quagga mussel colonization of dam infrastructure threatens the consistent flow of cooling water required to generate both municipal water and hydroelectric power. The magnitude of such threat calls for reassessment of currently available control methods, both in terms of associated costs and specific life stages they target. Presently, mechanical methods such as physical scrubbing and antifouling paint demands much time and oftentimes laborious. Also, chlorine and other chemicals used to treat infested water are expensive and constrained by stringent environmental regulations. Furthermore, rather than expanding their scope to the mussel's whole life history, established strategies predominantly target life stages that follow or occur immediately prior to settlement; earlier life stages occurring post-fertilization and pre-settlement are largely neglected. In further developing a comprehensive management plan that reduces long-term costs and increases long-term effectiveness, we urge experimenting with other possible control methods. Currently, we are testing the applicability of two types of technology: germicidal UV radiation and seismic technology. Germicidal UV can be artificially generated to induce lethal effects in microorganisms upon exposure. Hence, by using laboratory dose-response data, such process may be applied in the field to target neglected planktonic life stages. Experiments involving pulse pressure technology will investigate the potentials of seismic guns, tools that have recently been pioneered in application to combat various invasive fish species. We hypothesize that fine manipulation of seismic waves may effectively combat quagga mussels larvae and adults. Given confirmation of effectiveness, non-toxic UV radiation and seismic waves may benefit management by reducing current costs associated with mitigation procedures. Other possible strategies to reduce quagga mussel settlement and recruitment are under investigation.

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Management of Invasive Quagga Mussels in a Large Water Supply System

Ricardo De Leon*, Ph.D., William Taylor, Ph.D., Paul A. Rochelle, Ph.D.

The invasive mussel infestation of Western States has very high potential cost implications due to rapid growth and proliferation in the warmer and extensive waterway networks of the West. Although a number of controls for invasive mussels have been reported in the literature, current drinking water and environmental regulations limit the options available for implementation, especially in the Western United States. In response to quagga mussel infestation from the Lower Colorado River, the Metropolitan Water District of Southern California has developed a quagga mussel control plan (QMCP) incorporating enhanced detection, surveillance, and mitigation strategies. Metropolitan's approach is based on Integrated Pest Management (IPM), a strategy developed by the U.S. Department of Agriculture to provide a science based decision-making process that identifies and reduces risks from pests and pest management-related strategies. The QMCP consists of three phases. Phase I addressed immediate quagga mussel detection, surveillance, and mitigation strategies for the first seven months of the mussel infestation. Phase II consists of infrastructure upgrades and a comprehensive, multi-year approach for mussel management, and Phase III will address long-term needs and cost minimization strategies.

Phase I Activities

The Scope of Phase I of the QMCP consisted of: (1) Increased surveillance of Metropolitan's source water conveyance systems for adult mussels by diver and maintenance personnel inspections and detection of larvae by water sampling and analysis.

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Phase II Activities

Interim Chlorination Systems

The presence and spawning of quagga mussels in the lower Colorado River from Lake Mead through Lake Havasu poses a threat to Metropolitan and other Colorado River water users due to the potential to continuously seed water conveyance systems with mussel larvae. Chlorination is the most frequently used means to control mussel larvae entering water systems. Chlorination facilities at the outlet of Copper Basin (5 miles into the aqueduct) and at two additional locations in its system, the outlets of Lakes Mathews and Skinner.

Isolation Barriers

Isolating portions of a water system can be used to conduct mussel control or treatments in smaller sections of a water system. Such localized treatments may include spot-chlorine or molluscicide treatments, use of low oxygen conditions and other approaches antagonistic to mussels. Hydraulic isolation barriers such as drop-gates, valves, floating bulkheads, or stop-logs may be utilized to isolate segments of a water system for treatment, potentially avoiding a complete shutdown of a water system.

Mobile Chlorination Equipment

Continuous chlorination of water entering the CRA at Copper Basin is essential to control the spread of mussel larvae. However, this application only inactivates free-floating larvae entering the aqueduct from Copper Basin, and due to chlorine residual dissipation, does not prevent downstream propagation of existing adult mussel populations. Although large portions of the aqueduct have been dewatered and dried as part of annual maintenance shutdowns with the added benefit of killing attached adult mussels, some siphons and tunnels can't be fully drained, given the limited time available for the shutdowns. Mobile chlorination equipment can provide the ability to periodically chlorinate short reaches of tunnels and siphons. The equipment can be stationed at the targeted facility to apply a controlled dosage of chlorine for two to three weeks.

Integrated Pest Management (IPM)

Integrated Pest Management (IPM) is a strategy developed by the U.S. Department of Agriculture to provide a science based decision-making process that identifies and reduces risks from pests and pest management-related strategies. While IPM was originally conceived to control food/crop-associated pests (e.g., insects), Fish and Game, U.S. Fish and Wildlife Service, and Metropolitan are collaboratively developing a similar approach that can be used to address quagga mussel infestation. Specifically, staff plans to evaluate tactical IPM control measures aimed at: (1) Changing environmental conditions in the CRA or in Metropolitan's reservoirs that will promote a suboptimal or antagonistic environment for quagga mussel attachment, growth or proliferation; (2) Identifying physical or mechanical processes to deter attachment or remove quagga mussels from surfaces; (3) Promoting the use of biological controls such as predators, parasites or diseases targeted to suppress or kill larvae or adult quagga; and (4) Applying oxidative chemical controls (i.e., chlorine) or non-oxidative controls (*i.e*., molluscicides). Limnological and flow pattern studies will be conducted to assess the feasibility of modifying environmental conditions such as oxygen demand, temperature, and pH to control mussels in Metropolitan's reservoirs. In addition, studies of surface treatments, which may deter attachment, and of molluscicide use, will be conducted under laboratory and field conditions. The results of these studies will be used to design infrastructure improvements for long-term management of quagga mussels.

Although IPM provides a framework for activities over several years, immediate actions will need to be prioritized in response to the progress of the infestation over time, and resources will need to be focused on the locations most affected. In addition, IPM strategies will need to be adapted to address the various components of Metropolitan's conveyance system. Based on an initial vulnerability assessment, Metropolitan's system can be divided into five separate environments for mussel colonization: (1) Whitsett Intake pumping plant; (2) Pumps and adjoining pipes at the other pumping plants; (3) Open canals; (4) Siphons and tunnels; and (5) Reservoirs. Each of these components provides a different environment for colonization by quagga mussels; thus, specific control tactics will be developed and applied accordingly.

Phase III Activities

The objective of Phase III will be to implement prioritized long-term infrastructure upgrades identified by work conducted in Phase II and optimize costs. Phase III will also incorporate, as appropriate, strategies for management of quagga mussels as identified by on-going work in Phase II and/or results from external research. It will be necessary to modify operational practices and control strategies as additional information becomes available.

As part of the QMCP, Metropolitan is developing novel approaches for detection, control and management of mussels within its 242 mile-long aqueduct and multiple reservoirs. These novel approaches consist of: 1) new analytical and detection methodologies which include molecular-based detection of veligers in water samples and viability stain studies. Improved monitoring tools will provide additional information needed for management decisions; 2) field testing of coatings that deter the attachment of veligers; 3) laboratory breeding of mussels with the goal of obtaining a consistent source of veligers for inactivation studies with disinfectants and alternative treatments and for developing approaches for interfering with the replicative cycle of mussels ; 4) bench-scale and flow-through disinfection studies of mussels to confirm laboratory-scale results with chlorine and chloramines, coagulants and polymers, and to optimize dose and exposure time at near real-world conditions and 5) lake management studies for control of quagga mussels through manipulation of oxygen levels, flow, and enhanced predation.