SPECIES AT A GLANCE

Zebra and Quagga Mussels

Amy Benson, U.S. Geological Survey

REPORT THIS SPECIES! Oregon: 1-866-INVADER or Oregon InvasivesHotline.org; **Washington:** 1-888-WDFW-AIS; **California:** 1-916-651-8797 or email invasives@dfg.ca.gov; **Other states:** 1-877-STOP-ANS.

Two tiny mussels, the **zebra mussel** *(Dreissena polymorpha)* and the **quagga mussel** *(Dreissena rostriformis bugensis)*, are causing big problems for the economy and the environment in the west. Colonies of millions of mussels can clog underwater infrastructure, costing taxpayers millions of dollars, and can strip nutrients from nearly all the water in a lake in a single day, turning entire ecosystems upside down. Zebra and quagga mussels are already well established in the Great Lakes and Mississippi Basin and are beginning to invade Western states. It takes only one contaminated boat to introduce zebra and quagga mussels into a new watershed; once they have been introduced, they are virtually impossible to control.

Species in the news

Oregon Public Broadcasting's coverage of quagga mussels: www.opb.org/programs/ofg/episodes/view/1901

Learning extensions

Like a Mussel out of Water

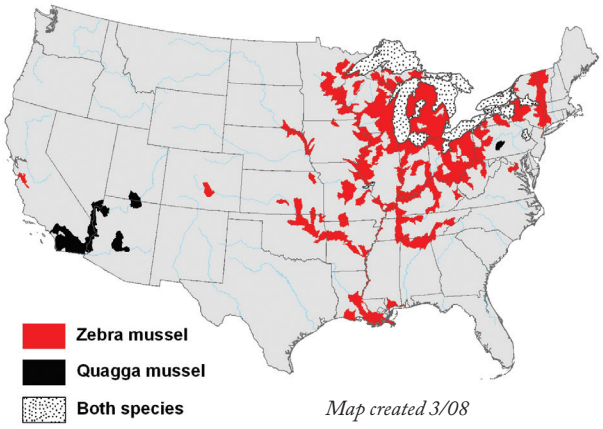
Resources

Invasion of the Quagga Mussels! slide show: waterbase.uwm.edu/media/cruise/invasion_files/frame.html

(Only viewable with Microsoft Internet Explorer)

Why you should care

These tiny invaders have dramatically changed entire ecosystems, and they cost taxpayers billions of dollars every year. They foul and clog pipes, water treatment plants, and dam turbines and give a competitive boost to toxic algae. By accumulating toxins in their flesh, they can become poisonous to animals that eat them. (They have killed thousands of birds in the Great Lakes.) Zebra and quagga mussels are just starting to invade the West Coast, threatening ecosystems, economies, and our way of life.



Data on map represents established population and species occurrence data

How they got here and spread

Zebra and quagga mussels were introduced to the Great Lakes from the Caspian and Black Sea region in the 1990s through ship ballast water. Since their introduction, they have spread by attaching to boat hulls, motors, and engine cooling intake lines or pipes, or by surviving as larvae in boats' water-holding areas.

What you can do

It is not too late to stop the spread. Every citizen can help. Boaters and anglers should clean and dry gear before leaving or entering a water body. Tell your friends and neighbors about aquatic invasive species, their dramatic impacts, and what we can all do to prevent their spread.

COOL FACTS

Researchers estimate that a large (18,000/m^2) population of mussels could filter the entire volume of Lake Dardanelle in Arkansas (13,600 ha/5,300 m^3) 20 times in a day.

Quagga and zebra mussels can stay alive out of water for up to 20 days!

Zebra and quagga mussels are the only freshwater mussels in North Amreica that can attach to things using byssal threads.

Zebra and Quagga Mussels

Randy Westbrooks

Zebra Mussel

Dreissena polymorpha

The zebra mussel is a freshwater bivalve that, true to its name, is often striped with dark bands like a zebra, but it can also be pure black or unpigmented. This small mussel (about 3 cm long) is easily recognized by its triangular shape and one flat edge where its byssal threads (for attaching to hard surfaces) emerge.

Wen Baldwin

Quagga Mussel

Dreissena rostriformis bugensis

Quagga are also tiny, but wider and thinner than zebra mussels. They are fan shaped, with sharp edges on both sides, and white with dark rings on the outer edge. Both mussels are about the size of a fingernail.

NATIVE AND INVASIVE RANGE

Zebra mussels are native to the Caspian and Black Seas (Eurasia); quagga mussels are native to the Dneiper River drainage in Ukraine. Both mussels have invaded freshwater systems of the UK, Western Europe, Canada, and the United States. In the United States, zebra mussels were established in the Great Lakes by 1986; quagga mussels were discovered in the Erie Canal and Lake Ontario in 1991. Now, zebra mussels are widespread in the Great Lakes and all the major river drainages east of the Rocky Mountains. Quagga mussels are mostly confined to the lower Great Lakes area and seem to be replacing zebra mussels where their populations overlap.

WEST COAST DISTRIBUTION

Quagga and zebra mussels have breached the Rockies and invaded Western states. Quagga mussels were discovered in Lake Mead (Arizona) in 2007, and within months their shells were washing up on the shores of Lake Mohave (borders Arizona, California, and Nevada) and Lake Havasu (borders California and Arizona). In southern California, quagga mussels have been found in several reservoirs that are part of the Metropolitan Water District, which brings Colorado River water to southern California, supplying the region with half of its drinking water. In 2008, zebra mussels were discovered in the San Justo Reservoir in central California. Overland transport of boats fouled by zebra and quagga mussels likely aided their transport across the Rockies. Boaters need to take special care to wash their boats and help keep these mussels from spreading north to Oregon and Washington.

ECOLOGY

Life cycles and migration patterns

Zebra and quagga mussels are closely related and thus have similar biological and ecological traits that allow them both to be highly invasive. Both species have a very high reproductive capacity: the zebra mussel can produce up to one million eggs in a spawning

season! Also, both species are dioecious, which means male and female reproductive organs are in separate individuals. Males and females release their eggs and sperm simultaneously into the water, where they become fertilized and develop into microscopic larvae called *veligers*. Veligers are planktonic (free floating) for several weeks before developing into the juvenile stage, where they settle, attach to any hard substrate, and develop into adult mussels. Zebra mussels reach sexual maturity in the first or second year of life and live for three to nine years. Rapid reproduction and a planktonic life stage allow both species to spread quickly throughout a water body.

Habitat and food webs

Both zebra and quagga mussels occupy freshwater habitats such as lakes, waterways, and ponds, where they colonize underwater surfaces such as rocks, boat hulls, and other mussels and crayfish. To attach themselves, they use an external organ called a *byssus*, which consists of many sticky, glue-like threads that are extremely strong. No other freshwater mussel in the United States has them!

Zebra and quagga mussels differ as to what substrate they are able to attach to. Zebra mussels tend to be limited to hard surfaces, whereas quagga mussels can also colonize soft surfaces such as sandy lake bottoms.

COOL FACTS

Through a very selective filtering mechanism, zebra mussels are able to distinguish between different species of algae, rejecting the cyanobacteria that are responsible for toxic algae blooms.

Zebra mussels can stay alive out of water in cool, moist conditions for up to 15 days!

Mature female zebra mussels may have the highest fecundity among freshwater mollusks, producing up to 1 million eggs per year!

Quagga mussels are named after the *quagga*, an extinct African relative of the zebra.

In their native range in the Dnieper River, populations of zebra mussels have been largely replaced by quaggas; anecdotal evidence indicates that similar trends may be occurring here in the Great Lakes.

Also, while quaggas are able to colonize more surfaces in a lake, zebra mussels are more likely to successfully invade river systems (but will not settle in currents greater than 2m/sec). These differences may be related to the strength of their byssal threads (the zebra mussel's are stronger), but also the distinct flat edge of the zebra mussel could increase its stability and grip on hard, flat surfaces.

The optimal temperature for zebra mussel reproduction is 14 to 16°C, while the minimum spawning temperature for quagga mussels is much lower, at 9°C. In one case, a female quagga mussel with mature gonads was found in Lake Erie at a temperature of 4.8°C! The lower temperature tolerance of quagga mussels enables it to invade deeper, cooler waters than the zebra mussel and reproduce more often throughout the year (including winter months, in some climates).

Differences in temperature tolerances and ability to attach to substrate may be giving quagga mussels a competitive edge in the Great Lakes. In a system once dominated by zebra mussels, quagga mussels are now outnumbering zebras in Lake Michigan, probably because they survive in deeper waters and attach to the soft, sandy substrate. It is thought that exploding quagga mussel populations in the Great Lakes will make a bad problem worse by magnifying the impacts.

North American comparisons of salinity tolerances revealed that neither species could survive salinity levels greater than 5 parts per thousand (ppt). However, zebra mussels in their native range (Ukraine) show greater acclimation to salinity extremes than in North America, which suggests that estuaries may also be at risk of invasion.

Zebra mussels are generally restricted to water bodies that have high calcium levels (>20 mg/L). They need calcium for osmoregulation (maintaining the correct salt and water balance in their blood). Calcium is also used for shell and gamete production. (There is conflicting evidence about the quagga mussel's calcium requirements, and a clear need for additional studies.) A calcium-based risk assessment for zebra and quagga mussels in 2008 ranked the Columbia River and most of California's water bodies as high risk (calcium concentrations >28 mg/L). The Pacific Northwest in general was ranked either as low risk or highly variable. However, even in areas of low risk, pockets of high calcium levels exist and could still be invaded.

Zebra and quagga mussel comparison chart

Trait	Zebra Mussels	Quagga Mussels
Habitat occupied	Lakes, waterways, and ponds; and rivers with currents less than 2 m/sec.	Lakes, waterways, and ponds
Salinity tolerance	Up to 6 ppt	Up to 6 ppt
Calcium requirement	Above 20 mg/L	Not tested
Minimum spawning temperature	12°C	9°C
Substrate colonized	Hard only	Hard and soft

Bacteria are the main food for the veligers. As adults, quagga and zebra mussels filter-feed phytoplankton and zooplankton from the water column. They are voracious filter feeders: one mussel can filter one liter of water per day. These high filtration rates have dramatically increased the water clarity of the Great Lakes.

HOW THESE SPECIES GOT HERE

Zebra and quagga mussels were introduced to the Great Lakes as larvae transported in ballast water on a commercial cargo ship.

HOW THESE SPECIES SPREAD

Transport vectors for adult mussels include contaminated machinery, aquarium dumping, and, most importantly, trailered boats with adult mussels attached to the hulls, motors, or engine-cooling intake pipes. It is estimated that, given average summer temperature and humidity conditions, adult zebra mussels attached to a trailered boat could survive an overland trip for up to five days, and up to several weeks under high humidity and cool temperatures. Larvae are easily transported overland in bilge pumps, through fish stocking from aquaculture, on bird feathers, on scientific sampling equipment, or on scuba gear. Passive downstream transportation of larvae also contributes to zebra mussel's rapid range expansion in the United States.

ECOLOGICAL IMPACTS

Scientists have documented numerous ecological impacts of zebra and quagga mussels, and many of the impacts are due to their enormous but selective filtering capacity.

The Great Lakes are naturally pelagic-based ecosystems, which means that free-floating pelagic plankton form the base of the food web. By filter-feeding large amounts of plankton, zebra and quagga mussels remove a major food source for most of the lake life. Their filter-feeding capacity can substantially clear the water column, allowing more light to reach the lake floor, which increases photosynthesis in bottom-dwelling plants. However, increases in light have often led to a chain of unintended consequences by stimulating large increases in aquatic invasive weed and heavy blooms of cyanobacteria that can turn toxic. As mussels filter plankton from the water column, they also deposit rejected food and feces on the lake floor. All this extra fertilizer, combined with the increased light, makes the lake bottom much more productive than normal. Bottom-dwelling organisms, such as crayfish and plants, enjoy the increased nutrients and sunlight, while pelagic-based organisms find less food available. Thus, the tiny zebra and quagga mussels are able to engineer a shift from a pelagic-based to a benthic-based ecosystem. This is called benthefication.

Zebra mussels don't filter everything, though. Amazingly, zebra mussels are able to selectively avoid filtering toxic cyanobacteria. This gives the cyanobacteria a competitive advantage and increases the possibility of cyanobacteria toxic blooms. (See *Selective Filtering In Action*, under *Videos* in *Additional Resources*.)

NOAA Great Lakes Environmental Research Laboratory

Excessive aquatic plant growth as a result of increased water clarity in Lake St. Claire, MI.

Courtesy U.S.Geological Survey

Zebra mussels are no longer than a fingernail.

In addition to efficient filtering, zebra mussels' rapid colonization of most substrates can lead to other impacts. Zebra mussels have covered gravel-beds, which are important spawning grounds for lake trout and other fish. Massive zebra mussel colonization causes suffocation, shell deformity, starvation, and energetic stress, leading to the death of native mussels. The loss of native mussel populations in the Great Lakes and the Mississippi River is among the best-documented impacts of zebra mussels.

As they filter-feed plankton and particles in the water column, zebra and quagga mussels accumulate environmental contaminants in their fatty tissues. These toxins can cause disease and death in other organisms that prey on the mussels. For example, thousands of gulls and loons in the Great Lakes have died from eating round gobies (also an invasive species) that became infested with botulism after eating zebra and quagga mussels. This process is called *bioaccumulation*. Bioacumulation compromises the reproductive success of fish and birds that prey on zebra mussels, and ultimately represents a potential health hazard to humans. (See *Zebra Mussels Rule*, under *Articles* in *Additional Resources*.)

ECONOMIC IMPACTS

Zebra and quagga mussels colonize any hard, stable, submersed substrate. Quagga mussels can colonize soft surfaces, including plants. Such biofouling clogs water supply pipes of hydroelectric and nuclear power facilities, restricting flow and compromising function and safety of these industries. In California, approximately 1,000 km of major freshwater aqueducts and pipelines in the State and Federal Water project systems that provide water to cities and agriculture in many areas of the state can be affected. Any shut down or effects to these systems caused by zebra mussels would cause major economic and health impacts in California. If allowed to invade the Columbia River, zebra and quagga mussels could clog the many hydroelectric dams and increase the cost of maintenance. This increased cost would be passed on to the customer.

Recreational boaters experience equipment damage and increased drag (hence, increased fuel consumption) due to biofouling of hulls and motors. Biofouling can also cause overheating and damage to irrigation pump motors and weight and sink buoys, and it can accelerate deterioration of dock pilings. Control efforts cost facility operators about one billion dollars per year.

Commercially and culturally important fish, such as walleye in the Great Lakes and salmon in the Pacific Northwest, can be negatively impacted by ecosystem impacts from zebra and quagga mussels.

CULTURAL SIGNIFICANCE

Some people appreciate the increased water clarity resulting from zebra mussel filter-feeding; however,

The consequences of benthefication

The shift from a pelagic- to a benthic-based ecosystem, or *benthification*, can impact the food web of an entire lake, river, or reservoir. Planktivorous fish that normally feed on free-floating zooplankton may suffer a population loss or shift feeding from pelagic to benthic habitats. Increased benthic plant populations (as well as vast colonies of zebra mussels) can create food sources and habitat for benthic-feeding fish and macroinvertebrates. In addition, increased water clarity will make certain species more vulnerable to predation by visual predators.

they mistakenly equate clarity with cleanliness. Zebra mussels filter only the plankton, but leave behind pollutants and toxin-producing cyanobacteria.

LAWS CURRENTLY IN PLACE

- The National Invasive Species Act of 1996 requires ballast water management in an effort to prevent the introduction and further spread of non-indigenous species in U.S. waters.
- In Washington, California, and Oregon, zebra and quagga mussels are classified as a *prohibited* species and are therefore illegal to possess. In Washington, it is illegal to transport plant material (which may have zebra mussels attached) on boats.
- California requires all trailered boats entering the state to stop for inspection at agricultural inspection stations. Boats containing zebra mussels will be quarantined.

HEALTH HAZARDS

Zebra and quagga mussels can accumulate environmental contaminants and therefore represent a significant threat to human health. Fish that have accumulated pollutants from eating contaminated mussels may wind up on our dinner plate!

Alos, mussel shells can accumulate on the beaches of reservoirs or lakes with large populations. Recreational use of beaches could be impacted by large deposits of these sharp shells and odors from decomposing mussels on beaches.

MANAGEMENT STRATEGIES

Prevention

Once mussels invade a water body, they are virtually impossible to remove. Therefore, control efforts are focused on reducing their spread by launching public education campaigns and intercepting vectors, such as trailered boats.

One example of a public education campaign is the online training program offered by the 100th Meridian Initiative, at www.100thmeridian.org/certificate.asp. The program provides simple steps for stopping aquatic hitchhikers such as the quagga mussel. The 100th Meridian Initiative is a cooperative effort of state, provincial, federal, local, and private interests that seeks to prevent the westward spread of aquatic invasives in North America.

One way to keep mussels from growing on your boat is to use appropriate coatings. Select the coating carefully since some, such as copper and zinc, are toxic. There are also some non-toxic, silicone-based boat coatings available. Toxic constructed piping (copper, brass, galvanized metals) can also help prevent mussels from growing.

There are also some high-tech prevention strategies, such as an early-detection technique that uses polymerase chain reactions (PCR) to amplify zebra and quagga mussel DNA. This technique allows scientists to detect mussels at the planktonic stage and before adult mussels are visible.

Control of established populations

Many poisons don't control zebra mussels, because the mussels will stop filtering once they detect a toxic substance in the environment. However, researchers at the University of Cambridge in England have found a way to trick the zebra mussel into ingesting toxins. By coating the poison potassium chloride with vegetable oil, zebra mussels mistake these particles as food and concentrate them in their gut at lethal levels. In a controlled environment, 60% of mussels died when exposed to the cloaked poison. However, the effectiveness of this control method still needs to be tested in the natural environment.

Researchers at Marrone Organic Innovations in Davis, California, are working with Cambridge Field Research Laboratory at the New York State Museum to develop biocides from the soil bacterium *Pseudomonas flourescens*. This bacterium is toxic to zebra and

Cathy McBride

Shoe encrusted with quagga mussels after just 3.5 months.

quagga mussels and appears to have minimal impact on other aquatic organisms. This product, however, has not been approved by the US EPA for use and is still in the testing phase.

The following methods can be used to temporarily remove zebra mussels: **Important note: Many of these methods will harm other species and are appropriate only for settings isolated from natural ecosystems.**

- applying chemical molluskicides (chlorine, chlorine dioxide)
- manually removing organisms (pigging, high-pressure wash)
- dewatering/desiccating (freezing, heated air)
- using thermal techniques (steam injection, hot water at 3°C)
- applying acoustical vibration or electrical current
- using filters
- applying coatings: toxic (copper, zinc) and non-toxic (silicone-based)
- using toxic constructed piping (copper, brass, galvanized metals)
- injecting CO2
- applying ultraviolet light
- subjecting organisms to anoxia/hypoxia
- flushing

WHAT YOU CAN DO

Report any zebra or quagga mussel sightings: In Oregon, call 1-866-INVADER or go to www.oregoninvasiveshotline.org; in Washington, call 1-888-WDFW-AIS; and in California, call 1-916-651-8797 or e-mail invasives@dfg.ca.gov. In other states, call the National Invasive Species Hotline: 1-877-STOP-ANS.

Boaters, anglers, and water enthusiasts can take the following easy steps to help prevent the introduction and spread of zebra and quagga mussels:

- Use appropriate coatings on your boat—toxic (copper, zinc) and nontoxic (silicone-based); use toxic constructed piping (copper, brass, galvanized metals), which can help prevent mussels from growing.
- Inspect all exposed surfaces—small mussels feel like sandpaper to the touch.
- Wash the hull of each watercraft thoroughly, preferably with high-pressure hot water.
- Remove all plants and animal material.
- Drain all water and dry all areas.
- Drain and dry the lower outboard unit.
- Clean and dry all live wells.
- Empty and dry any buckets.
- Dispose of all bait in the trash.
- In most cases, it is recommended that you quarantine your boat for at least 30 days before transporting to an uninfested water body.

If you are not a boater, you can still make a difference by cleaning your gear and not transporting untreated water from one body of water to another. Tell your friends and neighbors about aquatic invasive species, their dramatic impacts, and what we all can do to prevent their spread.

INFORMATION GAPS

- Researchers are exploring options for zebra and quagga mussel-specific control methods that don't harm other organisms.
- The ecological effects of zebra and quagga mussels in Western waters are unknown.

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ADDITIONAL RESOURCES

Web sites

Oregon Public Broadcasting's "Silent Invasions" Web site, in partnership with the Oregon Invasive Species Council and The Nature Conservancy. www.opb.org/programs/invasives/videos.php?page=mussels

The *Statesman Journal* 10-month series, Invasive Species of Oregon. www.InvasiveSpeciesofOregon.com

Great Lakes WATER Institute. www.glwi.uwm.edu/

Aquatic Nuisance Species Project. www.aquaticnuisance.org/index.php

Oregon Clean Marina Program. www.oregon.gov/OSMB/Clean/ANS.shtml

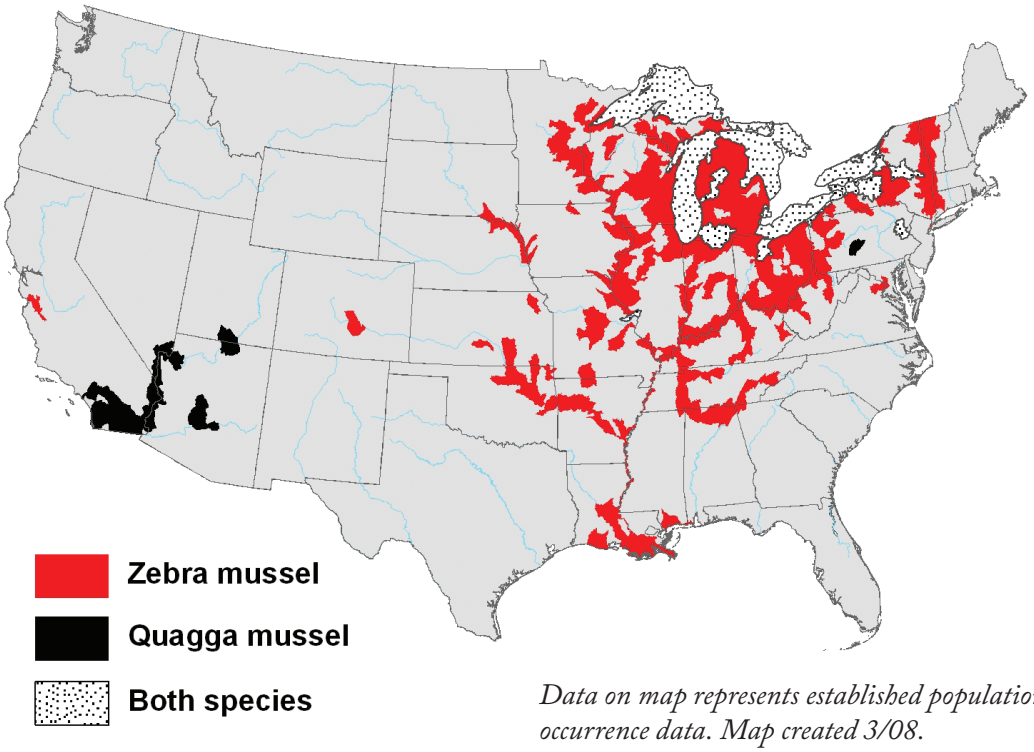
California Fish and Game Web site on zebra and quagga mussels. www.dfg.ca.gov/invasives/quagga-mussel/

100th Meridian Initiative. www.100thmeridian.org/

Protect Your Waters. www.protectyourwaters.net/

Videos

The *Statesman Journal* 10-month series, Invasive Species of Oregon. Includes a downloadable video about quagga mussels. www.InvasiveSpeciesofOregon.com



Data on map represents established population and species occurrence data. Map created 3/08.

Oregon Public Broadcasting show on quagga mussels www.opb.org/programs/ofg/segments/view/1622. (also available on the Resource CD)

Quagga Mussel Video Report by "In Wisconsin," a show on Wisconsin Public Television. www.wpt.org/inwisconsin/greatlakes/ (also available on the Resource CD)

BioFouling Video Report by "In Wisconsin," a show on Wisconsin Public Television www.wpt.org/inwisconsin/greatlakes/ (also available on the Resource CD)

Selective Filtering in Action: Zebra mussel expelling alga as pseudofeces. View video on line at www.glerl.noaa.gov/res/Task_rpts/1991/nsvander10-1.html. This video is also included on the Aquatic Invasions electronic resources CD that is included in the curriculum.

Articles

"Zebra Mussels Rule." Describes food chain impacts and provides an example of how to write and share science with a more general audience. www.csd509j.net/cvhs/staff/cornelp/APES/Readings/Chapters%2011-13/zebra%20mussels%20rule.pdf

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"Mussel-sniffing dogs fight invaders for Fish and Game," from the SFGate, 2008. www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2008/04/03/SP9MVTE76.DTL

"Big water-rate hike on the way (to pay for cleanup associated with the invasive quagga mussel)," from the California Coastal Coalition, 2008. www.calcoast.org/news/water0080219b.html

"A new invasion: Quagga mussels take over lake" from the *Milwaukee Journal Sentinel*. Available on line at: www2.jsonline.com/story/index.aspx?id=423678

Educational sites

Online slide show about quagga mussels, by the Great Lakes WATER Institute. http://waterbase.uwm.edu/media/cruise/invasion_files/frame.html (Only viewable in Microsoft Internet Explorer.)

Zebra Mussel Mania Travelling Trunk. www.seagrant.umn.edu/educators/tt

Nab the Aquatic Invader. www.sgnis.org/kids/