Santa Barbara County Parks Department

Quagga Mussel Overview & Management Actions at Cachuma Lake County Park

January 2008

Background

Quagga and Zebra Mussels are non-native aquatic nuisance freshwater mussels from Eastern Europe that clog waterways, undermine healthy lake ecosystems, ruin boat engine cooling systems, and financially burden water resource agencies. They were introduced into the Great Lakes region in 1988 through balast water emptied from ships, and they have spread throughout the midwest and eastern United States. Quagga Mussels (QM) were first discovered in California in Lake Mead and the Colorado River system in January 2007 and have recently been found in several Southern California lakes. Adult Zebra Mussels (ZM) were recently discovered in San Justo Reservoir in Hollister, CA. Quagga and Zebra Mussels are spread primarily by two ways: 1) on recreational boats as living, adult mussels that have adhered to such surfaces as boat hulls and engines and are introduced into uncontaminated lakes; and 2) in microscopic larval form as "veligers" that live in the water column and settle on underwater surfaces and may survive in water on recreational boats.

The following information is taken from many sources. In several cases, text has been taken verbatim, and in those cases, the master source is cited and fully referenced in end-notes.

Potential Impacts

Impacts on Structures
Source: *California's Response to the Zebra/Quagga Mussel Invasion in the West,* May 2007

Mussels of either species are costly fouling pests that cause the greatest economic damage when infesting the pipes, pumps or other components of municipal and industrial water supply systems or power plant cooling water systems. Mussel populations on these and similar structures can build up astonishing densities of up to 750,000 individuals per square meter in layers more than a foot thick. Affected facilities include the intakes, conveyance structures and treatment plants of municipal drinking water systems; industrial cooling, flushing and process water systems; cooling water and service water systems in nuclear, fossil fuel and hydroelectric power plants; dams and impoundments, including inflow and outflow conduits and water level control mechanisms; surface and subsurface agricultural irrigation systems; golf course and park irrigation systems; fire-fighting (hydrant) distribution systems that use untreated surface water; institutional chilled water air conditioning systems that use a surface water supply for makeup water; locks, buoys and other navigation facilities and equipment; and ballast intake and service water systems on cargo vessels that take in fresh water. In treatment plants, impacts can include loss of intake head, obstruction of valves, blockage of rotating screens, cavitation-mediated wear on pump bells and impellers, putrefactive decay of proteinaceous mussel flesh and the related methane gas production...and increased electrocorrosion of steel and cast iron pipelines resulting from bacterial growth around the mussels' byssal attachments.

Ecosystem changes

Quagga and ZM are in the genus *Dreissena*. They are filter feeders, and their primary food source is zooplankton and phytoplankton, which form the basis of the food web. One mussel can filter up to one litre of water/day, and they are considered "ecosystem engineers," as they modify the physical environment by increasing water clarity because of the amount of plankton they consume. This allows deeper penetration of light, which can alter the distribution, diversity, and abundance of submerged plants and algae. For example, Parks staff have spoken with Everett Laney, a biologist with the Army Corps of Engineers in Tulsa Oklahoma, who has seen regional lake clarity increase from six inches to 10 to 12 feet where ZM are present. Native plankton populations have been replaced in lakes with QM from 60-90%. Lake ecosystems can shift from primary food sources being phytoplankton in deeper open waters to macrophytes (aquatic plants) nearshore. This shift in the food web may be detrimental to some species and beneficial to others, however, by far the ecological effects have been overwhelmingly negative. For example, the average weight of whitefish in the Great Lakes as gone from 5 lbs. In 1988 to 1.6 lbs in 2006. Dreissenids, as filter feeders, accumulte heavy metals, trace elements, chemical contaminants, and such toxins as naturally-occuring botulism, in their tissues. These can be passed up the food web to water fowl and other organisms that consume them. There have been massive die-offs of water fowl in the Great Lakes area, which has been contaminated for nearly 2 decades, and the theory is that QM are the culprit (*Why Great Lakes Birds are Dying*, James Janega - CHICAGO TRIBUNE 29 Jan 2008).

Researchers and biologists emphasize that every lake system is unique and predicting effects is difficult. There is a large body of literature on the topic of the effects of Dreissenids; resources are provided at the end of this document

Economic costs of quagga mussel infestation

Source: California's Response to the Zebra/Quagga Mussel Invasion in the West, May 2007. Sources cited *within* this section have been removed, however they will be found in the master document referenced.

The U.S. Department of the Interior says maintenance costs for infested structures and intakes cost millions of dollars annually.

- Plant redesign and zebra mussel control for 72 nuclear and fossil fuel generating plants in the Great Lakes Basin are anticipated to cost in excess of $860 million over the next 10 years.
- Water system overhaul and fishery repair in the Great Lakes region will cost an estimated $4-$5 billion during the next decade. Some facilities are already spending $250,000 a year to combat the zebra mussel.

Quagga/zebra mussels are a problem because they colonize docks, locks, ship hulls, water intake pipes, and other mollusks, and cause great damage to power plants and water treatment facilities. Controls include biocides, chlorine, thermal treatment, and mechanical/manual removal. There are many estimated costs for zebra mussels but the estimates are not always reported in the same units nor do they measure the same impacts, which makes aggregation difficult. O'Neill (1997) reports on a 1995 study of 35 states and three Canadian provinces that found the economic impact of zebra mussels to have total costs of $83 million annually. A number of sources report the general costs of the mussel to be around $6.5 billion for a 10-year period (1990-2000) in the Great Lakes. However, another estimate puts the cost of damages over 10 years to intake pipes, water filtration equipment, and power plants at $3.2 billion.

Many of the cost estimates deal with the impacts on power plants and water treatment plants. Costs to **power plants** range from $6,700 per hour for a 200-megawatt system to $127 million annually for U.S. Great Lakes power plants.

For Great Lakes water users with lake water intake structures, Park and Hushak (1999) report that total monitoring and control costs were $149 million from 1989 to 1994, and averaged $37 million annually from 1992 to 1994.

Costs for water users in the Great Lakes range from $318 per facility in 1994 and $3.3 billion annually. Source: Agricultural and Resource Economics Review, April 2006

Extrapolating from surveys conducted in 1995 of a portion of affected facilities, the retrofitting, operations and maintenance costs to facilities in eastern North America appears to be somewhere around $100 million per year—not including secondary economic costs or environmental costs.

A few general considerations will shape efforts to extrapolate from estimates in the East to projections of costs in the West. Strayer's rough early map of [ZM] potential distribution in North America showed ranges that included most of the United States (including nearly all of California except for the southeastern portion of the state) and much of southern Canada. Strayer noted that low calcium concentrations might limit zebra mussels within this range, and subsequent studies have confirmed this. The U.S. alkalinity map shows low levels of alkalinity over many large areas of the East (especially in New England and the Southeast), but in fewer and smaller areas in the West. Alkalinity is a reasonably good proxy for calcium concentrations, so it appears that in the West a substantially larger portion of the region is chemically suitable for zebra mussels than in the East.

Regarding comparative economic impacts, there are no nuclear power plants in California that draw cooling water from surface freshwater systems (in the East, nuclear plants incurred the highest costs of any type of facility), and there is no inland freshwater system of barge canals, barge and ship locks, or a freshwater cargo fleet. However, California has a much larger and more far-reaching water transport and delivery system, a much greater reliance on agricultural irrigation systems, and a much larger number of hydroelectric power plants. Its economy is more deeply dependent on keeping large volumes of water moving over long distances than is that of any eastern state.

California also has one of the highest concentrations of rare freshwater fish, amphibians, and aquatic invertebrates of any state in the country, many of which are already stressed from pollution, habitat fragmentation and exotic species. In the upper part of San Francisco Bay and the western Delta, the clam *Corbula amurensis* has depleted phytoplankton blooms and probably contributed to the decline in pelagic organisms that is the latest crisis in this ecosystem. If [QM] became established in the Delta, combining its efficient plankton filtration with that of *Corbula*, the results could be devastating.

Given the probably greater vulnerability of western waters, the greater dependence on transporting water long distances, and the highly stressed aquatic ecosystems, the overall economic and environmental impacts of. . . mussel invasion are likely to be at least as great and possibly greater than the impacts in the East.

Prevention

Quagga and ZM cannot be eradicated once they contaminate a water body. Preventing introduction is crucial. The Parks Department is following best management practices recommended in the National Park Service document, *Quagga/Zebra Mussel Infestation Pregention and Response Planning Guide* for prevention/education, early detection and monitoring, and response.

Preventative measures include:
Boat inspections
Boat decontamination after exposure to infected waters
Boater screening/Public education
Monitoring
State protections

Boat Inspections
Parks staff have spoken with several natural resource and recreation agency biologists across North America that have either QM or ZM. Boat entry inspections are still conducted, even where mussels have invaded. Inspections are also conducted by the CA Department of Food and Agriculture and the California border. Parks staff have received training and have conducted boat inspections at Cachuma Lake since December 2007.

Beginning a year earlier, in January 2007, boaters were screened as to their lake visitations. Casitas Lake has also inspected boats since late 2007. After Parks staff surveyed several regional lakes, Parks learned that Casitas is the only other lake conducting boat inspections and sanctioning suspect vessels. Staff at other lakes were either just beginning to take preventative actions such as boat inspections; aware of the threat but without resources to inspect vessels; or not aware of the severity of the threat but at least distributing educational materials to boaters.
It is in the interest of all resource and recreation agency managers of all uninfected lake in California to conduct thorough boat inspections, quarantine boats that have attached mussels or are otherwise suspect, and establish boat decontamination stations.
Biologists in Wisconsin and Minnesota, where quagga and or zebra mussels have been present for nearly 20 years, have stressed emphatically to Parks staff that boat inspections make a difference in preventing and significantly slowing the spread of the mussels (Herman, Montz, pers comm), in no small part due to the value of education.

Boat Decontamination

Vessel decontamination in high pressure washing stations is effective at killing veligers and either killing or removing adult mussels. Water temperature between 104 ^{o} and 140 ^{o} F is necessary, and containment of waste water is required to meet environmental guidelines. Decontamination stations are in use by the Dept of Food and Agriculture at the California/Arizona border and have been installed at Lake Mead and will likely be installed soon in Southern California by the Metropolitan Water District. Parks is actively researching boat washing stations and is in contact with two companies that have provided products to the National Park Service at Lake Mead and to Montana Fish, Wildlife, and Parks. Eight to 10 weeks is required to complete installation and training. Cost estimates range from just under $70,000 for portable stations to $175,000 to $300,000 for permanent stations.

Boater Screening/Public Education

Among the many Park staff contacts made in learning about QM, individuals stressed boater and public education over and over. The value of public outreach cannot be overemphasized. Among natural resource individuals in Minnesota, Wisconsin, and Oklahoma at lakes with established mussels, education was considered crucial to containment of spread. For example, by Wisconsin state law, all waters are open to the public, yet the spread of mussels has been greatly slowed through proper education and monitoring (Herman, pers comm.).

Since Febrary 2007, Parks has promoted the following outreach:

- Signs posted at the Park entrance, boat launching area, bait and tackle shop, and fish cleaning stations
- Fliers about the invasive mussel distributed to all boaters entering the Park
- Promote to boaters the guidelines of the national Stop Aquatic Hitchhikers campaign:
  - Remove vegetation, mud and animals from the boat, motor and trailer
  - Drain water from live wells, bait wells, bilge and motor
  - Rinse the boat and trailer with hot water OR let it dry for five days.
- Boaters verbally screened to determine whether they had been in any infected waters
- Boats inspected (since December 2007)

- Park staff attendance at meeting of the Santa Barbara Sport Fishing Club to provide information about QM and the boat inspections at Cachuma Lake

Monitoring and Sampling
Monitoring protocols for early detection of QM/ZM have been established by the Center for Lakes and Reservoirs, Portland State University, and adopted by the CA Dept of Water Resources and Dept of Fish and Game. All manner of submerged surfaces are inspected visually and tactiley, including docks, loglines, boats, anchor cables, etc. "Settler" QM are described as feeling like sandpaper. In addition, a sampling device, a "portland sampler" has been designed for agencies to reproduce and use in monitoring stations. The samplers are suspended at different depths to provide surface for any QM veligers to colonize. Inspections can also involve collecting samples of plankton to analyze for veligers, in which the samples are sent to specific labs for analysis. This is ideal, and it could mean early detection, howver it is costly, as veligers are microscopic and difficult to identify. However, an increasing number of agencies are arranging training and anaylzing their own samples.

In summer 2007, Parks began monitoring the Cachuma Lake marina for QM using protocols from the Department of Water Resources. Complete details are included in the Parks Quagga Management Summary.

State Protections
Its imperative that funding at the state level be secured to support prevention programs such as monitoring, inspections, and public education. Minnesota set an excellent example by galvanizing efforts to stall spread from the beginning of infestations of ZM. After 20 years of ZM, only a handful of inland lakes have become infested. Minnesota imposed a surcharge on boating licenses to fund education, monitoring, and inspections.
Possible funding sources need to be identified and sanctioned by our state legislators, even in light of state budget shortfalls. The costs of managing infestations far outweigh, by orders of magnitude, the costs of prevention.

Eradication / Control

Source: California's Response to the Zebra/Quagga Mussel Invasion in the West, May 2007. This discussion addresses control in the context of Lake Mead, however, the information can be generalized to apply to other bodies of water.

Lake Mead
After eight years of drought, Lake Mead is currently (4/25/07) 106 feet below its full surface elevation, holds 50% of its maximum volume and covers 61% of its maximum surface area. The mussel-infested areas appear to cover a little under a third of the lake, or about 30,000 acres. This is a large area, but there are several technically feasible eradication methods that would have a strong chance of success if they were promptly and diligently applied at an appropriate scale. The Panel believes that this can be done at a reasonable cost relative to the economic and environmental costs of not acting, and recommends that a determined effort be made to eradicate D. bugensis from Lake Mead.

An efficient eradication effort will likely use a number of methods in combination. We here describe six distinct approaches for killing or removing settled mussels, in the order of their individual effectiveness as ranked by the Panel.

• Dewater:
In experimental treatments, D. bugensis lives for only a few days out of water, so lowering the lake level is a sure method of killing mussels. Hoover Dam has two intake towers on the Nevada side of the lake and two on the Arizona side. From these, water can be withdrawn through tunnels located at 76 feet and 227 feet below the current water surface. This water is usually discharged through the penstock and the power plant turbines, but can also be discharged directly through the jet flow gates under emergency or flood conditions or to empty the penstocks for maintenance work. Assuming mean 2006 net rates of inflow, releasing water at the maximum rate of discharge would lower the lake by about 120,000 acre-feet a day.
Because of impacts to the City of Las Vegas' water supply, it may not be feasible to lower the lake surface below Southern Nevada Water Authority's (SNWA) upper or lower water intakes.

Lowering the lake surface to either the upper SNWA intake or the upper Hoover Dam intake would take about 7 weeks at maximum discharge, and would drop the water by 73-76 feet, reduce the current surface area of the lake by one quarter, and reduce the current volume by almost 40%. This would kill the majority of D. bugensis in the lake,29 and would make the treatment of the remainder considerably easier as they would be closer to the surface and distributed over a smaller area. In addition, a large part of the remaining area is covered by fine lake-bottom sediments that have accumulated since the construction of Hoover Dam,30 which provides a relatively poor substrate for the mussels. If it proved feasible, lowering the lake 123 feet to the lower SNWA intake would require about 11 weeks total, and would reduce the lake to about 55% of its current area and 30% of its current volume; lowering it 227 feet to the lower Hoover Dam intake would take about 16 weeks and would reduce the lake to about 30% of its current area and 15% of its current volume.

• Isolate and Treat:
Mussel populations can be isolated behind barriers or under coverings and then killed with an appropriate biocide. The "killer algae" Caulerpa taxifolia was eradicated from two southern California lagoons by covering the infested areas with plastic mats and pumping liquid sodium hypochlorite or placing chlorine-releasing tablets under the mats.31 Plastic isolation curtains, hanging from floats and anchored to the bottom, have frequently been used for herbicide treatments of aquatic weeds. Similar barriers have been used to contain sediment generated by construction or dredging activities and to contain chemical spills.

A number of biocides are available that would be effective in killing D. bugensis.32 Potassium chloride was used to eradicate D. polymorpha from a 12-acre quarry pond,33 and copper sulphate and sodium hypochlorite were used to eradicate the related black-striped mussel, Mytilopsis sallei, from three boat basins in Australia.34

• Cover:
Plastic mats laid on the bottom are routinely used to kill aquatic weeds. Field trials applying this technique to D. polymorpha produced over 99% mortality in 9 weeks. Mortality was

apparently due to hypoxia, though accumulation of waste products, lack of food or other stresses may have contributed to the effect.35 Covering D. bugensis on the bottom, or tightly wrapping them where they occur on structures, could be an effective, biocide-free technique.36

• Heat:
Water heated to 40° C (104° F) kills D. polymorpha on contact.37 The invasive seaweed Undaria pinnatifida was eradicated from the hull of a vessel sunk in the ocean off Chatham Island, New Zealand, by using electric heating elements inside a shroud fixed to the hull and treating small, inaccessible areas with a modified cutting torch.38 Superheated steam has been applied to benthic populations of Undaria.39

• Batch Treatment:
Batch treatment means treating the entire infested area with a biocide—either all of Lake Mead, or Boulder Basin alone if it can be isolated from the upper part of the lake by a temporary barrier. California has conducted some large batch treatments—including applying rotenone to Lake Kaweah, Frenchman's Lake and Lake Davis to kill white bass and northern pike—but treating Lake Mead would involve a much larger volume of water.

• Mechanical Removal:
Various mechanical techniques have been used to remove mussels and other fouling from structures such as water intakes and pipes which could be employed in Lake Mead. These range from the use of handheld scrapers with attached suction hoses to abrasive blast cleaning using sand, grit or carbon dioxide pellets.

The most efficient program will likely include a combination of approaches. Thus, for example, even a limited draw-down of the lake would improve the effectiveness of other approaches by reducing the area or volume to be treated. Populations could initially be covered, and those not killed by covering alone could be treated beneath the covering with appropriate biocides as regulatory permits become available. In situations where covering is difficult or impractical, heat treatment or mechanical removal may be more cost-effective. Efforts at water intakes and at marinas, boat launches or other locations where recreational boats congregate should receive the highest priority to reduce the infestation of critical infrastructure and reduce the risk of transport to other water bodies. In addition, the large-scale use of plankton tows in Lake Mead in conjunction with these approaches would reduce the further settlement of mussels during the eradication effort and reduce the number of veligers transported downstream. The eradication effort should be guided by a team that includes expertise in zebra mussel biology and ecology, reservoir/riverine hydraulics, mechanical engineering, aquatic species eradication and containment, pesticide (molluscicide) use and aquatic environmental toxicology.

Field trials of Cover, Heat and Mechanical Removal approaches, and of large-scale plankton tows to reduce veliger densities, should begin immediately in Lake Mead, along with trials of the Isolate and Treat approach as soon as regulatory approval can be obtained. Such field trials are equally needed for large-scale eradication planning in the lake, for eradication/control efforts focused on intakes, marinas and boat launches, and for developing rapid response techniques that can be used if zebra mussels are discovered in other water bodies.

Investment should also be made in promising approaches that need longer development times, such as:

• Zebra mussel-specific toxins derived from bacteria or other sources;

• Encapsulating and delivering a biocide in microscopic controlled-release particles ingested by mussels;

• Delivering a biocide in a gel that remains in contact with mussel populations on horizontal, sloped or vertical surfaces.

Downstream Veliger Flow

Veligers that survive passage through the Hoover Dam waterworks and into the Colorado River can drift downstream and settle in the river, in reservoirs or in water diversion systems. Methods of reducing the downstream flow of veligers should be investigated, and implemented if feasible. These could include:

• Large-scale plankton tows, as mentioned above;

• Monitoring veliger distributions in the lake and choosing the timing, location and depth of intake to minimize the number of veligers entrained through Hoover Dam;

• Treating the water drawn though Hoover Dam with a biocide with a very short contact time and a short life and/or no impact at applicable doses on important non-target organisms or public health;43

• Hydrocyclone or filtration to remove veligers from the water drawn though Hoover Dam.

Where they are applicable, these approaches should also be investigated at Davis Dam on Lake Mojave and at Parker Dam on Lake Havasu.

Below Lake Mead

Surveys to date indicate that populations below Lake Mead are small and limited in distribution, and eradication seems feasible with modest effort. Hand picking alone might eliminate the mussels from Lake Havasu. The approaches mentioned above—Mechanical Removal, Cover, Heat or Isolate and Treat—may suffice for the infested marinas and the hatchery in or near Lake Mojave. Any populations in the river itself are likely to be small, and would die out over time if upstream sources of veligers were eliminated.

Eliminating the populations below Lake Mead would have at least two distinct benefits:

• It would substantially reduce the supply of veligers to the Colorado River Aqueduct, the Central Arizona Project, the All American Canal and other large water systems that divert water from the Colorado River below Lake Mojave.44

• It would eliminate two major sources of mussels (Lakes Mojave and Havasu) for accidental transport on boats hauled to other Western waters.

Additional Controls

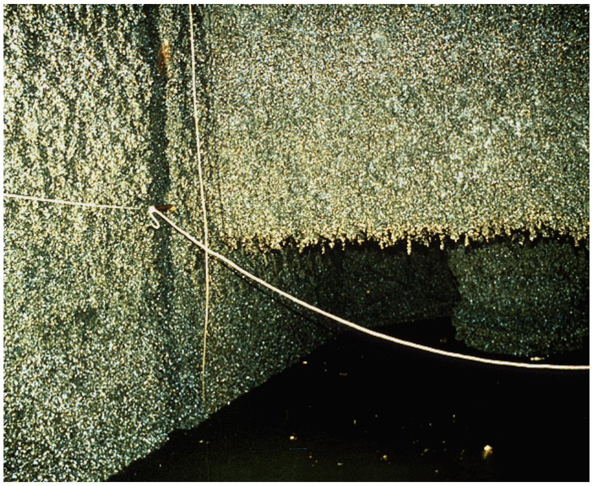
Source: *The U.S. Army Corps of Engineers, Tulsa District, Operations Division, Zebra Mussel Action Plan*, 1993.

Control Measures ⇒ Each facility will have to be assessed independently to determine which control measures will best reduce Zebra Mussel impacts at the various areas of concern. Control measures can be classified as chemical or non-chemical controls.

Chemical Controls ⇒ There are various oxidizing and non-oxidizing chemicals that can be used to control Zebra Mussel. Some of the more commonly used are chlorine, chlorine dioxide, bromine, potassium, and ammonium nitrate. Chemical treatments are costly and labor intensive to install, operate and maintain. Also, a leak in the control system inside our confined facilities would create a safety hazard. The Environmental Protection Agency requires permits and regulates the effluent from the treated water, therefore, a detoxification system would be required: an additional installation, operation, and maintenance cost.

Non-Chemical Controls ⇒ The non-chemical control options are widely diverse. Some of the more proven techniques include; surface coatings, mechanical/physical removal, filters, cathodic and electric fields, freezing, oxygen deprivation, desiccation, thermal, increasing water velocity, copper ionization, and the use of toxic metal components.

Surface Coatings ⇒ Surface coatings are typically in the form of paints that have a base component that Zebra Mussel do not like. Paints that have a silicone or toxic metal base, such as copper, lead, zinc, etc., will deter settling of Zebra Mussel. Zinc plating is also very effective. These methods would require extensive surface preparation and repetition every few years, requiring additional budget, manpower, and downtime. Not all locations would be accessible to surface coatings.



Mechanical or Physical Removal ⇒ Once Zebra Mussel have settled they can be removed by physically scraping or using a hot water high pressure spray to remove them from the surface. There are also some commercial mechanical devices (such as scrubbers) that are effective. After the Zebra Mussel have been removed those that can not be flushed through the structure will have to be removed from the site and disposed of. This method is labor intensive and requires a suitable disposal site for the Zebra Mussel.

Filters ⇒ Filtering of Zebra Mussel from piping systems, such as the cooling water piping for the turbines, require a minimum 40 micron(absolute) filter to prevent passage of veligers. In turbid water pre-filters would be required to remove larger particles. Filter systems would have to be able to provide a continuous flow of raw water, in a sufficient amount, and be self-cleaning. Several manufacturers have stated that they can handle our needs, but at the flows we have the size of the filter system may be extensive. We would likely have problems locating them within the structure, requiring re-routing of the water lines. The piping from the intake to the filter and the backwash water drains would require separate control measures.

Cathodic Protection ⇒ Metal surfaces can be protected with a cathodic current of approximately 50 $mA/m^{2.}$ This technique is site specific but can be effective at specific locations, especially where cathodes are already being used.

Electric Fields ⇒ Some studies have shown that electrical fields can be used to protect metal, concrete, wood, and open water. Electrical fields of 10 mA/ft^2 at 40 V have been applied to concrete surfaces by installing an electrically charged metal mesh to the concrete surface. Another study used 1/8 inch electrodes spaced 2 inches apart over concrete and steel surfaces with 8.05 V/in. Installing such a network of metal mesh or electrodes would be extensive and its durability would be unlikely for most of our applications. The system would be costly to install, maintain, and supply electric for.

Open water areas of our systems (such as within pipes) may be able to be protected for some distance with pulses of electric at a rate of 6.5 kV/cm for 770 nanoseconds. The Zebra Mussel are stunned and pass through the system without settling. Modeling results indicate that efficiencies of more than 50,000 gallons/kWh may be reached. The expense to install this system would likely be acceptable but the electric supply to operate it could be substantial (the Webbers Falls Powerhouse cooling system is 550 GPM and would therefore require 0.66 kw). The effectiveness of this system could be lost when flows cease, possibly allowing the Zebra Mussel to recover, settle, and remain established beyond the electrical field.

Freezing ⇒ Exposure to freezing conditions will kill Zebra Mussel. This technique would be effective and inexpensive on surfaces that can be de-watered during the winter.

Oxygen Deprivation ⇒ If oxygen levels can be maintained low enough and long enough Zebra Mussel can be suffocated. Oxygen depletion can be promoted in water systems with a variety of chemical additives. If chemicals are used EPA permits would likely be required and the system would have to be out of service for an estimated 20 - 120 days. After the Zebra Mussel have died they would then have to be physically removed from sensitive areas.

Desiccation ⇒ Exposure to warm and dry conditions can kill Zebra Mussel over time. They can survive in open-air conditions over seven days, depending on humidity and ambient air conditions. After they have died they would then have to be physically removed from sensitive areas.

Increasing Water Velocity ⇒ Zebra Mussel are not capable of settling on substrate if the mean water velocity is higher that 4.5 fps. If higher velocities can be maintained during operation it could prevent Zebra Mussel establishment.

Thermal ⇒ Water temperatures over 95° F for one hour will kill Zebra Mussel. Higher temperatures will reduce the time needed for 100% mortality. Using this technique requires a hot water source and the ability to hold the water in the system during the treatment. Areas that can not be enclosed for thermal treatment can be cleaned with a high-pressure, hot water (140° F) sprayer that will kill the Zebra Mussel instantly and remove them from the surface being cleaned.

Copper Ionization ⇒ Controlled releases of copper ions will inhibit the establishment of Zebra Mussel. When used in conjunction with a highly hydrated aluminum hydroxide flow that settles in low and laminar flow areas that are most susceptible to Zebra Mussel settlement, its anti-fouling properties are increased. The initial cost for the system and O&M is relatively low. The installation of a feeder line to the cooling water intake may be difficult. The technology for fresh water use is relatively new, but proven.

Toxic Metal Components ⇒ Toxic metals such as copper, zinc, brass, lead, mercury, silver, etc. are less susceptible to Zebra Mussel infestations. Use of copper, brass, or zinc-plated metal instead of steel will deter settlement at those locations.

No Action ⇒ Some locations can be left without control measures if the impacts are insignificant, or installation of controls would not be cost efficient.

SB County Parks Quagga Management Summary

The Santa Barbara County Park Department took the following steps at Cachuma Lake to prevent further spread and introduction into Cachuma Lake and other regional lakes when QM arrived in California in January 2007:

- Signs posted at the Park entrance, boat launching area, bait and tackle shop, and fish cleaning stations
- Fliers about the invasive mussel distributed to all boaters entering the Park
- Boaters verbally screened to determine whether they had been in any infected waters
- All ranger staff viewed boat inspection video.
- UCSB Rowing Team management notified to decontaminate vessels before reintroduction to Cachuma Lake
- Determination that trout plant contractor to Cachuma Lake does not have contact with contaminated waters.
- Determined that Fillmore Hatchery (DFG) does not receive water from Lake Piru, a recreational boating reservoir.
- Created spreadsheet quagga management actions at regional lakes

Continued

- Created Quagga Mussel Centeral Information Folder for Parks staff on a shared drive containing:
  --History of spread and ecology of quagga
  --Fliers and educational materials for public
  --Management strategies and recommended actions
  --Quagga monitoring and boat inspection forms

Monitoring

Parks follows monitoring protocols established by the Center for Lakes and Reservoirs, Portland State University, and adopted by the CA Dept of Water Resources and Dept of Fish and Game. Monitoring inspections are conducted monthly in the Cachuma Lake marina. Visual and tactile inspections are conducted on docks, anchor lines, shoreline, log booms, the boat hanger, and park watercraft. In addition, monitoring stations are being set up on nylon line at varying depths in the marina. Parks is also in the process of establishing a diving inspection in the marina.

Future Monitoring Training: Parks has filled out a survey to participate in a pilot training program in spring 2008 for early detection and monitoring of quagga mussels and other freshwater invasive invertebrates. It is being offered by the University of California Cooperative Extension and the California Sea Grant Extension Program.

Increased Management Actions

Increased management actions were begun in December 2007 and are consistent with protocols at this level of infestation (i.e., no mussels, but moderate-to-high risk based on risk assessment in the National Park Service document, "*Quagga/zebra Mussel Infestation Prevention and Response Planning Guide*"). In addition, these actions are beyond measures being taken at all other lakes in the south coast region with the exception of Casitas Lake.

Vessel Survey and Inspection

- Administered to all boaters
- Boats must have a dry bilge, dry wet well, and clean undersides.
- Copies of surveys are kept on file and CF numbers are kept in database (P:/Icons: Boat Inspections).
- Inspections conducted beginning in the morning when the lake opens
- Frequent boaters given abbreviated interview
- Live bait limited to on-site vendors and night crawlers

Further preventative measures are being initiated, studied, and considered:

- Contractual: Restrictions put into language of permits
  -Permit-only fishing tournaments
  -Trout plants
  -UCSB Rowing Team
- Boat inspection:
  -Boat washing stations
- Additional monitoring:
  -Diving
  -Plankton tows for early detection

Contacts
Parks has been in contact with several individuals regarding QM since January 2007. A complete list is included in the back of this document.
Cachuma staff have been in contact with individuals representing agencies and organizations including the California Departments of Fish and Game, Water Resources, Food and Agriculture, Boating and Waterways; the Minnesota and Wisconsin Depts of Natural Resources; Montana Fish, Wildlife, and Parks; Army Corps of Engineers; National Park Service; US Bureau of Reclamation; Pacific States Marine Fisheries Commission; UC Cooperative Extension, California Sea Grant.
The Casitas Lake operations manager and a ranger acting as quagga coordinator have been exchanging information with SB Parks staff since January 2007. In addition, the following lake managers have also been contacted in the interest of outreach: Castaic, City of San Diego, Nacimiento Lake, Lake San Antonio, Lopez Lake, Piru Lake.

Training
January 2008
1) Boat Inspection Training presented by the Pacific States Marine Fisheries Commission and sponsored by the CA Dept of Fish and Game: Attended by Ranger III and Park Naturalist
2) Boat Inspection Training, Casitas Lake, for seasonal staff. Parks staff attended for observational purposes.
3) Boat Inspection Training DVD: *The Battle to Prevent the Spread of Zebra Mussels on Trailered Watercraft*, Pacific States Marine Fisheries Commission. All Cachuma staff

February 2007
Boat Inspection Training DVD: *The Battle to Prevent the Spread of Zebra Mussels on Trailered Watercraft*, Pacific States Marine Fisheries Commission. All Cachuma staff

Biology

Source: http://el.erdc.usace.army.mil/zebra/zmis/zmishelp4/ecology.htm Citations referenced in this section have been left intact and full citations can be found in the master document at the web address above.

- Ecological relationships are dynamic, two-way interactions:
- Mussels entering a new waterbody are impacted by the characteristics of the water body.
- The mussels will, in turn, alter the characteristics of the water body as their densities increase.

In general, a mussel population will thrive as long as there are:

- Soft or hard substrates for quagga mussels and hard substrates for zebra mussels to settle on and attach to.
- Appropriate physical and chemical conditions in the water (e.g., pH, calcium level, temperature, salinity level, water velocity).
- Appropriate biological conditions (e.g., adequate food resources).

Water Body Characteristics Impacting Mussels

When mussels enter a water body, their chances of establishing a viable and successful population are dependent on the characteristics of the new habitat. In particular, a number of physiochemical and biological factors play key roles in this process.

Physiochemical Factors

Often the most critical physiochemical factors in determining successful zebra mussel establishment in a water body are: water temperature; levels of calcium, pH, dissolved oxygen, salinity; water velocity, substrate availability.

Effect of Temperature on Survival

The minimal temperature for growth and development in ZM is approximately 50^{o} F. Quagga and ZM cannot survive freezing temperatures. Optimum upper tolerance is below 77^{o} F, though upper tolerances could shift after years of selective pressure, resulting in higher temperature tolerance over time.

pH Level

The amount of hydrogen ions in the water, i.e., the pH, is a very critical characteristic determining whether zebra mussels will be able to survive and reproduce in a water body. Sprung (1987) indicated that a pH lower than 7.4 inhibited zebra mussel larval development. Kornobis (1977) reported that pH levels of 7.2-8.7 had little effect on veliger densities. Stanczykowska (1977) recorded zebra mussels in European lakes with pH levels of 7.7-8.5. Laboratory studies by Bowman and Bailey (1998) have indicated that the upper pH tolerance limit of zebra mussels is between 9.3 and 9.6.

For zebra mussels to successfully grow and reproduce, a sufficient amount of oxygen must be dissolved in the water. Karatayev et al. (1998) indicate that zebra mussels require at least 25 percent oxygen saturation. This is usually not a problem in their preferred shallow-water habitats. The quagga mussel, however, is apparently more tolerant of low oxygen conditions (Karatayev et al. 1998). Mussel oxygen consumption varies with ambient water temperature and physiological condition of an organism. Oxygen levels near the saturation values for a body of water are best for successful zebra mussel growth and reproduction. Stanczykowska (1977) found zebra mussels in European lakes with hypolimnetic oxygen levels ranging from 0.1-11.2 mg/l. Epilimnetic oxygen levels for the same lakes ranged from 4.2-13.3 mg/l (Stanczykowska 1977). These levels are common in most North American lakes. Zebra mussels (especially smaller ones) can survive for days under anaerobic (little to no oxygen) conditions, with longer survival at lower temperatures (Matthews and McMahon 1999). Although zebra mussels can survive for periods of time at very low oxygen concentrations, these conditions may not be conducive to growth or successful reproduction (Woynarovich 1961).

Salinity Level

Zebra mussels are freshwater organisms, but do possess a limited ability to tolerate brackish conditions. North American populations will tolerate salinity levels up to 5 ppt for short periods of time, but they will not generally survive at constant salinity concentrations above this level. They have, for example, invaded the oligohaline portion of the Hudson River Estuary and are surviving in 2-5 ppt salinity (Walton 1996). Zebra mussels are able to tolerate salinities better when they have been acclimated to increasing levels over time (Wilcox and Dietz 1998).

Water Velocity/Settlement

The speed that water moves impacts settlement and attachment of zebra mussels and plays a role in their ability to feed. Juveniles will settle in internal piping and along any submerged area with a flow rate of less than 1.5 m/sec (Claudi and Mackie 1994). Zebra mussels avoid such high-velocity flow locations and typically will detach from such a poor settlement location and move (e.g., crawl, float) to a more suitable site.

Feeding

The laboratory feeding studies of Ackerman (1999) have indicated that the ability of dreissenid mussels (both *D. polymorpha* and *D. bugensis*) to clear plankton can be affected by water velocity. Increasing ambient velocity up to approximately 10 cm/sec led to increased clearance rates by the mussels, but the higher velocity of approximately 20 cm/sec was inhibitory and resulted in reduced clearance rates. Although there were no detectable differences in the clearance rates of *D. polymorpha* and *D. bugensis* of equal size tested at approximately 10 cm/sec, large mussels of both species had greater clearance rates than small ones.

Substrate Availability

One of the most critical factors that affects the distribution and abundance of *D. polymorpha* is suitable substrate for attachment (Karatayev et al. 1998). Juvenile and adult zebra mussels are epifaunal and sessile. They are most abundant on hard surfaces, particularly rocky surfaces, and on aquatic plants.

Although possible, it is more rare that they will successfully establish a colony on soft, fine sediments like silts and clays. Zebra mussels can often live in such silty sediments by initially attaching to small fragments of plants, wood, shells, and stones and subsequently attaching to each other to form colonies. Berkman et al. (1998) have provided evidence that zebra mussels can directly colonize sand particles smaller than 1 mm and then use their byssal threads to bind sediments into conglomerates.

Food Supply

Quagga and [ZM] feed primarily on planktonic algae and zooplankton. Other nutritional sources are bacteria, detritus, and organic mater. When food resources are limiting, intraspecific competition within a zebra mussel population for food can probably be a significant mortality factor and a major density-dependent, population-regulating mechanism. Adult zebra mussels in high-density populations, for example, may compete with their planktonic larvae for limited food resources, thus reducing survival of their planktonic larvae. Strayer et al. (1996) provided evidence that adult zebra mussels outcompeted their pelagic larvae for phytoplankton in the Hudson River and suggested that such food-limited zebra mussel populations may be especially frequent in rivers and estuaries, where ratio of food supply to available substratum is small.

The laboratory investigations of Schneider et al. (1998) indicated that food quality may be a better indicator of environmental conditions suitable for zebra mussel growth than food quantity. Their results suggest, therefore, that the conditions of high suspended inorganic sediment concentrations in large, turbid rivers represent a difficult growth environment for [QM and ZM].

Natural Enemies

Natural enemies are organisms that debilitate or kill *Dreissena*, including predators, parasites (both multicellular and microbial), and benthic competitors (i.e., organisms capable of competitively displacing *Dreissena* from substrates). In their review of the international literature on natural enemies of *Dreissena*, Molloy et al. (1997) cited 176 species involved in predation, 34 in parasitism, and 10 in competitive exclusion of *Dreissena*. The vast majority of species that are natural enemies in Eurasia are not present in North America, but ecologically similar organisms do exist, particularly among predators (Molloy et al. 1997). *Dreissena* is a novel and abundant organism for these North American species, and they have become the new natural enemies of *Dreissena*. The idea that these organisms might eliminate mussel populations, even in limited areas of North America, however, is far more hopeful than realistic.

As zebra mussel populations attempt to expand in density and biomass within North American water bodies, natural enemies, particularly molluscivores, undoubtedly are exerting a suppressive influence, but to what extent is unclear. Although seasonal and localized reductions of *Dreissena* densities by natural enemies have been documented in both North America and Europe (Molloy et al. 1997), the high recruitment rate typical of *Dreissena* populations inherently makes them very difficult for natural enemies to control over the long term. One theory holds that *Dreissena* in North America, being a nonindigenous pest, quickly reached high population densities in the Great Lakes and elsewhere primarily due to the absence of an established natural enemy complex. The ability of natural enemies to regulate prey populations, however, depends upon the prey's rate of increase. If the net rate of increase is too great, then the prey population can escape control. i.e., no matter what functional and numerical responses are mounted by natural enemies, they simply cannot keep up with prey reproduction (Crawley 1992b). Molloy et al. (1997) therefore, concluded that in North America, as in Eurasia, there will likely be isolated reports of major impacts by natural enemies, and on the whole, a cumulative effect of a complex of enemies having a constant, but limited, role in suppressing *Dreissena* populations is likely.

Reproduction

The amount of time required for a fertilized gamete to develop into a fully developed juvenile is longer at colder water temperatures and thus can range from 8 to 240 days (Nichols 1996). Mussels are considered adults when they become sexually mature. Adult mussels range from approximately 6 to 45 mm and generally live to be 2-3 years old in temperate climates.

Zebra mussels are diecious (i.e., separate sexes) and are almost always capable of reproducing within their initial 12 months of life. Mussels settling in late spring or early summer typically grow and mature quickly during the warm summer months. Adults with shell lengths exceeding 8 to 9 mm can start to spawn (release gametes into the water column) as early as May of the following year. Fertilization occurs in the water column, and adults have been known to annually produce over 1 million eggs or 10 billion sperm (Sprung 1991).

Veliger densities typically peak in midsummer in North America, with lower densities present in spring and autumn. California's mild climate allows QM and ZM to spawn year-round, thus, veligers could be detected at any time of year. In colder climates, spawning stops in winter. Primary veliger settlement generally occurs between 18 and 90 days after fertilization, when they attach to a substrate. The veliger crawls on the surface of a substrate until it receives the appropriate cues (probably physiochemical) to attach a byssal thread. This thread provides the anchor that enables the veliger to stay securely attached during its transformation into the adult stage. Recently settled juveniles may be attached to any hard substrate, including other zebra mussels. Quagga mussels can attach to hard or soft substrates.

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Sources

California's Response to the Zebra/Quagga Mussel Invasion in the West, May 2007
Recommendations of the California Science Advisory Panel
Prepared for the California Incident Command: California Department of Fish and Game, California Department of Water Resources, US Fish and Wildlife Service, California Department of Food and Agriculture, California Department of Boating and Waterways

Zebra Mussel Action Plan, Everett E. Laney, U.S. Army Corps of Engineers, Tulsa District, Operations Division, U.S. Army Corps of Engineers, 1993.

http://el.erdc.usace.army.mil/zebra/zmis/zmishelp4/ecology.htm:
Section edited for scientific content by Danielle M. Crosier and Daniel P. Molloy, Division of Research & Collections, New York State Museum, Field Research Laboratory, Cambridge, New York 12816

Quagga/Zebra Mussel Infestation Prevention and Response Planning Guide, May 2007Natural Resources Program Center, Fort Collins, CO, National Park Service, U.S. Department of the Interior

Why Great Lakes Birds are Dying, James Janega - CHICAGO TRIBUNE 29 Jan 2008

Contacts

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Wisonsin Dept of Natural Resources, Clean Boats, Clean Waters volunteer boat inspection program; heavily involved in public outreach. Provided data indicating an 80% increase over three years in boaters taking preventative steps to clean boats, and a 90% increase in number of boaters who are informed about aquatic invasive species.
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Steven Wells
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Designed the "Portland Sampler" for monitoring mussels. Runs lab that processes samples of plankton to identify QM and ZM. Has taught Metropolitan Water District and Idaho Fish and Game how to examine their own plankton samples. Can be hired to test samples and to teach veliger identification. Emphasized the value of public education and outreach.
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Bill Zook
Developer, Watercraft Inspection Training Program for Pacific States Marine Fisheries Commission. Retired Fisheries Program Manager for the Washington Department of Fish and Wildlife. Initiated the Aquatic Nuisance Species Program in Washington in the late 1990's, a program that is considered a model for the western US. For the last five years he has been the zebra/quagga mussel outreach and education coordinator for the western US as a contractor for the Pacific States Marine Fisheries Commission.

Web Resources

General information:
www.dfg.ca.gov/invasives/quaggamussel/
www.des.water.ca.gov/zmwatch/
nas.er.usgs.gov/queries/FactSheet.asp?speciesID=95

Fish & Wildlife Service 100th Meridian Project: www.100thmeridian.org

Quagga Monitoring:
ucce.ucdavis.edu/survey/survey
http://www.clr.pdx.edu/projects/volunteer/zebra.php

Sea Grant Database: http://nsgl.gso.uri.edu/search/

Watercraft cleaning stations:
www.greenfield-industries.com
www.hydroblaster.com

Brief, Encouraging, Closing Words:

Three biologists who have been involved in quagga and zebra mussel management for many years, and with whom Parks staff had detailed conversations, are not dispirited. To the question, “Are the mussels inevitable?” each individual replied, “No.”